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Energetic Effects of Green Roofs to the Urban Climate Near to the Ground and to the Building Surfaces

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Abstract

Green roofs are relevant to cool down inner city surfaces. This effect shall be explained by the measurements of the storage capacity, the run-off, evaporation, interception rates and climate parameters. The data set was taken in the vegetation period of 2004. The green roof values of the research area in Neubrandenburg (Mecklenburg-Vorpommern, Germany) are compared to a typical gravel-covered roof on the same building and older data sets from a research roof at the UFA-factory in Berlin. The amount of the cooling efficiency of a green roof can be calculated as an energetic process steered by the quantity of rain retained in the growing medium.

If the fact of cooling surfaces shall be a relevant factor in green roof planning, it is necessary to select a growing medium with a high storage capacity.

Begrünte Dächer können einen wichtigen Beitrag zur Verminderung der innerstädtischen Wärmeinseln (Urban Heat Island-Effekt) im Sommer leisten. Um dieses Potential quantitativ bestimmen zu können, müssen neben den klimatischen Bedingungen folgende Daten ermittelt werden: Speicherkapazität des Gründachsubstrates, Regenwasserabfluss, Evaporation, Transpiration. Die vorliegende Untersuchung wurde in der Vegetationsperiode 2004 durchgeführt. Die Daten der Dachbegrünung auf einem Versuchsdach in Neubrandenburg wurden dabei mit einem typischen Kiesdach auf dem selben Gebäude und älteren Daten von einer Versuchsfläche in Berlin verglichen. Der Abkühlungseffekt, den ein Gründach für das städtische Klima leisten kann, lässt sich als energetischer Prozess darstellen, der maßgeblich durch die gespeicherte Wassermenge gesteuert wird.

Durch die Auswahl von Substraten mit hoher Wasserspeicherkapazität lässt sich der Abkühlungseffekt deutlich erhöhen.

1. Introduction

The discussion of the urban heat island effect has increased in the last decades. Hot city surfaces are well known not only in hot climate regions but also in summer times in temperate regions nearly all across the world.

High temperatures in cities are one main problem of urban climate. The temperature, even in the night, influences the quality of life. This could be important mostly to handicapped and elder citizens in not well insulated houses (Wong, 2003). At last, it is a question of quality standards in architecture.

In traditional architecture, a lot of information about climate adapted buildings still exists. But in the post modern architecture a lot of this knowledge is lost. „Concrete-buildings“ which ignore the climate adaptations are found all over the world in a similar style. Multi-storied and „wind closed buildings“ with huge window facades are quite the opposite to „cross ventilated“ traditional buildings.

What does the green roof technology offer? There is a demand for a new style in architecture, which considers the old climate knowledge of buildings, region-specific solutions and new methods in renewable technologies. The demand is a new style in architecture, called „the biophilic architecture“ (after Kellert 2003, 2004). Greenery will be an integral element in these new concepts. City planners must adapt old regional structures into new concepts for liveable neighbourhoods. This includes regional specific materials, orientations of the buildings, energy balances of the buildings and last but not least the technology of greenery in the streets, front yards and in direct contact with the buildings.

Inside the biophilic architecture, green roof technology plays a strategic role as a multi-purpose element.

In the last decades a lot of research was done to quantify the various green roof benefits. This article will report some basic results with regard to urban climate effects. Ongoing measurements are done on real green roof research fields in Berlin and Neubrandenburg. Other working groups had started to develop models in order to simulate these effects for whole neighbourhoods. Both ways of getting data have their pros and cons. But there is a gap between real measurements and transferring these data to

whole cities. Both strategies must come together in the following years to get an estimation about the climatic benefits that green roofs can offer to cities and their inhabitants.

2. Measurements

The first sparse data sets from measurements on green roofs and bitumen roofs were taken in the 70's by Hoeschele u. Schmidt (1978). They explained the significant differences in surface temperatures between bitumen roofs and extensive green roofs roughly. Green roofs reduced the maximum surface temperatures significantly.

