Green structures and energy-efficient building

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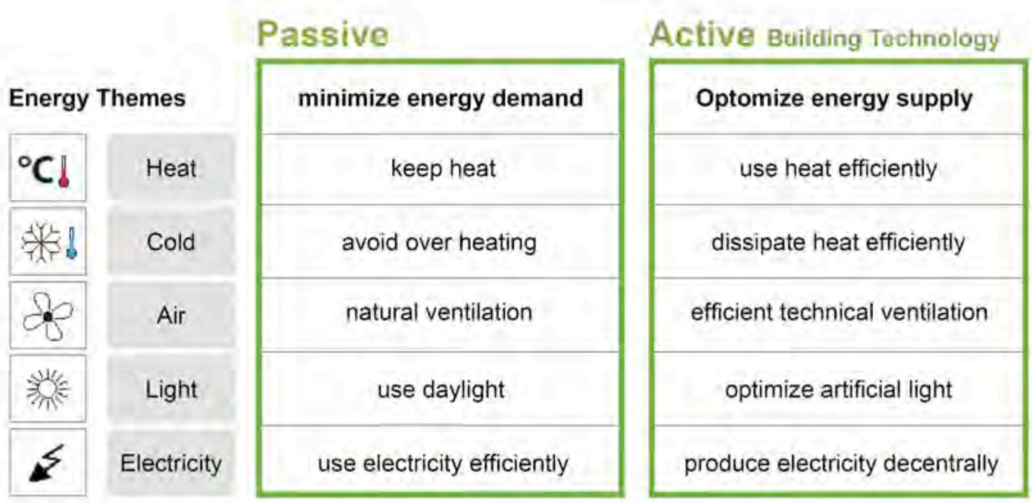
1. Principles of energy-efficient building

The main focus of „energy-efficient building“ lies on increasing a building’s efficiency in order to reduce the energy demand and at the same time ensure convenient usages as well as comfort in a building. In addition the remaining power demand is supposed to be completely covered by regenerative energy. Thereby the essential measures both in restoration as well as in new construction are based on two consecutive steps: the minimisation of energy use and loss (passive strategies) and the provision of renewable energies (active systems / regenerative energy sources).

The passive methods include the optimisation of a building’s form (relation between the surface of the building envelope to the volume), the insulation of the envelope to reduce heat loss, as well as the minimisation of solar heat gain through shadows in summer and accordingly it’s best use during the heating period.

The active measures include regenerative energy gain systems as photovoltaic or solar thermal applications, which use the naturally provided solar radiation to gain heat and electricity.

Alongside exist partially active systems as air collectors or transparent heat insulation. They use solar radiation in order to avoid unnecessary energy expenditures.



	Passive	Active Building Technology
Energy Themes	minimize energy demand	Optomize energy supply
Heat	keep heat	use heat efficiently
Cold	avoid over heating	dissipate heat efficiently
Air	natural ventilation	efficient technical ventilation
Light	use daylight	optimize artificial light
Electricity	use electricity efficiently	produce electricity decentrally

Graphic:
The five energy issues
(TU Darmstadt, FGee, FGe+f)

