GREEN ROOFS AS A CONTRIBUTION TO REDUCE URBAN HEAT ISLANDS

Manfred Köhler [1], Marco Schmidt [1], Michael Laar [2]

[1] University of Applied Sciences Neubrandenburg, Germany, manfred.koehler@fh-nb.de
[2] ITT, Univ. of Applied Sciences Cologne, Germany, michael_laar@hotmail.com
Web-page: www.fh-nb.de/LU/mankoehler.html

Abstract - The urban heat load is being increasingly conceived as a mayor problem in many cities. In Germany urban climate has become an important factor in urban planning since the late seventies. The expression of the “Urban Heat Island” (UHI) was established then.
Urban heat islands can occur in different climate zones. On a hot summer day in cities like Berlin, Chicago, Buenos Aires or Beijing, the difference in temperature between the city centre and the outskirts is significant. The city dwellers will try to find some cooler environment in the surrounding country side. In winter the negative effect of heat accumulation in cities turns into an advantage: less heating is required.
Now cities in the tropics and subtropics suffer almost all year around from urban heat islands, creating a considerable discomfort and increasing the use of air conditioning wherever possible.
More and more research projects are popping up worldwide. In the USA, the thermal profile of different cities are being monitored by satellite since December 2000, in order to get some clues on how heat islands work exactly and how to resolve this problem. Some steps have already been taken to improve the indoor climate of poor people, who live in badly insulated houses and can’t afford air conditioning: the program “White roofing” improves the existing black bitumen roof with a high absorption of solar radiation through the application of a white coating.
Another solution could be the implementation of green roofs, multiplying the benefits: beside the reduction of the roof surface temperature, it also improves the micro-climate through the evapotranspiration process, delays and reduces the storm water run-offs, which many times is linked to urban flooding, improves the visual impression and avoids the glare problem white roofs can create.
A data set of own measurements from July 2003 will be used to explain some aspects of surface temperatures and the temperature graph inside different substrates.

1 Introduction

Since the late seventies the phenomena of the urban heat island is being measured in several German cities like Munich, “Ruhrgebiet” (Northrhine-Westphalia) and Berlin. Summarized, the average annual temperature of inner city neighbourhoods is about 1 – 2 degrees higher than at the city limits (Horbert, 2000). The main difference in temperature is not only determined by a higher daily-maximum, but also by higher temperatures in city neighbourhoods at night. The higher temperatures correlate with the type of neighbourhood. Oke (1990) describes this correlation with the following formula:

$$I = 7.54 + 3.97 \ln (H/S) \quad (1)$$

H: Height of the building structures; *S*: Width of the street;
I: Intensity of the urban heat island

The UHI – depends also from the size of the city and the climate situation, e.g. the cloud cover and inversion weather (see Sukopp & Wittig, 1998). Other aspects, like a lack of ventilation canyons, the heat emission of car motors, the high absorption factor of most street pavements combined with a lack of shadow spending trees, can significantly contribute to urban heat islands (see Laar, 2002).

Many urban heat islands are not a temporary state. They can influence the micro-climate for up to 24 hours a day, due to the stored solar energy in the thermal active masses of the built environment, e.g. street pavements and building envelops. This leads to higher temperatures also at night time, increasing the need for air conditioning in urban dwellings. Maps visualizing the temperature distribution within cities display significant higher temperatures in areas with high density compared to those with inner city parks or low density suburbs. UHI monitoring via satellites is being carried out in the USA by NASA (see Wong, 2003).

2 Green Islands against Heat Islands

The best solution to improve the urban micro-climate in existing neighbourhoods with high density is the increase of green areas, improving the shadowing and increasing the evaporation rate, which can be considered as the decisive action (see Stülpnagel, 1987). The air humidity in cities is generally lower than in the surroundings. Therefore cooling efforts by evaporation have a huge potential. In some cases it might be possible to implement new parks, e.g. within the revitalization of a former industrial area close to the city centre (see Laar, 2002 (2)). Also de planting of trees along the streets might be a possibility to improve the micro-climate. Actually in most cases these solutions are not viable, considering the existing high density. So the green roofs come into play.

