greening rooftops
for sustainable communities
Boston, May 11-12, 2006

5.3: Aesthetics and Cooling – Green Roofs and Walls

The evapotranspiration of greened roofs and façades

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Summary

The evapotranspiration of greened roofs and greened façades has a potential to significantly reduce the urban heat island effect. Additionally, the retention of stormwater dramatically reduces the peak load into combined sewer systems and prevents combined sewage release into surface waters.
Real evapotranspiration (ETP) can be measured with lysimeters. We integrated 6 small units in two green roofs to measure the water content of the substrate. The system is continuously weighed by a computer which is connected to the internet.
One of several measures of sustainable architecture applied at the Institute of Physics in Berlin-Adlershof is a façade greening system. This project includes permanent monitoring of water consumption from different plant species and the cooling effect of evapotranspiration that influences the energy balance of the building. Additionally, the plants provide shade during summer, while in winter time, when the plants lose their foliage, the sun's radiation is able to pass through the glass-front of the building.
The experimental data from Adlershof and other projects has been used in conjunction with historical 5-minute precipitation data of the past twenty to thirty years to provide long-term simulations and predictions. Daily potential evapotranspiration data (PET) is also required to be included in this model. The long-term simulation of precipitation, PET and real ETP will be an important step to allow the transposition of real measurements to different climatic conditions and to determine the potential for stormwater retention function and cooling rate of green roofs and façades.

Key words: green roofs, green façades, evapotranspiration, lysimeter measurements, evaporative cooling, stormwater retention

1. Introduction

In the natural landscape most of the precipitation is evaporated or transpired (evapotranspiration [ETP]), whereas in urban areas rainwater disappears rapidly into the sewer system. For example, in the natural watersheds of the rivers Spree and Havel, in Germany, approximately 80% of the precipitation is subject to ETP by plants and the surrounding soil (see "meadow" columns in Fig. 1).
Retained rainwater within greened roofs has to be evapotranspirated and the ETP of green roofs and green façades has a potential to significantly reduce the urban heat island effect. Additionally, the retention of stormwater dramatically reduces the peak rainwater run-off load into combined sewer systems and prevents combined sewage release into surface waters.

The precipitation/ runoff-ratio depends on local climate, vegetation and the type of green roof, which is mainly defined by the field capacity of the substrate and is related to the storage capacity for rainwater. Fig. 1 shows the mean annual evapotranspiration rates of different surfaces, three of which are different green roof types. These values have been measured at our institute in Berlin-Wilmersdorf. A meadow on a loamy soil shows evapotranspiration rates of 87 and 89%, depending on the groundwater level. In addition, Fig. 1 shows the surface runoff, evapotranspiration and groundwater recharge of semi-permeable surfaces. Generally, semi-permeable surfaces permit more groundwater recharge compared to the natural landscape.