2. Efficiency factor of building vegetation

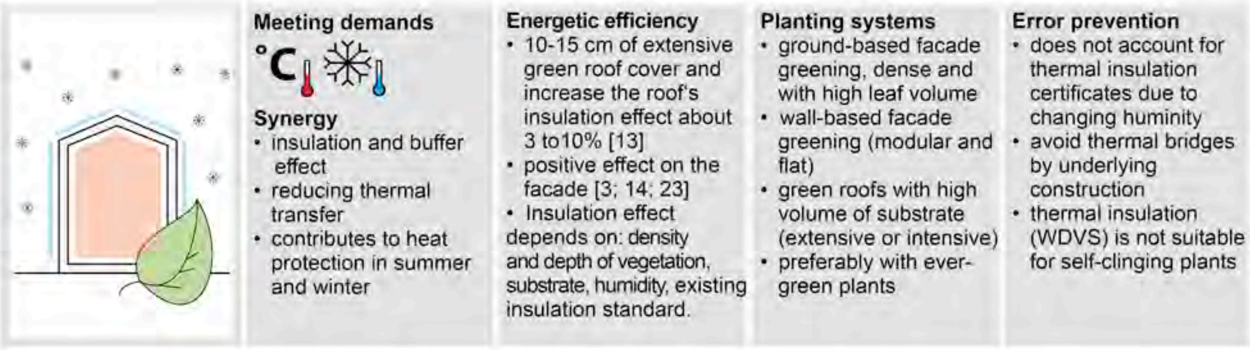
2.1 Passive systems and measures

2.1.1 Heat insulation and building vegetation [* S. 104 ff.]

The greening of buildings contributes to the attenuation of temperature extremes. Building vegetation thus has a balanced temperature amplitude in regard to the outside temperature.

In contrast to a bitumen roof for example, a green roof has a considerably lower day-night difference. The summer heat insulation, which in this case is more relevant than winter heat insulation [13], benefits from this temperature regulation. In the summer the roofs heats up less during the day and shows a lesser cooling at night. Winter measuring on a façade greening revealed a temperature difference of 3 °C between the outer leaves and the wall surface [3; 14]. However the façade greening of the municipal administration building in Vienna (MA 48) showed a higher data: the hibernal heat loss was reduced by about 50 %. The wall behind the system had a 7 °C higher temperature than the outer greening [23].

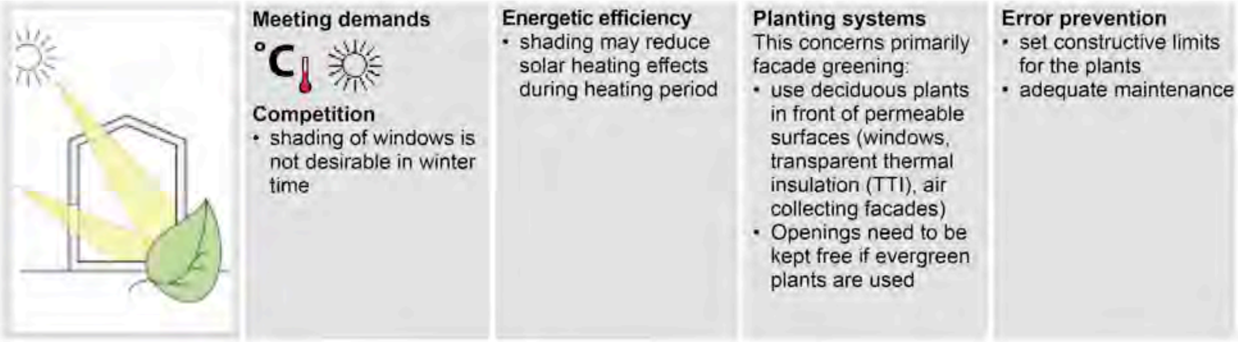
The substrate structure of green roofs adds to the reduction of heat losses. An extensive vegetated roof with a 10 cm thick substrate layer achieves under maximum water saturation an additional thermal resistance of 0,14 to 0,40 m²K/W. In comparison to a gravel covered roof the heat loss of an extensive roof greening with a thickness of 10-15 cm was discovered to be 3-10 % less [13; 24]. As 15-20 % heat is typically lost over the roof, an additional insulation effect is very positive [25]. Measurements on the Ufa-factory in Berlin showed a temperature amplitude of 50 K on bitumen roof in contrast to 10 K on a green roof [25]. The prevention of extreme temperatures on the roof surface demonstrably results in comfortable tempered rooms. This poses a great economic advantage also in regard to mechanical ventilation. [13]