Green roof measurements of our research group started in the mid 80's. At this time, the technology of data logger has allowed to take longer campaigns in measurements, like weeks, months or in enhanced measurements whole periods of the year. The first project was at the „Paul-Lincke Ufer“ in Berlin, Germany (see: Koehler & Schmidt 1990). The effect of a complete greenery was measured before and after the greenery of the facade, the backyard and on the roofs.

At present, long time studies are done as online measurements at the UFA-factory in Berlin - Tempelhof and at the University of Applied Sciences in Neubrandenburg. (see: Koehler 2004).

Factor	How it will act	Effects	Variables
growing medium / drainage layer	additional layer, a porous system, like an isolation layer	reducing the maximum and minimum temperatures	size, colour type of material
plant species	plant layer shades the surface of the roof; parts of the plants will evaporate water	the efficiency is variable to the type of vegetation and the number of vegetation layers	type of vegetation / plant species, height, density, structure.
water content of the growing medium	the efficiency of the growing medium as an isolation layer depends on the relation between massive and hollow areas	a typical growing medium has a storage capacity between 10 – 40 litre / square metre	type of material, irrigation: yes or no

Table 1: Climatic effects on green roofs are influenced by several factors.

The efficiency of a green roof to reduce the inner city surface temperatures can be enhanced by considering the above mentioned facts.

Shade by plant species is important. But most of the cooling effects are caused by the energetic balance. Green roofs retain precipitation, that's well known for several years. The annual storage of rain

water varies between 50 and 80 % of the annual rain. This amount of water will evaporate from the vegetation layer. The energy supply during the evaporation process works like an air conditioning system. However the water retention of green roof systems is not a constant factor, it is a variable, steered by the following facts:

Indicator	Value	
storage capacity of the growing medium and the drainage layer	in most cases between 10 and 40 l/ square metre	growing medium specific value field capacity.
saturation of the growing medium	the additional storage capacity depends on the current soil water content.	free capacity in liter /square metre
climatic factors	temperature, wind, evaporation rate	difference between summer and winter values.
intensity and quantity of the rainfall	quantity and distribution of the rain.	litre /square metre x time
plant specific water supply	the need of the plant species	litre / day x plant species.

Table 2: Steering facts of the retention efficiency of green roof systems

The questions are: Do green roofs in summer have a higher efficiency in water retention? Do they evaporate water also in winter time? What about a full saturated green roof? Has it the same run off like a gravel roof?

Cooling the surface temperature by evaporation or transpiration is a process of physics. The energetic amount which is required to evaporate water is well known, it's about 2669 Joule per gram or 2670 kJ per litre or mm precipitation. Beside transpiration and evaporation part of the water is also required for the plant growth, herbs are made of about 90% water. The plant growth on extensive green roofs is limited to phases with sufficient water supply. From gardening is also well known that the irrigation of garden land requires about 10 mm per irrigation. So, the vegetation on green roofs can be used as an indicator of the degree of water saturation within the growing media. How much water does an extensive green roof require? Some answer to this question will be given in the following chapter.

2.1 Climate Measurements

The long-term temperature measurements on the research roofs are done with RTD- temperature sensors, infrared – surface measurements and shaded RTD's. These instruments allow to calculate surface temperatures and temperatures inside the growing media.