Own researches compare extensive greened roofs with conventional non greened roofs, roofs sealed with bitumen as well as gravel-covered roofs. First measurements were published by Koehler et al (1993). Bitumen covered roof areas had the highest daily - temperatures. On the other hand green roofs not in each case had the lower night temperatures. This aspect depends on the water content of the substrate and the storage capacity of the building itself.

The difference between the peak values for day and night temperatures is higher on non greened dark roofs than on green roofs. This is one of the reasons for the impressive durability of the waterproofing layer of green roofs.

3 Research Results

Measurements on greened and non greened roofs in Germany are the basics for this interpretation. Some results of this working group have been already published (see: e.g. Köhler et al. 2002). A growing interest in green roofs is leading to the start of intensive research activities in this field, e.g. in Spain, the USA, Mexico etc. A data exchange between research groups and regions is possible. Also first measurements in Rio de Janeiro have been started in 2003 in cooperation with the authors.

The values of Table 1 demonstrate the data base, measured at the University of Applied Sciences, Neubrandenburg, Germany, in July 2003. This research site was started in 1998 on one building, it was completed by an additional research field on a second building in 2001. So more different types of substrate could be tested under a wide variety of conditions.

1) Surface measurement means, that, protected by a stainless steel shelter, a temperature sensor is installed above a gravel and a green roof. The values are nearly the same. The

shelter influences the sensor a little bit like an umbrella. To reduce this effect, infrared – sensors measure the surface temperature without touching the surface. These sensors integrate the values of an area of about 100 cm².

2) The measurements "Inside" mean, these sensors are mounted inside the substrate / gravel, just on top of the sealing layer.
3) Radiation balance explains the difference between solar radiation input and the reflection of the roof in form of heat radiation (measured wave range from 0.3 – 30 µm) The higher the value in the radiation balance, the higher the stored radiation energy stored in the respective roof system.

The data collection has been carried out with a data logger and a PC – System, with measurements each 5 seconds. A five – minute average value had been stored and this data set was transformed into Excel files.

The summer of 2003 was extremely hot in Germany. The warm and dry summer period started in May. One significant rain fall was measured on the 22nd of July. So in the following figures 1 – 3 the data source around this date has been selected to demonstrate the relation between precipitation and the run off of the storm water (see fig. 1): The precipitation follows a "staircase structure". While the run-off from the gravel covered roof starts almost immediately, the green roof delays the start of the run-off by almost three quarter of an hour. The line representing the green roof, measured also at a real green roof of about 100 m², is shifted in time and quantity, compared to the precipitation. With a precipitation of 40 mm, a run off of only 15 mm was measured at the green roof. The both other lines explain the run off from small tipping gauges –systems, installed in lysimeter systems. Lysimeter are a type of balances. They contain a section of the undisturbed growing medium. So it is possible to measure online the changes in moisture caused by precipitation and evaporation. In this case they have a size of 40 to 40 cm and a depth of about 10 cm like the green roof in the surrounding. The measured run off was around 10 mm run off in the same amount of time.

The cooling effect of the rain fall: the evaporating rain water cools the surface of the building down. Fig. 2 demonstrates this effect, comparing between a dry substrate on the 21st of July and after the rain on the 23rd: the difference is about 5 degrees Celsius. Fig. 3 demonstrates the different surface temperatures, all three examples cooled down after the rain fall.

Photo 1: Research site 1: since 1998

Photo 2: Research site 2: since 2001

For July the potential evaporation rate after Haude (1934, see also Geiger et al.1995) shows a deficit of about 120 mm which means, that the potential for evaporation was not exploited, pointing to arid conditions. In August this deficit increased up to 190 mm, with a precipitation of 21 mm for the whole month. In fact this period was atypically hot and dry for

German conditions. So the substrate of both extensive green roofs dried up completely. Most plant species also dried up, waiting for new rain to re-generate.