Meeting demands	Energetic efficiency	Planting systems	Error prevention
°C ❄ **Synergy** • insulation and buffer effect • reducing thermal transfer • contributes to heat protection in summer and winter	• 10-15 cm of extensive green roof cover and increase the roof's insulation effect about 3 to10% [13] • positive effect on the facade [3; 14; 23] • Insulation effect depends on: density and depth of vegetation, substrate, humidity, existing insulation standard.	• ground-based facade greening, dense and with high leaf volume • wall-based facade greening (modular and flat) • green roofs with high volume of substrate (extensive or intensive) • preferably with ever-green plants	• does not account for thermal insulation certificates due to changing huminity • avoid thermal bridges by underlying construction • thermal insulation (WDVS) is not suitable for self-clinging plants

2.1.2 Openings: Solar gains and building vegetation [* S. 108]

Solar heat gains through window surfaces are used for room conditioning. According to their orientation façade openings are valued differently. In buildings with a high use ratio of solar gains, like in the passive house, the biggest window surface percentage is oriented south. To the north the window surface percentage is kept low in order to minimise heat loss. Solar heat gains are usually used in winter and transition months. Because solar radiation is reduced in these months, shading of the window surfaces should be avoided (exceptions are inner protection blinds). As building vegetation normally has a shading effect, window areas should be kept free during winter and early transition months. [21]



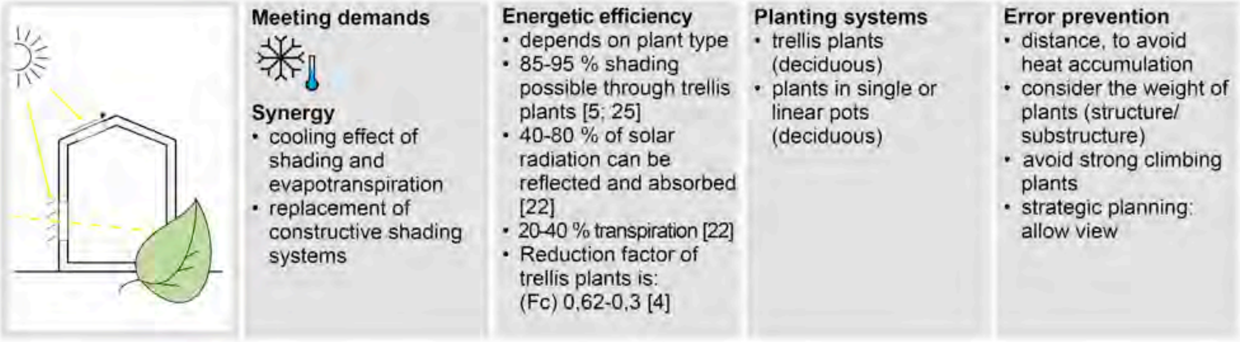
Meeting demands	Energetic efficiency	Planting systems	Error prevention
°C ☼ **Competition** • shading of windows is not desirable in winter time	• shading may reduce solar heating effects during heating period	This concerns primarily facade greening: • use deciduous plants in front of permeable surfaces (windows, transparent thermal insulation (TTI), air collecting facades) • Openings need to be kept free if evergreen plants are used	• set constructive limits for the plants • adequate maintenance

2.1.3 Sun protection and building vegetation [* S. 109 ff.]

The vegetation's shading and evaporation provide a cooling effect by reducing long-wave radiation. Though conventional sun protection systems decrease short-wave irradiation, they convert it into long-wave radiation and sensible heat. [25]

Deciduous plants are suitable for a seasonal impact. The necessity and greening period almost fully superpose in their time span. During summer months, when a shadowing effect is desired, the shading leaves prevent solar radiation. In winter moths solar heat gains are possible because of the leaf-free greening. As greening is able to substitute sun protection systems, its influence on the avoidance of cooling loads is valued highly. Measurements have quantified the shading rate of frame creepers. According to the measurements of KIESSL/RATH/GERTIS (1989) 40-80 % of solar radiation is being absorbed or reflected by the foliage. In another research the summer solar radiation transfer of the shading of a deciduous plant (Parthenocissus quinquefolia, Wisteria sinensis) was measured to be 5-30 % (shading rate 70-95 %) [25]. This is an excellent data to avoid mechanic cooling devices. Ottelé's measurements on vegetable sun protection systems allocated a saving of 43 % on air conditioning costs [19].