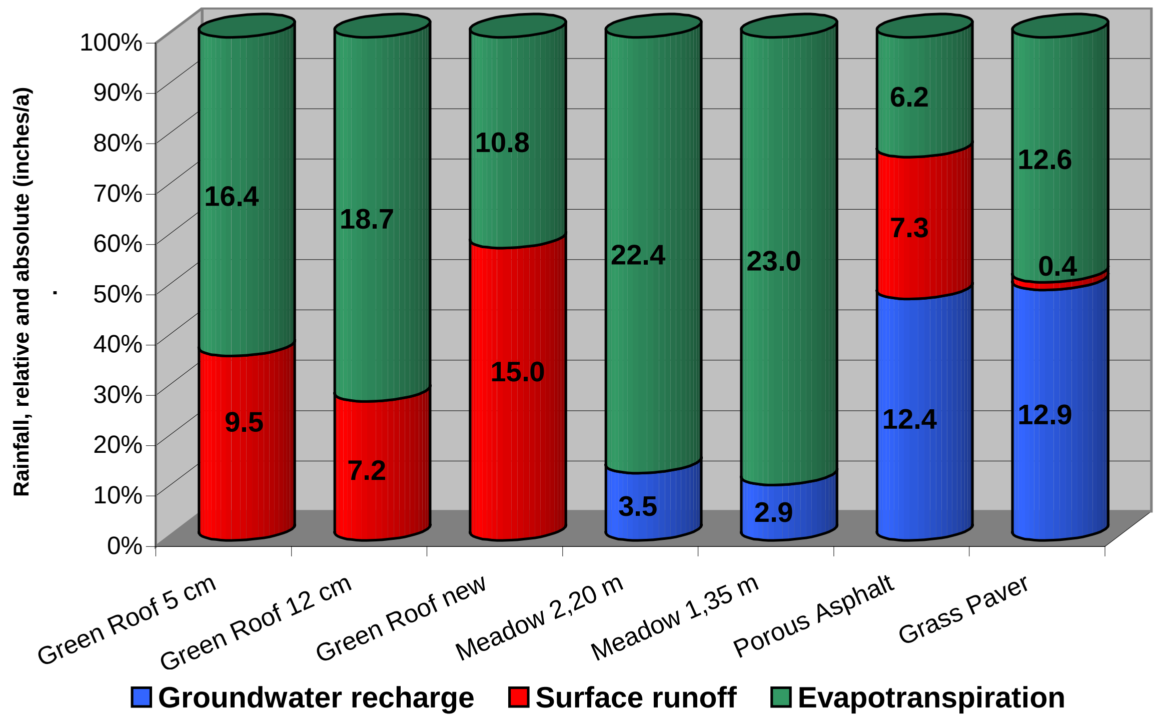

Fig. 1 Hydrology of different surfaces (inches/a and %), 1/1/2001 – 12/31/2004 TU Berlin Dahlem

Several environmental changes in urban areas are caused by reduced evapotranspiration of precipitation. An increase in thermal radiation can be observed due to higher surface temperatures and the capacity of many materials, such as concrete, to store heat. Urban surfaces convert up to 95% of the net incoming solar radiation into heat [Schmidt 2003].
As a result, air temperatures inside buildings rise and lead to discomfort or increased energy consumption for indoor climate control. An effective solution to lower temperatures inside and outside of buildings is to apply roof and façade greening systems, thereby dissipating thermal energy by ETP.

2. Methodology

Real ETP can be measured with lysimeters, which consist of troughs containing planted soil that is continuously weighed [Schroedter 1985; Zenker 2003]. A permanent record of the changes in the water content of the soil entering or leaving the lysimeter at its upper surface (precipitation and evapotranspiration) as well as its bottom plane (percolation and capillary rise) is acquired [Markwardt, Diestel, Schmidt 1993].

The first method, i. e. measurement of the real ETP, is used in our lysimeter station ("meadow" columns in Fig. 1 on a loamy soil). The lysimeter station consists of 12 soil monoliths with three soil types and two heights of groundwater table [Diestel, Zenker, Schwartengraeber, Schmidt 2002]. In order to measure the real ETP of the greened roofs we integrated 6 small lysimeters in two green roofs at the University of Applied Sciences Neubrandenburg (Prof. Dr. M. Köhler). The balances and runoff tipping buckets are monitored by a computer system which is connected to the internet.

Fig. 2-5 Lysimeter-measurements at the Univ. of Technology Berlin (soil monoliths, left, surface and underground system) and University Neubrandenburg (green roofs, right)

A second, simpler method to obtain the real ETP is to measure the difference between precipitation and runoff (Fig. 6-9). Inaccuracy in precipitation and runoff measurements would accumulate mistakes in the calculated ETP which represents the balance of both values. This method, i. e. measurements of precipitation and runoff, is carried out on several roofs, like those of UFA-Fabrik in BerlinTempelhof, and the testing field at our Institute in Berlin-Wilmersdorf (see “green roof” columns in Fig. 1). A testing field of semi-permeable surfaces is also included for comparison (see “porous asphalt” and “grass paver” columns in Fig. 1). Measurements of precipitation and runoff on several green roofs at the KICT in Ilsan, Republic of Korea, have been carried out with the support of our department since 2004.

