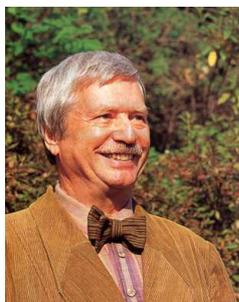


## **INCLINED GREEN ROOFS – ECOLOGICAL AND ECONOMICAL ADVANTAGES, PASSIVE HEATING AND COOLING EFFECT**



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### **Summary**

In special climatic regions of Australia and USA green roofs are already quite common, but due to their thick earth cover still more expensive than usual roofing. Green roof systems of wild grasses and herbs on thin earth layers of 8 to 16 cm only and inclinations of 5 to 30 % as used nowadays in many buildings in Europe and preferably in Germany, proofed not only to reduce environmental pollution, to save heating and cooling energy and to reduce the penetration of high frequency electromagnetic waves, but stated to be more economical than common roofing, when taking into account their lifespan. The paper gives a survey of the advantages of inclined green roofs with thin earth cover versus common roofing, describes the different “extensive” systems, explains their physical effects and names the adequate plants for each solution. Also the results of a research project, in which the cooling effect in summer and the warming effect in winter was measured on a green roof in Germany, are shown.

**Keywords:** Green roofs, passive heating and cooling

### **1 Introduction**

In the centre of big cities we can observe several negative effects due to sealing of the surface, density of buildings, traffic and heating of the buildings: Increased pollution and the decreased oxygen content of the air, increased temperature of the ambient air and dust clouds over the city.

It is well known that green parks, dense trees in alleys and other green areas in cities reduce these negative effects considerably. The optimized green roofs described in the following text, with a green leaf area 5 to 10 times higher as the one of a green park, are a much more effective and economic means to create better climatic living conditions in cities. Besides this advantage for the microclimate of cities there are more positive effects for the users of buildings with green roofs.

The most interesting are:

- The cooling effect in summer
- The warming effect in winter
- The increase of lifespan for the roof

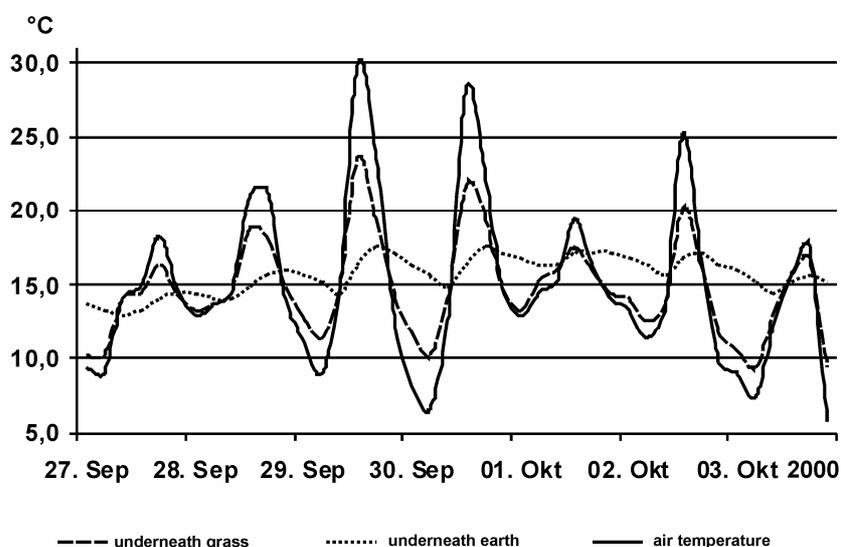
## 2 Physical functions of green roofs

### 2.1 Cooling effect in summer

The heat transmission through a roof from outside to inside can be reduced by more than 90 % through a green roof. In Germany measurements in summer showed that even in extreme hot periods with daytime temperatures of 35 °C, the temperature underneath a grass roof never exceeded 25 °C.

In **Fig. 1** the temperatures of a period in autumn are shown within a green roof in Germany which exists of 16 cm of earth covered by wild grasses. When the air temperature reached 30 °C the temperature underneath the earth was only 17,5 °C.

This cooling effect is derived mainly by the evaporation and shading effect of the vegetation, but also by its ability to reflect sun radiation and by the energy consumption through photosynthesis and heat storage by its embedded water.



**Fig. 1** Temperatures of a green roof at Kassel, Germany, during autumn

### 2.2 Heating effect in winter

If the vegetation is forming a thick layer like a fur it increases the thermal insulation effect of the roof effectively. In **Fig. 2** the temperature during one week in January are shown of the same roof of **Fig. 1**. When the air temperature reached -14 °C the temperature underneath the 16 cm of earth was only 0 °C.