Next to the percentage shading indications also the shading rate was referred to the reduction factor DIN 4108 (today known as Fc value). This factor is arranged uniformly for sun protection systems and indicates the reduction of solar radiation by the sun protection system. In reference measurements it was possible to determine radiation attenuation values adequately to aluminium blinds for diverse forms of creeper vegetation. Reduction factors according to DIN 4108, part 2, are indicated equivalent from 0,62 to 0,3 [4].



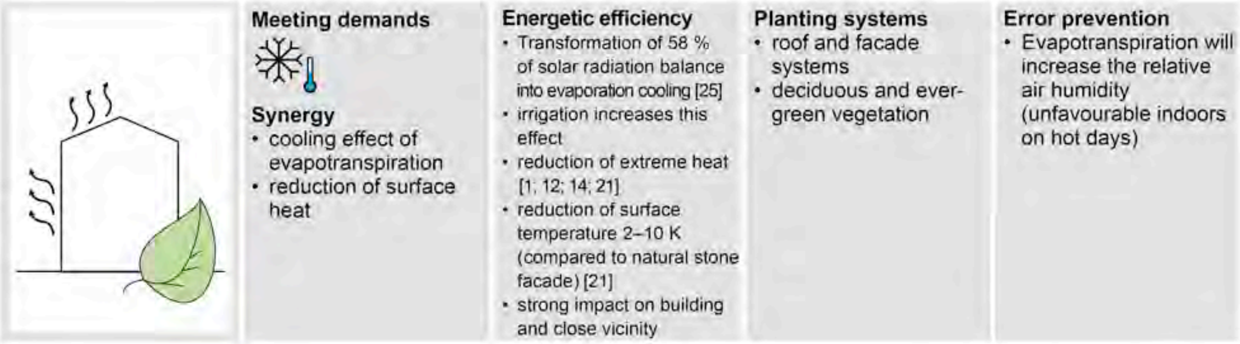
Meeting demands	Energetic efficiency	Planting systems	Error prevention
Synergy • cooling effect of shading and evapotranspiration • replacement of constructive shading systems	• depends on plant type • 85-95 % shading possible through trellis plants [5; 25] • 40-80 % of solar radiation can be reflected and absorbed [22] • 20-40 % transpiration [22] • Reduction factor of trellis plants is: (Fc) 0,62-0,3 [4]	• trellis plants (deciduous) • plants in single or linear pots (deciduous)	• distance, to avoid heat accumulation • consider the weight of plants (structure/ substructure) • avoid strong climbing plants • strategic planning: allow view

2.1.4 Adiabatic cooling and building vegetation [* S. 112 ff.]

Heat dissipation through evaporation is based on the thermodynamic effect of the aggregation change of water. Water needs 680 kWh/ m³ (at 30 °C) energy to change its physical state from liquid to gaseous. This amount of energy is extracted from the air in heat. Therefore the air is cooled down. Referring to a litre of water this amounts to 0,68 kWh. This is equivalent to a millimetre of Water evaporating on an area of 1 m². [25]

An evaporation measurement on plant containers as roof garden greening determined an evaporation amount of 200 l/m² in one vegetation period [2]. With regard to the evaporation energy this means an extraction of 136 kWh/m² from the air. The impact of adiabatic cooling by building vegetation is additionally quantified by measurements on wall surface temperatures. Exemplary measurements on a wall-linked, extensive greening of the Musée du Quai in Paris on a warm day in august showed a temperature reduction of 1,3—3,5 K in comparison to the ambient temperature [20].