Table 3 gives an overview of nearly four years of measurements. The selected green roof growing medium and the type of vegetation is called „extensive green roof“. It is compared to a roof covered with gravel which is a typical alternative in Central Europe to the bare bitumen flat roofs. In the above mentioned publication, statistics (SPSS) are printed. Data analysing was done in steps of 5 degrees centigrade from low temperature to

high temperature between greened and gravel research areas. At extreme low temperatures (under -5 degrees centigrade) the green roof areas are warmer (insulation effect) than the gravel roofs. At extreme high temperatures, above 25 degrees centigrade the green roof is cooler than the gravel roof. In between, it differs. In comparison to the bitumen roof the temperature differences between green roofs and gravel roofs are less distinct. In a lot of nights, green roofs were warmer than gravel roofs. This is due to the fact that green roof systems contain a bigger amount of material with a higher

Parameter (Short name, measurement in ..., Type of Sensor).	Min.	Max.	Mean	Std.-dev.
Green roof soil temp. inside a growing medium (BTZ, Degree Celsius, PT-100)	- 13,4	44,7	11,5	9,1
Soil temp. below a gravel layer (BTS, Degree. Celsius, PT-100)	- 16,8	60,1	10,8	9,7
Air temperature (LTB, Degree. Celsius, Thermometer, with sheltered cover – Thiesclima. Exposition : 1 metre)	- 18,2	36,5	9,4	7,9
Surface temperature 10 cm above the gravel roof , sheltered by a small "against radiation" – cover, BOS, Degree Celsius, PT-100; own construction.	- 15,8	39,6	9,9	8,6
Surface temperature 10 cm above the green roof , sheltered by a small "against radiation" – cover, BOZ, Degree Celsius, PT-100; own construction.	- 16,3	41,0	10,0	8,5
Radiation Balance, 1 m above the Gravel roof , (SBS, Watt/ sq-metre; Sensor Fa. Schenk, Austria)	- 172,8	693,7	52,4	127,7
Radiation Balance , 1 m above the Green roof , (SBZ, Watt/ sq-metre; Sensor Fa. Schenk, Austria)	- 90,9	736,4	56,8	141,3

Table 3: Surface temperatures and temperatures inside of two growing media (from Koehler, 2004, modified. *Descriptive statistics of selected climate values taken from Jan. 2000 – Dec. 2003 continuously (1397 Days)*)

For calculation of the energy balance, further parameter are measured continuously: global radiation, wind velocity at two heights, relative humidity and precipitation.

storage capacity than it is inside a gravel layer. In addition, gravel acts very quickly in the sense of temperature variation.

In cold times, the green roof insulates. The temperature amplitude of the gravel roof on the surface and inside the gravel layer is nearly the same. Between the surface and under the growing medium there can be a difference of about 5 degrees centigrade.

If the growing medium dries up in summer, the surface of the green roof can be warmer than the gravel roof. Under rainfall conditions the temperature of the green roof will decrease for several centigrade. This is a physical process of the radiation balance of the roofs. It can be explained by energetic components, like it was done for the example of the UFA-factory (see: Koehler u. Schmidt, 2002). The radiation supports the evaporation of rain water and influences the water content inside the growing medium. This process of cooling will be explained for the green roof research area of the University of Applied Sciences Neubrandenburg with a selected data set from spring / early summer 2004 (see table 4 and the following chapter).

2.2 Water content of the growing medium

Most processes of urban climate alterations on green roofs are steered by storage and evaporation or transpiration of water. The deposition of the rainfall, storage capacity of the growing media and the evaporation are the variables, which can be influenced by the planner of the green roof project depending on the aims. In order to obtain real figures for these processes, the following methods are used for measuring the climate conditions at the research roof in Neubrandenburg:

- a) measurement of the precipitation (automatically Lambrecht-rainmeter and manual daily or weekly precipitation collection).
- b) climate data registration of radiation, radiation balance, wind speed and several temperature sensors. The site is to be seen at image 2, for a selection of data, see table 4. These data allow to calculate the typical water balance of the investigation area.
- c) tipping buckets / flow meter, installed inside the drain pipe system of the building (storage capacity: 1 l per each impulse). The measured area is 153 m² for the gravel roof and 102 m² for the green roof (see image 4).

- d) lysimeter instruments for an online registration of the water content within the growing media, size of about 40 x 40 cm. The run off will be measured at these systems with drain-spoons of a capacity of 5 ml (see image 3).