These effects come mainly from the thermal insulation effect of the air cushion within the vegetation and the fact that the cold wind does not hit the earth surface. Some minor effects are the thermal mass of the earth layer, the reflection of infrared radiation

from the building by the plants and the heat production if dew is formed in the morning (the condensation of 1 g water releases 530 calories of heat).

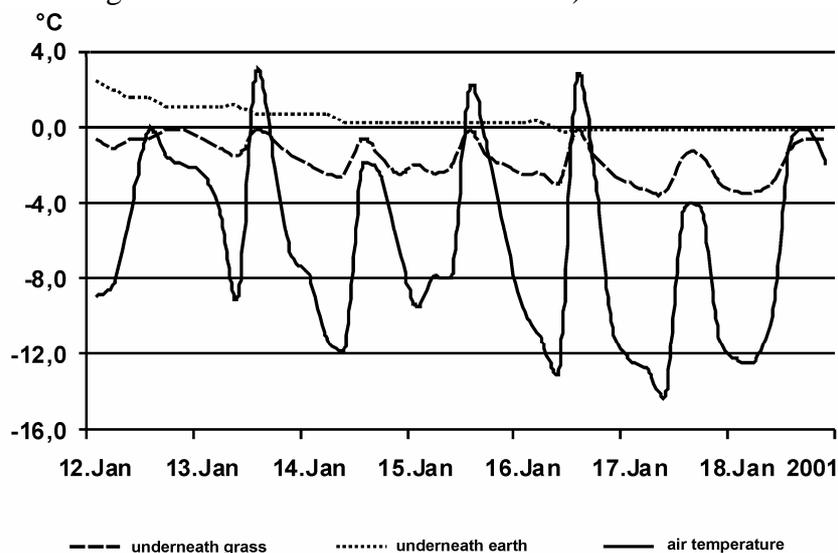


Fig. 2 Temperature of a green roof at Kassel, Germany, during winter

### 2.3 Retardation of drain

Due to the German Standard DIN 1986 a green roof with 10 cm of earth releases only 30 % of precipitation, the rest is stored and evaporated. That may mean a considerable reduction of the dimensions of the sewage system. But much more important is the retardation effect of drain. Fig. 3 shows the amount of drain of a green roof with 14 cm substrate and 12° inclination after an 18 hours lasting rain. The drain only started after 12 hours of rain and continued 21 hours after the rain had stopped. [2]

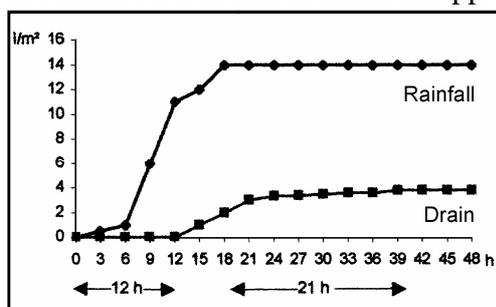


Fig. 3 Amount of rainfall and drain of an inclined green roof after a 18 hours lasting rain in September 1989 at Kassel, Germany [2]

### 2.4 Sound absorption

Whereas the vegetation of a green roof absorbs sound only by 2-3 dB, the earth acts as a strong acoustic barrier. Humid earth 12 cm thick reduces sound transfer by 40 dB. A 20 cm thick layer even about 46 dB.

### 2.5 Fire resistance

In Germany green roofs are counted as “solid roofing” which means they do not burn and are fire resistant as long as the earth layer is at least 3 cm thick.

## 2.6 Shelter effect for roof cover

Covers like bitumen or tar felt, bitumen or wood shingles, wooden planks or plastic sheets deteriorate under uv-light and high temperature difference.

This is eliminated by a cover of substrate and vegetation, and therefore green roofs, if well designed, have an extreme long lifespan and create hardly any care or repair.