The adiabatic cooling effect on a building envelope is relevant not only with regard to the ambient temperature. Especially with contrast to other surface temperatures it is important for the building and for the urban climate. Also the level of reflectance and other material features play a role in the temperature comparison to other envelope materials. For instance a bitumen or gravel roof is able to heat up to 40 – 55 °C at midday during summer. However, roof greening show in comparison up to 25 °C lower surface temperatures. [25; 26, p.163]



Meeting demands	Energetic efficiency	Planting systems	Error prevention
Synergy • cooling effect of evapotranspiration • reduction of surface heat	• Transformation of 58 % of solar radiation balance into evaporation cooling [25] • irrigation increases this effect • reduction of extreme heat [1; 12; 14; 21] • reduction of surface temperature 2–10 K (compared to natural stone facade) [21] • strong impact on building and close vicinity	• roof and facade systems • deciduous and ever-green vegetation	• Evapotranspiration will increase the relative air humidity (unfavourable indoors on hot days)

2.1.5 Natural ventilation and building vegetation [* S. 115 ff.]

Building vegetation is able to support the natural ventilation by attenuating temperature extremes on component surfaces: In summer months the façade greening is cooling down the surrounding surfaces, whereas in winter the (evergreen) plants are able to serve as a natural buffer. As already described in point 2.1.4, the reduction of the surface temperature in summer through the diminution of the long-wave radiation is caused by the evaporation cooling of the plant and the substrate surface. Thus the supply air during the night is not warmed up by the heat emission of the surrounding building envelope, which supports the night cooling effect. Another positive effect is the air humidification as well as the dust filtering or rather the suppression of fine particulate caused by the plant. The relatively large green surface results in the absorption and adsorption of atmospheric trace substances, which leads to an improvement of the air quality close to the building [16]. Through the leave volume dusts are intercepted. The dust amount after one vegetation period was measured to be 4 g/m² (Parthenocissus) or rather 6 g/m² (Hedera) [3]. The dust contained 71 % of respirable substances whereby the supply air was accordingly relieved [1].

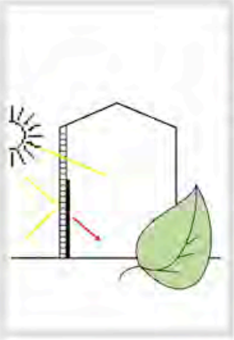
Another measurement compares the surface temperature reduction of an ivy greening to two different wall surfaces of a semi-detached house. By contrast with an almost white wall (lightness coefficient 83 with 36 °C) the surface behind the greening achieved a temperature reduction of ~ 8 °C. In comparison to a brown wall (lightness coefficient 64 with 52,8 °C) the surface temperature behind the greening is reduced by ~19 °C. [21]

	Meeting demands	Energetic efficiency	Planting systems	Error prevention
	**Synergy** • cooling of building surfaces (summer) • Reducing temperature through natural ventilation in summer/ supporting ventilation at night • dust filtration • noise reduction [18; 28]	• reduction of surface temperature 2–10 K (compared to natural stone facade) [21] • air humidification: 20-40 % increas in summer, 2-8 % increase in winter) [22]	• roof and facade systems • deciduous and ever green vegetation	• Entry of pollen possible • avoide plants provoking allergies • avoid development of high air humidity on warm/humid day

2.2 Partially active systems and measures

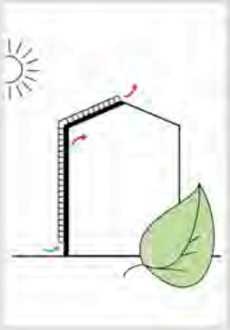
2.2.1 Transparent thermal insulation and building vegetation [* S. 118 ff.]

Transparent thermal insulation (TTI) is a dynamic insulation system. It consists of translucent panels with small inner-reflecting tubes that are firmly glued together and transport the light. Its deck surface is transparent either on both sides or only on the outside and serves as a dust- free completion of the countless light-transmitter canals. The sunlight with its infrared component is led trough the panels from the outside to the inside. In the case of an opaque inside surface a usually dark surface area absorbs the heat content of the incident radiation. The inside area therefore functions as a heat storage or rather a radiating unit. As a translucent element the TTI conducts the short-wave solar radiation into the room.
In the course of a BMWi-project (federal ministry of economy and energy) the effect of a seasonal sun protection system made of a deciduous façade greening on top of a TTI during hot summer months was quantified. It was possible to decrease the maximum absorbertemperatures from 50 °C to 25 °C. The greening thereby poses an easy, cost-efficient and extraordinary effective shading variant. [5]