Fig. 6-9 Measurements of precipitation and runoff at *Ufa-Fabrik* in Berlin-Tempelhof (left) and the University of Technology Berlin (green roofs and semi permeable surfaces, right)

Another more demanding project is the building of the Institute of Physics in Berlin-Adlershof, a project of the architects Augustin and Frank (Berlin). This venture is a research and office building that features a combination of sustainable water management techniques, including the use of rainwater to cool the building. One of several measures of sustainable architecture applied is the reduction of energy consumption via a façade greening system. The plants provide shade during summer, while in winter time, when the plants lose their foliage, the sun's radiation is able to pass through the glass-front of the building. The project includes permanent monitoring of water consumption from different plant species and the cooling effect of ETP that influences the energy balance of the building. In this project the irrigation of the façade greening systems is controlled and monitored by a computer system, which is also connected to the internet (more detailed information see http://www.gebaeudekuehlung.de).

Fig 10: Façade greening system at the Institute of Physics, Berlin-Adlershof

3. Results

3.1 Roof greening

Fig. 11 shows the change of the weight of one 0.15 m² (1.6 ft^2) lysimeter system of the University Neubrandenburg, resulting from precipitation and ETP. “Zero” in fig. 11 was set to an assumed value of a low water content. The daily precipitation is included in this figure.
A low water content of the soil causes a lower ETP than when the soil has a high water content (Fig. 12). Condensation during night time can be observed as well.
ETP is the most important factor for the environmental benefit of green roofs and green façades in urban areas. It influences the urban hydrology, reduces the surface temperatures and is essential for stormwater retention. Calculating the real ETP value is necessary to estimate the saturation of the roof substrate for the stormwater retention. Long term simulations need to include real precipitation and real potential evapotranspiration (PET) data. Measurements of PET are carried out with Czeratzki-sensors. PET is calculated as well by the Penman-Monteith approach (1976). For the relation between PET and ETP a transfer calculation is needed, which considers the field capacity of the substrate and the type of vegetation (coverage, leaf index,

species etc.). Other climatic conditions such as the condensation of water at night have to be estimated.

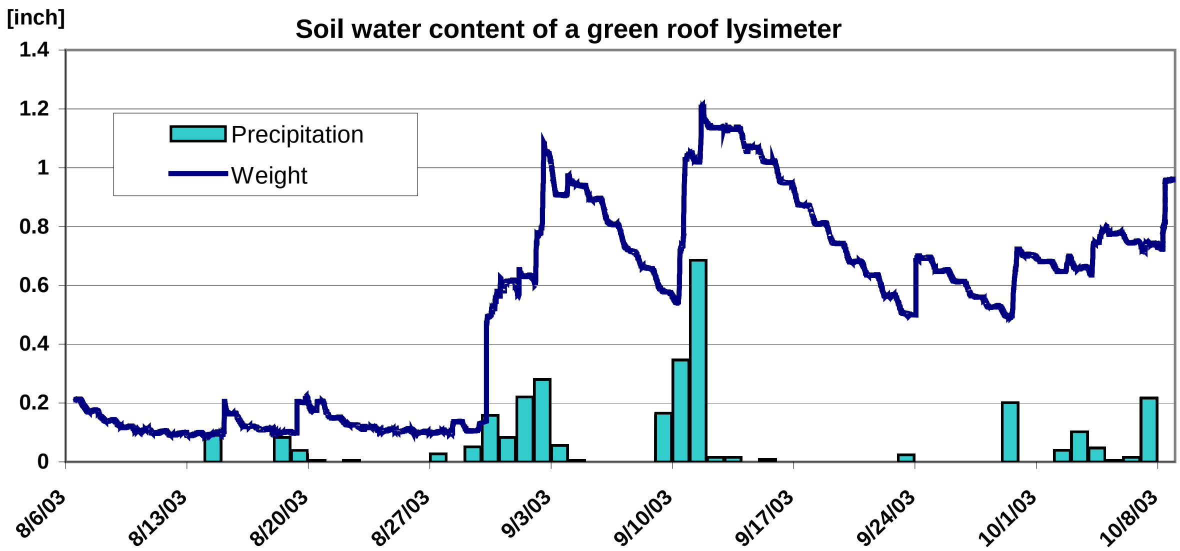

Fig 11: Soil water content in variation of the evapotranspiration and precipitation