Summarised data of the water balance of the research green roof at the University of Applied Sciences Neubrandenburg (Spring / Summer 2004) are displayed in table 4.

The precipitation that reaches a certain roof area is influenced by the structure of the roof landscape. A roof has a distribution in rainfall of up to 20% difference depending on special roof constructions (see: Koehler et al 1993). The rain field is disturbed by a lot of facts. Also the count between two rain collection systems differs of about 10% (see both precipitation-columns in fig. 2). The climate factors are characterised by three categories each. The temperature „cool“ means the average temperature of the day is below the typical value of this season. Moderate temperature is about the average value of the season, hot is above the average temperature. The wind speed on roofs is about 50% higher than beside the house. This means on roofs we have a higher evaporation rate, measured with „Piche – Evaporimeter“ (see: Koehler et al. 1993). It has also an influence on the quantity of the evaporation. The column of the relative water content is focused on the variation in water contents between complete saturation after intensive rainfall and very dry conditions (e.g. summer 2003 in Central Europe).

The complete table 4 shows what happened on the green roof: the precipitation of about 60 mm, the daily reaction of the change in the water content of three different growing media and the gravel. The values of days without rain are set into „Italics“.

During observation time dry weather conditions didn't occur. It was an unusual wet season, the plants at the extensive green roof didn't have any water stress in this time of observation.

The data presentation is simplified, nevertheless it allows to look beyond the processes of: - distribution of the precipitation - the changes in the soil water contents and the run off quantity inside the calculation:

$$\textit{Interception} = \textit{Precipitation} - \textit{Soil water change} - \textit{run-off}$$

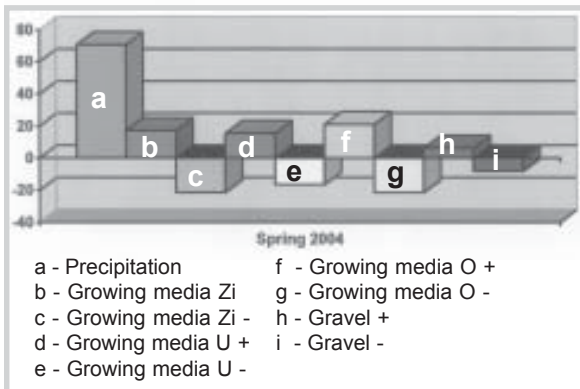


Fig. 1: Graph of the Data set in table 4: Precipitation of about 70,7mm and the storage/run off values of three different types of growing media and a gravel layer. (Source: measurements with lysimeter). (+ additional weight, - reduced weight)