	Meeting demands	Energetic efficiency	Planting systems	Error prevention
	**Synergy** • shading and adiabate cooling of absorbers • avoid overheating of facade and indoor areas in summer	• 85-95 % shading possible through trellis plants [5; 25] • Reduction of maximum absorber temperatures up to 50% possible [14] • shading effects depends on the planting system	• Facade greening with deciduous trellis plants	• no shading in winter • enable backside ventilation • underlying construction needs to be conceived without thermal bridges • consider the play of light and shadow in the context of translucent facades

2.2.2 Air collectors and building vegetation [* S. 120 ff.]

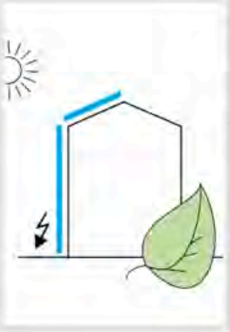
Air collector facades are used as dynamic insulation and / or to temper the supply air. Transparent, rear-ventilated curtain façade elements create a kind of buffer zone, in which heated air warms up the storage mass behind it. The solar heating results in a natural movement of the heated air – which is to some extent supported by ventilators.
In summer, when solar heating of the façade is undesirable, the top part of the façade is opened in order to use the solar chimney effect and let out the warm air. An overheating of the air interspace is despite the airflow still possible during summer moths. This leads to an undesired heating of the storage wall, which can be prevented by seasonal shading of deciduous plants. The shading rate of framework climbers (example of Parthenocissus quinquefolia bzw. Wisteria sinensis) can reach 70-95 % (also see point 2.1.2.).

	Meeting demands	Energetic efficiency	Planting systems	Error prevention
	°C ☼ **Synergy** • shading and adiabate cooling of absorbers • avoid overheating of facade and indoor areas in summer	• 85-95 % shading possible through trellis plants [5; 25] • temperature reduction up to 2-5 K possible [21] • depends on the planting system	• Facade greening with deciduous trellis plants	• no shading in winter • enable backside ventilation • underlying construction needs to be conceived without thermal bridges • consider the play of light and shadow in the context of translucent facades

2.3 Active systems and measurements

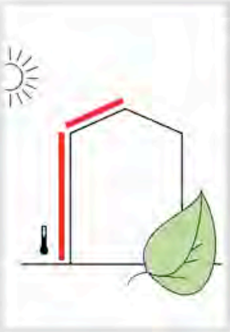
2.3.1 Photovoltaic and building vegetation [* S. 122 ff.]

Photovoltaic (PV) serves the regenerative energy production from sunlight. It possesses characteristics, where building vegetation can increase its performance: adiabatic cooling and the underground shading of greening are able to attenuate the ambient temperature around the photovoltaic modules and therefore have a positive influence on their capacity. The surface temperatures beneath greening stay close to the outside temperature, whereas other materials (as Bitumen) experience higher temperature fluctuations. For example, with an outside temperature of 20 °C a green flat roof has a temperature of 25 °C in contrast to a gravel covered roof with 50 °C [25; 26, p.30]. Referring to flat roof systems greening companies name a 4-5% increase in performance of PV-roof systems in contrast to bitumen roof [27].

	Meeting demands	Energetic efficiency	Planting systems	Error prevention
	⚡ **Synergy** • reduction of surface temperatures through adiabate colling (efficiency increas) • irrigation increases this effect • substrate replaces ballast (roof-mounted PV-installation)	• efficiency increase of roof-mounted photovoltaic installation about 4-5 % [27]	• wall-based facade greening (modular/flat) • extensive roof greening (moss, shallow-rooting shrubs and small woody plants)	• avoid shading • avoid permanent pollution

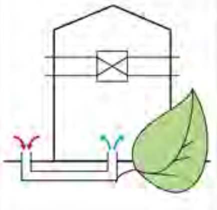
2.3.2 Solar thermal energy and building vegetation [* S. 126 ff.]