Table 1: Monthly Data set July 2003; (Univ. of Applied Sciences; Building 1: BV, Building 2: ALT). (STDV*: Standarddeviation)

Location of the Sensor	**Building, Signature**	**Type of Sensor**	**Min**	**Med**	**Max**	**STDEV***	**Unit**
Surface of gravel, shaded	1: TBOT1	Pt 100	10.2	19.9	37.4	5.2	°C
Surface of Green roof 1 (Zinc)	1: TBOT2	"	11.4	20.4	37.4	5.2	"
Inside Growing medium 1 (Zinc)	1: BT 1	"	15.6	22.4	33.8	15.8	"
Inside Gravel 1	1: BT 2	"	13.3	21.7	38.2	13.3	"
Radiation Balance above Gravel roof	1: SB 1	Schenk	-68	103	646	159	W/m^2
Radiation Balance Green roof 1 (Zinc)	1: SB 2	"	- 69	118	688	182	"
Inside substrate 2 (Opti)	2: Opti PT 100-1	Pt 100	20.5	25.5	30.9	5.2	°C
Inside substrate 3: (Ulop.)	2: Ulopor-PT 100-2	"	20.6	25.1	30.5	5.0	"
Inside Gravel 2	2: Kies PT 100-3	"	26.5	32.6	40.4	7.0	"
Surface substrate 2 (Opti)	2: Ray_1T	IR-Sensor	14.5	22.8	38.1	12.0	"
Surface substrate 3 (Ulop.)	2: Ray_2T	"	13.9	23.9	43.4	15.1	"
Surface Gravel 2	2: Ray_3T	"	12.9	21.0	34.2	10.9	"

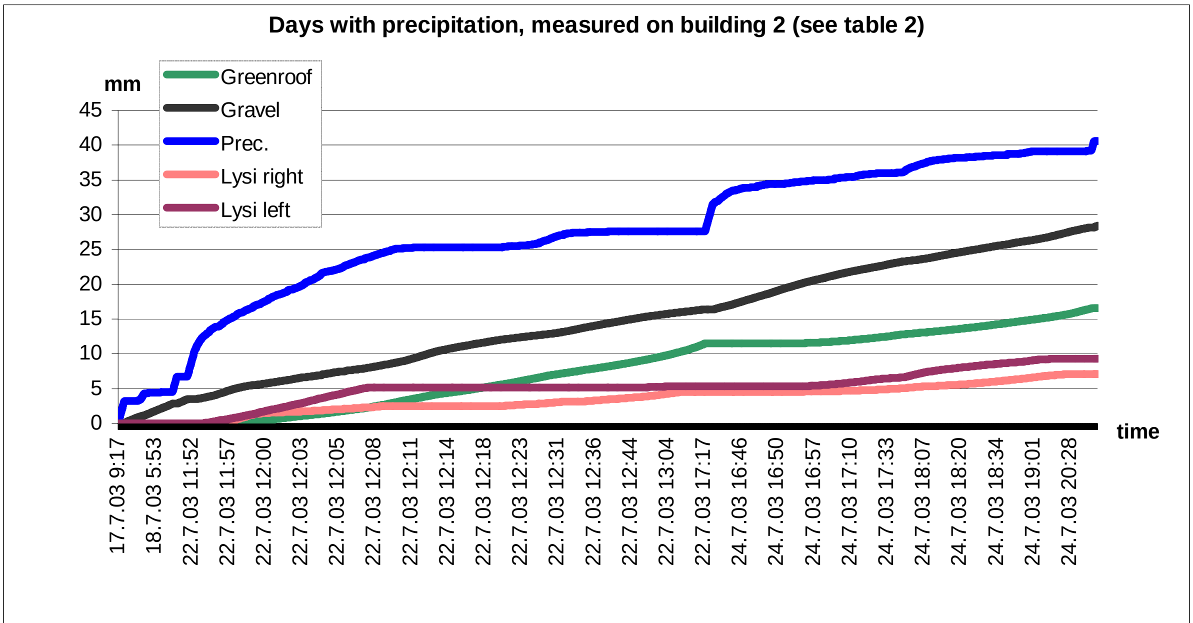

Fig. 1: Precipitation and run off from a gravel roof, a green roof and two small scaled Lysimeter in July 2003 (Research field, Univ. of Applied Sciences Neubrandenburg).