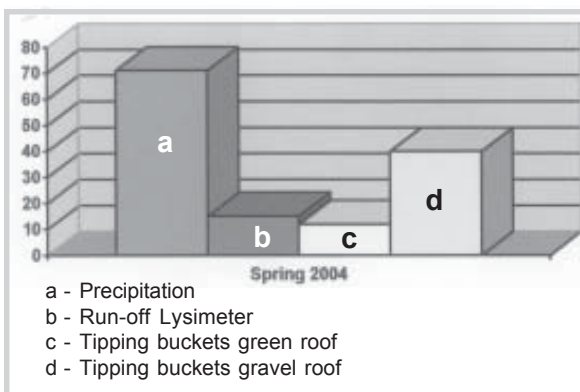


Fig. 2: Precipitation; and three different run-offs

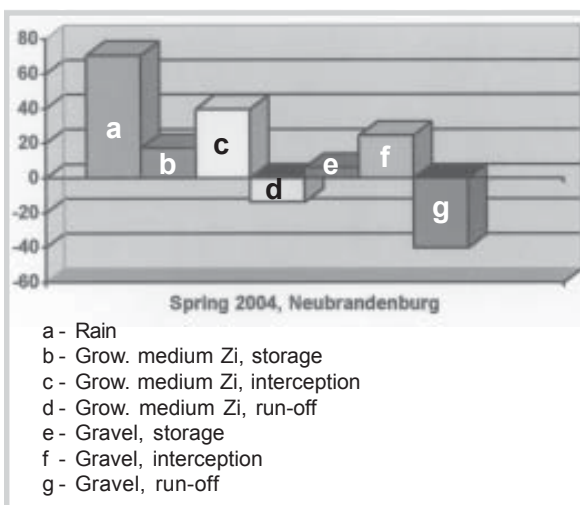


Fig. 3: Analysing the components of a roof water balance model: Comparison of a green roof and a gravel roof. (Rain= 71 mm).

3. Energetic estimation and cost savings

These measurements allow to estimate the different water retention rates of gravel roofs and green roofs. All these data are based on days with only moderate rainfalls. The results of this study are in good agreement with earlier calculations done on the data base of the radiation balance from the research field at the UFA-factory (Koehler & Schmidt 2002). The bitumen roof at the UFA displayed a daily rate of energetic exchange of only 123 WH, whereas the green roof attained about 1185 WH. In comparison with the UFA, the green roofs in Neubrandenburg reached similar values (1258 and 1303 WH) and the gravel roof displayed an intermediate position (about 685 WH).

Studies of Schmidt & Teschner (2002) show, that the run-off on green roofs is about 2 hours delayed in comparison to bitumen or gravel roofs. The retained water is available for evaporation days after the rainfall. So the cooling effect will be stretched out to days without rainfall and higher temperatures.

The following table 5 displays the energetic aspect of the retained and later evaporated water in summer 2004, calculated as daily energetic values. To have a better understanding of the energetic savings, these values are also transferred into the units of „Rohöleinheiten“, „RÖE“, cubic metre „Natural Gas Units“ and „British Thermal Units“. On base of the current prices of electricity and gas the potential financial savings are shown.

About 80% of the annual precipitation will evaporate directly off the green roofs in the days after the rainfall. Only 20 % will run off immediately without a cooling effect.

In Central Europe the normal annual precipitation is about 600 mm per square metre and year. This leads to a potential energetic exchange of 480 mm x 2670 KJ = 356 KWh or 30,6 RÖE or 40 m³ Natural-Gas Units or 1214717 BTU (British Thermal Units). The energetic relation between the bitumen roof and the green roof is about 1:10. Consequently 10% efficiency of the bitumen roof must be deducted from the calculation of the green roof to get the netto benefit of green roofs in comparison to conventional bitumen roofs. For the economics, the **cost saving per 1 m² and year** is given with regard to the gas prices in 2004. **It's about 14,4 € and about 42,0 € considering the current price of electricity.** (see web links to the cost calculation base).

Aus Wissenschaft und Forschung Science and Research

The general heat load of a city is affected by the heat balance of building surfaces, paved street areas and parking lots. To influence the urban climate in a positive way, the flat roofs of the cities which are able to carry extensive green roof constructions can make an important contribution (see calculation above).

Facades, streets and parking lots need other solutions, like different kinds of paving and bioswale systems to retain run off water near by streets. Facade greenery is another opportunity in cities. Working with bio-architecture or living walls are in their infancy, but studies like in Berlin-Adlershof, (building of physics, see Schmidt 2003) will offer also hard facts about the influence of plant species in front of glass windows. For each city a specific combination of all these elements must be selected to reduce the urban heat island effect worldwide. The potential of plant species to contribute to the urban climate change are in the beginnings. Planners must make decisions in selection of the adapted plant species, the right growing medium and technical solutions to give long warranties.

The big potential of these bio-solutions implies not only technical terms, it will also offer better living conditions for the citizens.



Image 1: One general overview of Sciences



Type of roofs*
Gravel roof
Green roof 1
Green roof
Bitumen
Green

Table 5
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calc