The efficiency of solar thermal energy depends on the direct solar radiation as well as the ambient temperature. The bigger the difference between outer air and absorber, the higher is the heat loss of the collector. Evaporation cooling and shading may therefore reduce the performance. Typical operating temperatures of flat-plate collectors range between 60-90 °C [7]. If the building vegetation lowers the temperature of the outer air, the loss of power increases. As solar thermal energy should already meet the warm water need in April, it produces unused surplus energy between Mai and August due to its construction. The performance reduction by adiabatic cooling is small. If the temperature difference rises by about 7 K, the efficiency of an elevated flat-plate collector is expected to decrease by 4 %, the utilisation rate drops about 1 %.

	Meeting demands	Energetic impact	Planting systems	Error prevention
	°C ❄ **Competition** • Efficiency reducation possible because of evapotranspiration cooling and shading	• Efficiency reducation through adiabate cooling is relatively low: balanced by heat oversupply in summer	• wall-based facade greening (modular/flat) • extensive roof greening (moss, shallow-rooting shrubs and small woody plants)	• avoid shawing • keep distance to distribution and collector lines because of high temperatures

2.3.3 **Controlled ventilation and building vegetation** [* S. 128 ff.]

Controlled ventilation can be used to supply fresh air, but also to avoid ventilation heat loss and to condition (cooling and warming) the air if necessary. A connection to heat recovery reduces aeration heat losses. Conditioning can happen through the fresh air conveyed over earth tubes. The air above water or green areas can be sucked in for additional cooling purposes. In the counter-current process spraying water into the exhaust air can cool the supply air.

	Meeting demands	Energetic efficiency	Planting systems	Error prevention
	°C🌡 ❄🌡 **Synergie** • cooling effect through adiabate cooling und shading • cooler surfaces in summer • reduction of extreme temperatures • dust filtration through greening	• Temperature differences 2-10 K (natural stone facade/summer/ decentral system) • Temperature difference up to 20 K (compared to bitumen cover/ summer/decentral) • air humidity (20-40 % higher relative air humidity)	• all facades/roof greening systems	• avoid input of high air humidity on hot days • keep 1 meter distance to fresh air suction intake • use filters to avoid intake of pollen/dust/ bacteria

2.3.4 **Rainwater utilisation and building vegetation** [* S. 130 ff.]

In connection with a so-called retention roof, greening is able to hold back and clean rainwater as well as filter pollutants. Moreover the water surfaces can be used for the direct cooling of the building or the collected rainwater can serve technical cooling purposes (such as a heat exchanger). In model projects these systems have already been realised as building greening in form of multifunctional roof vegetation (retention roofs with reposition plants). [10]

	Meeting demands	Energetic efficiency	Planting systems	Error prevention
	≋ ❄🌡 **Synergy** • cooling effect in summer (adiabate cooling) • cooling of rain water (treatment for technical cooling functions) • rain water purification (clearing gray water) • water retention	• only a few cases show evidence so far • temerature reduction 2,5-10 K • water retention: 60-99 % of rain fall [11; 15; 17] (depending on substrates) • water retention up to 50 l/m²	• green roofs: humid roof(regulated water layer underneath/inside or above the substrate) • roofs as retention area with reposition plants	• secure sealing of the roof • inverted roofs and roofs with subsequent insulation are not suitable