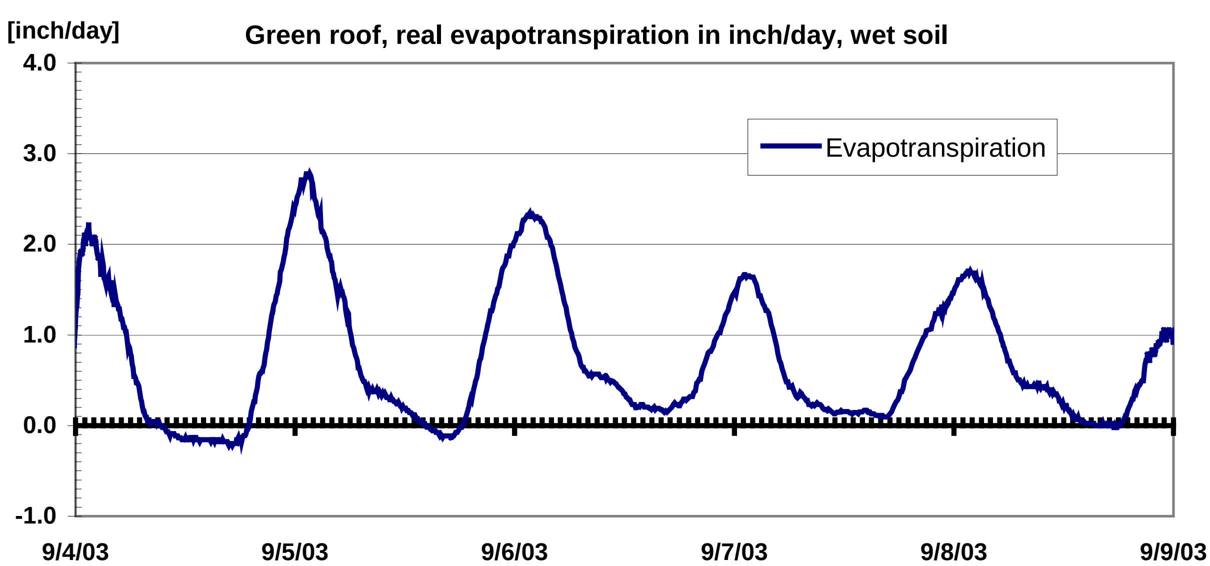

Fig. 12: Real evapotranspiration of a greened roof, lysimeter measurements

3.2 Façade greening

A major objective of the façade greening system in Berlin-Adlershof is to utilize ETP to improve the microclimate inside and around the building. Continuous monitoring has been carried out at this site since 2004.

There are 150 experimental troughs and these troughs are organized in such a way that the water content is maintained at a constant level. ETP has an immediate feedback to the water consumption. The troughs have no facility to be weighed. Therefore, ETP is determined by measuring the water supplied to the trough throughout the day. Figure 13 shows the mean daily ETP of this façade greening system. The water consumption has a direct relation to the real ETP. Compared to the PET the real ETP is extremely high. The plants have an optimized water supply and the surface of the trough is small compared to the surface of the plants.

The mean ETP between July and August for the south face of the building was between 0.2 and 0.44 inches per day (5.4 - 11.3 millimeters) depending on which floor of the building the troughs were located. This rate of ETP represents a mean cooling value of 157 kWh per day.