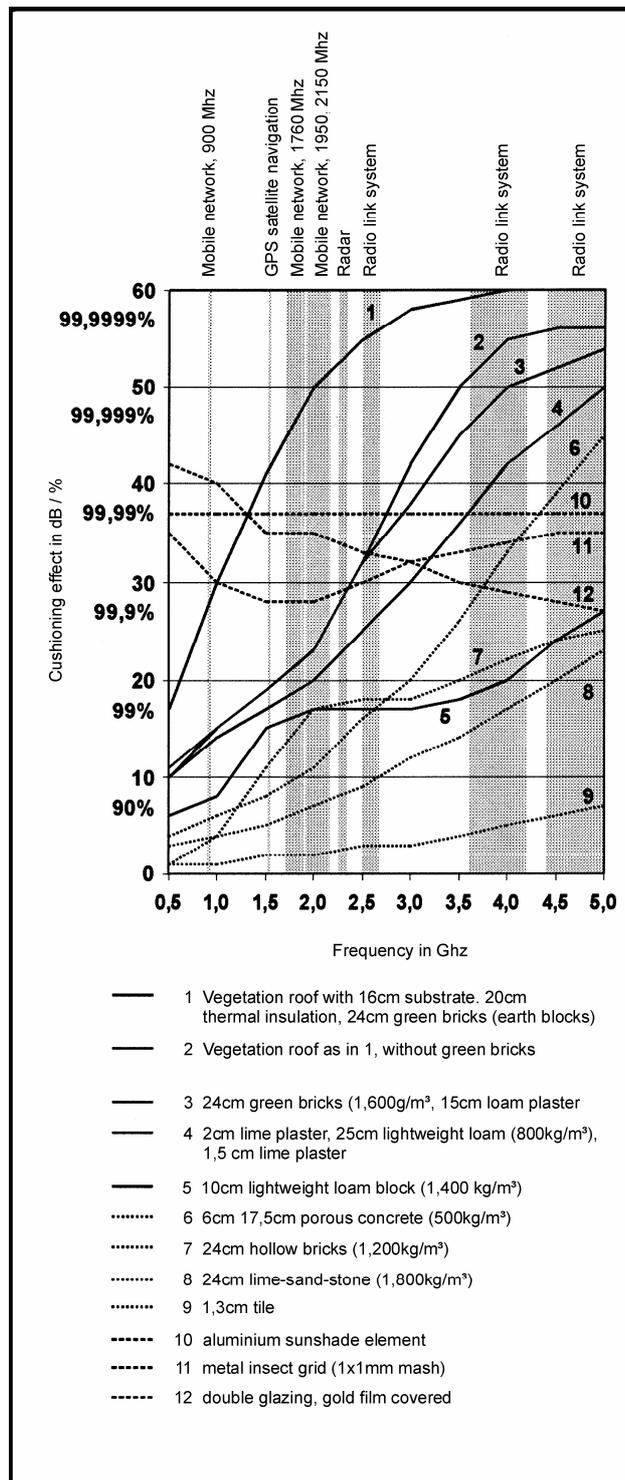


Fig. 4 Shelter effect of different building materials against high-frequency electromagnetic waves

## **2.7 Shelter against high-frequency electromagnetic radiation**

A green roof of 16 cm substrate and wild grasses reduces the radiation in the range of 2 Gigahertz, in which most cellular (mobil) phones are working, by 24 decibels, which corresponds to 99 %. In combination with a 24 cm thick mud brick dome a reduction of 99,999 % is reached, see **Fig. 4**.

## **2.8 Significance of leaf surface area**

The positive effects of green roofs are stronger the denser and thicker the vegetation layer is. This usually corresponds with its leaf surface area. Investigation of the BRI showed that a common park lawn in Germany with 5 cm of average height has about 9 m<sup>2</sup> of leaf surface area per 1 m<sup>2</sup> of park area, whereas a low inclined earth roof with a dense cover of wild grasses has up to 100 m<sup>2</sup> of leaf per m<sup>2</sup> of roof surface in summer. This dense vegetation can only be reached in middle-european climate if the substrate is 12-16 cm high and the inclination of the roof 5 to 40 % (3 to 22°). But a dense sedum vegetation on 8 cm of substrate only reached 2,4 m<sup>2</sup> of green leave surface. [3, 4, 5]

# **3 Systems, design aspects**

## **3.1 General**

Green roofs without inclination need to have either more than 30 cm of substrate (earth) or a special layer for drainage. In the first case the vegetation grows higher, needs care and usually watering and nutrition, – these roofs are called “intensive ”green roofs, and are not discussed here. If the substrate is only 3 to 16 cm thick, a special vegetation is needed, which is resistant against dryness and in cooler climates also against frost: That means wild grasses or herbs or special species of sedum and sempervivum. These kinds of green roofs are called “extensive”, they need no care and offer very economical solutions.

## **3.2 Influence of inclination**

The advantage with inclined green roofs is that they need no special drainage layer if the inclination is more than 5 % (3°). But with slopes of more than 20 to 30 % (11 to 17°) special barriers or other means, which prevent the substrate from slipping down, might be necessary. Also working on the slope is more difficult.

## **3.3 Influence of substrate thickness**

Extensive green roofs, which don't need care must have a substrate thickness of not more than 15 to 18 cm with little nutritive substance. Otherwise the vegetation grows to high, gets sensitive to wind and dryness, and might not survive or needs care and maintenance like “intensive” green roofs.