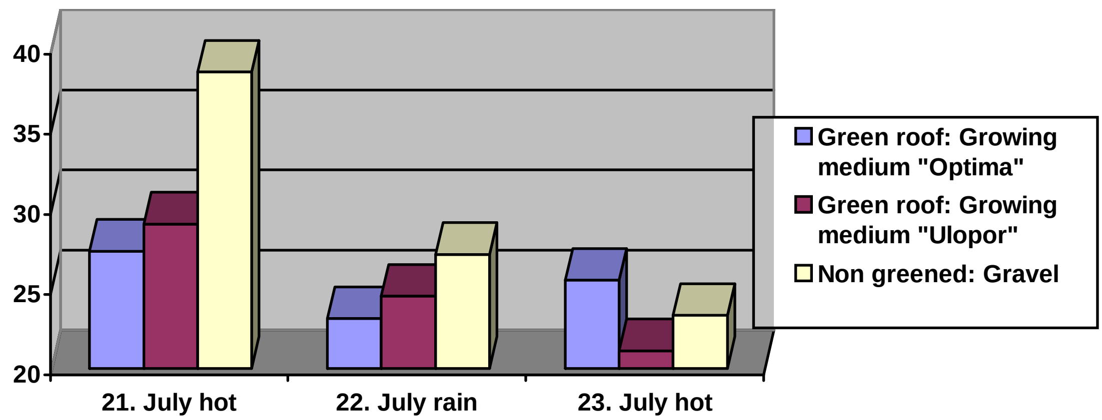

Fig 2: Temperature inside two substrates: Green-optima, Green Ulopor and under a gravel layer just above the sealing layer. Av. day temperature (x mean from 5 minute – value of the days) (Pt-100 – Values)

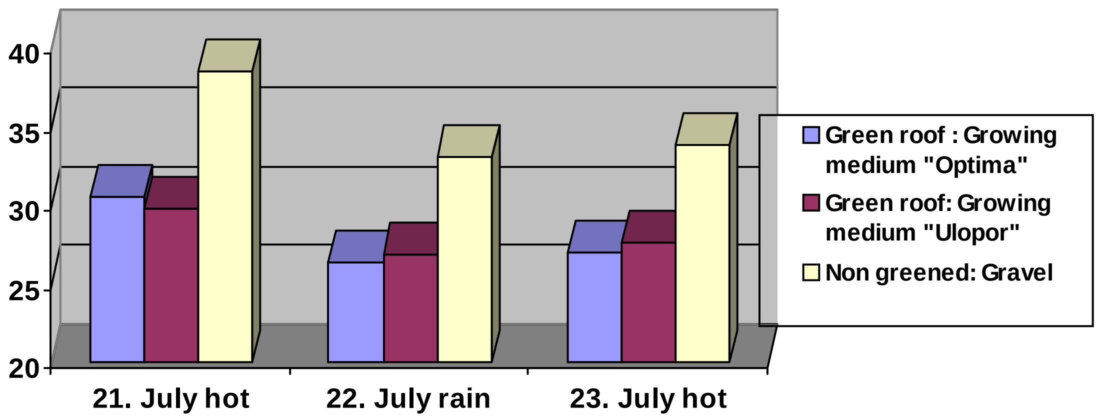

Fig. 3: Average surface temperature of two different green roofs and of a gravel layer (Infra-red-temperature measurements) on a hot summer day (21st of July), on a rainy day (22nd of July and on the following day).

4. Outlook

Heat load, pollutants and noise were important reasons for citizens with higher income to move from downtown to the suburbs. Programs of revitalization of central city areas and campaigns to increase the inner city greenery were started in the eighties. Green roofs are a part of these programs, starting about 20 years ago in Germany and Europe. Only a few years ago the multiple advantages of green roofs started to attract attention in North America and Asia.

Green roofs will certainly play an important role in future improvements of the urban environment. The exact advantages are only known for very few parameters and few locations, due to the complexity of its interaction with the urban environment. Many more aspects will be investigated in the near future, necessarily combining real measurements with theoretical simulations. After three decades of research activities on green roofs as a more or less isolated system, now we are on the threshold to understand its interaction with the much bigger system – the urban environment.

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