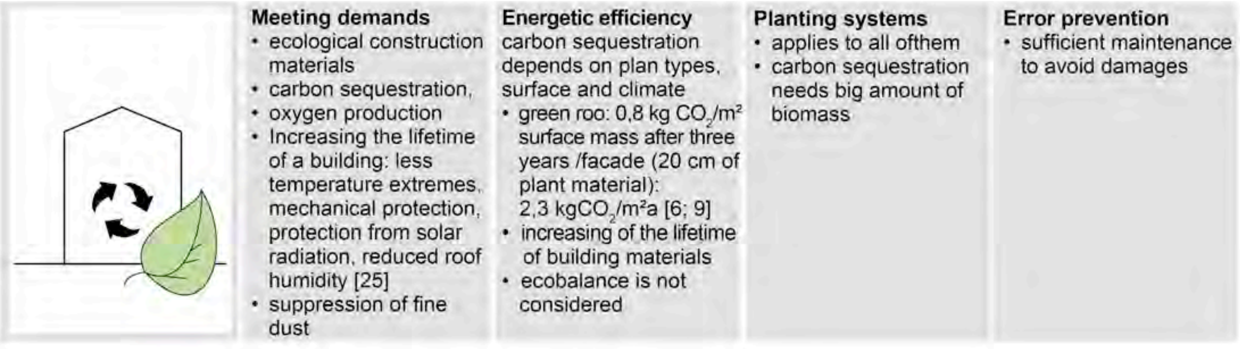
2.3.5 **Utilisation of biomass and building vegetation** [* S. 132 ff.]

Building vegetation does not count as a typical urban green area and its share of green waste emergence is assessed low. Green waste after the maintenance of façade and roof greening as well as autumn leaves are able to increase the surface potential and thus the biomass potential. Biomass with a high amount of fresh mass may serve for the production of biogas. Wooden biomass is unsuitable for the production of biogas, but can be utilised thermally instead.

	Meeting demands	Energetic efficiency	Planting systems	Error prevention
	°C🌡 ⚡ **Synergie** • increasing the amount of biomass in the urban area • clippings can be used for biogas or other types of energy production (i.e. fuel briquettes made of leaves)	• extensive green roofs: 13 MWh/ha a • intensive green roofs: 4-23 MWh/ha a • ground based facade greening: 5-9 MWh/ha a • wall-based facade greening 13 MWh/ha a • Fall of leaves: ca. 23 MWh/ha a [3] Source: Sieber, S. acc. to [8]	• shrubs and woody plants • deciduous plants	• humid clippings/foliage may cause slagging

2.3.6 Ecology, economy and building vegetation [* S. 136 ff.]

In addition to the energy consumption during operation every application of material causes energy demands and environmental impacts due to the resulting resource flow. Thus the energy use for production up until the disposal of a component or rather a building material plays a crucial role besides the operating energy. Eco balance assessments on the life cycle are increasingly requested by valuation systems of sustainable building standards. [7] Building vegetation itself is an ecological “building material”. Firstly it has the advantage of absorbing the climate relevant gas CO2 in form of carbon (C) into its plant tissue, as well as producing O2 through its life cycle and filtering air pollutants. Secondly fossil energy sources may be saved by the possible conservation of heat and cooling energy (see point 2.1.1, 2.1.3, 2.1.4).



Meeting demands	Energetic efficiency	Planting systems	Error prevention
• ecological construction materials • carbon sequestration, • oxygen production • Increasing the lifetime of a building: less temperature extremes, mechanical protection, protection from solar radiation, reduced roof humidity [25] • suppression of fine dust	carbon sequestration depends on plan types, surface and climate • green roo: 0,8 kg CO_2/m² surface mass after three years /facade (20 cm of plant material): 2,3 kgCO_2/m²a [6; 9] • increasing of the lifetime of building materials • ecobalance is not considered	• applies to all ofthem • carbon sequestration needs big amount of biomass	• sufficient maintenance to avoid damages

3. Conclusion

For the handling of the nature given seasonal requirements on our living and working spaces there are at the same time natural solutions at our disposal. The possibility of a specifically demand-orientated building vegetation poses – next to the design and air-hygienic advantages – a cost-efficient and versatile tool to attenuate temperature extremes and to synergetically support measurements of building technology. Our ambition to increasingly reduce the utilisation of fossil energy resources demands both a return to the interaction of natural processes and the research of prospective planning terms and building methods in order to understand the structure of envelope surfaces and building technology as an integral strategy with the natural conditions and no longer as a defence against them.

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