Due to the thickness of substrate and the climatic conditions different types of plants have to be chosen.

In central and northern European climate it is possible to build inclined green roofs with only 3 cm thick substrate. In this case only moss and sedum species are able to survive if they are resistant against dryness and frost.

Obviously they cannot create a dense and thick green layer and therefore have very little positive effect in respect of passive heating and cooling.

With a substrate thickness of 5 to 10 cm a mixture of sedum and allium species together with wild grasses like *poa compressa*, *poa pratensis angustifolia*, *festuca vivipara* and *bromus tectorum* are forming a fairly dense cover.

The thickest cover with best effects of passive heating and cooling as well as longest lifespan will be created by a 14 to 16 cm thick layer of substrate covered by wild grasses like *festuca rubra genuina*, *festuca rubra commutata*, *festuca ovina*, *festuca scorparia*, *poa pratensis* together with some allium *schoeneprasum*, *thymus pulegiodes*, *thymus serpyllum*. [3, 4, 5]

Usual substrate of top soil mixed with 50 % of lightweight aggregate like pumice, slag, expanded clay or expanded slate weighs about 1000 kg/m<sup>3</sup> (10 kN/m<sup>3</sup>) in a wet condition, but if mixed with sand and gravel up to 2000 kg/m<sup>3</sup>.

### **3.4 Influence of orientation and inclination**

It must be taken into account that steep roofs oriented to the sun dry out much quicker than less inclined roofs which are partially shaded or reached by sun radiation only in a flat angle.

## **4 Components**

### **4.1 General**

The basic components of an inclined “extensive” green roof are: the water- and rootproof skin, the substrate and the vegetation.

### **4.2 Skin**

The skin underneath the vegetation roof must be absolutely waterproof and resistant against aggressive roots and humid acid. In Europe several materials with certified characteristics are on the market, mainly used are PVC-covered polyester fabric and polyolefin-covered glassfibre fabric. The joints are hot-air-welded and can be additionally sealed with liquid plastic. Bituminous roofing material is not rootproof. Some roots live with special microorganism in symbiosis, which dissolve the bitumen and use it for nutrition.

### **4.3 Substrate**

With very little inclination of 5 to 10 % usually a drainage system is afforded beneath the substrate. This can be a layer of 4-8 cm of expanded clay or similar aggregate of 4-8 mm diameter or a special porous mat with drain grooves. With steeper roofs no special drainage layer is necessary if the substrate has a certain drainage capacity.

The substrate must be able to store and drain water, should have enough air pores and little nutritive substance. Usually top soil is mixed with lightweight aggregates like pumice, slag, expanded slate or expanded clay. If the weight is of no importance sand and gravel can also be used. The thickness of it must correspond with the type of vegetation and the climatic conditions.

In European climate usually 14-18 cm of substrate is enough for water storage, as the period without any rain normally does not last more than 6 weeks. (In dry climates a watering system or special vegetation has to be used)

A thickness of more than 16 to 18 cm is not advisable for extensive green roofs. On a higher substrate the grasses and herbs will grow higher which creates problems with strong winds and long dry periods. The result might be that the vegetation dies out, at least partially. The same negative effect was observed with substrate of high nutritive substance.

#### 4.4 General

The vegetation must be resistant against severe climatic conditions, like dryness, strong wind and in many regions also frost. The thinner the substrate the more resistant against dryness the vegetation must be. The different types of vegetation for composite climates are already described in chapter 3.3.

### 5 Lifspan, costs

Investigations in Germany showed that extensive green roofs with little inclination though 5-10 % more expensive than normal flat roofs with bituminous cover and gravel shelter, are much more economical if taking into account their lifespan. Repair and maintenance costs of traditional flat roofs over a period of 30-50 years create about twice as much cost as the green roof.

The lifespan of a well designed green roof might be much more than 100 years.

### 6 Conclusion

In Germany in the last 25 years hundreds of green roofs were built for private houses as well as for public buildings. (Fig. 5-7). In some master plans for new settlements green roofs are nowadays compulsory as it was found that settlements with green roofs not only improve microclimate, but also reduce costs for drainage / sewage system. Besides also safe heating and cooling costs and improve indoor comfort for inhabitants. With public buildings it was stated that green roofs reduce maintenance cost drastically.



Fig. 5 Private houses with steep green roof at Siegen, Germany (architect: Jürgen Christ)



**Fig. 6** Kindergarten at Wennigsen-Sorsum, Germany (architect: Gernot Minke)



**Fig. 7** Settlement at Düsseldorf, Germany (architects: Bookhoff and Rentrop)

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