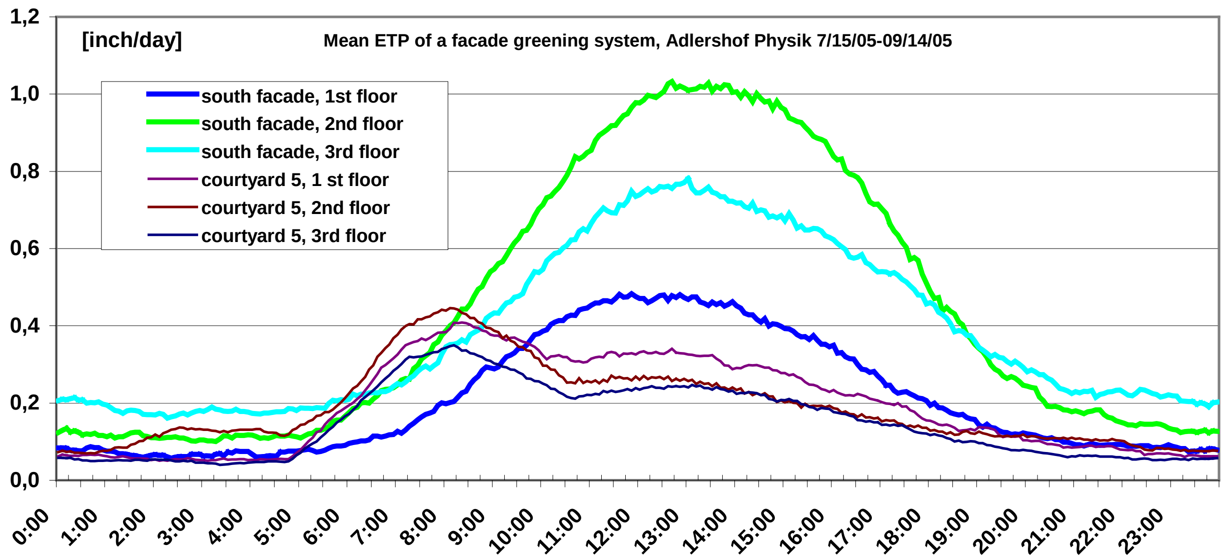

Fig. 13: Real evapotranspiration of a façade greening system, trough measurements

4. Conclusions

Greening a building's roof and façades results in significant additional ETP, which has a high potential to reduce the building's surface temperatures and to improve the climate inside and around the building. Both the PET and the real ETP are high compared to the natural landscape due to higher temperatures caused by the urban heat island effect and a lower humidity of urban areas, as well as a high global radiation and high wind speeds on rooftops.

The experimental data from Adlershof and other projects has been used in conjunction with historical 5-minute precipitation data of the past twenty to thirty years to provide long-term simulations and predictions. Daily PET data is also required to be included in this model. In order to predict stormwater, the model would additionally require information regarding the green roof area, the optional drainage area, the roof slope and the roof substrate parameters. Currently, we have not been able to create a general mathematical model to verify and transpose stormwater retention measurements, as our calculations for a mixture of non-saturated and saturated Darcy flow for different slopes have not yet been successful. The long-term simulation of precipitation, PET and real ETP will be an important step to allow the transposition of real measurements to different climatic conditions and to determine the potential for stormwater retention function and cooling rate of green roofs and façades.

5. References

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6. Acknowledgements

The author would like to express sincere thanks to Brigitte Reichmann, Department of Ecological City Construction of the Berlin Senate for organizing and financing the innovative project in Berlin-Adlershof. Thanks to Paul Early and Marion Pfeffing who improved this English version.

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Marco Schmidt studied Landscape Architecture in Berlin. He worked on several scientific projects of local rainwater management strategies, especially regarding water balance modifications in urban areas. 1992 master thesis about extensive greened roofs to improve the urban climate. Since 1992 research and teaching activities at the University of Technology Berlin and the Univ. of Applied Sciences in Neubrandenburg on developing the necessary skills and best practice in the landscape planning process. Research and testing fields in urban ecology, esp. rainwater management of pavements, roof greening and rainwater harvesting projects. He is also specialized in electronic acquisition and processing of environmental data.

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