

Thermal comfort and reduced flood risk through green roofs in the Tropics

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ABSTRACT: Green roofs are already quite common in temperate climates, like in central Europe. Advantages like the reduction of the run-off of storm water, the improved protection of the sealing against ultraviolet radiation and high temperature amplitudes are well documented. The application of green roofs in the tropics is quite recent and still in the beginning. Scientific results are rather rare. Since the beginning of 2004 there is a research project on green roofs going on in Rio de Janeiro/Brazil.

Two types of roofs are being compared: fibre cement and flat concrete roofs. The research site is composed of 4 roofs of 4m² each, one fibre cement roof and one concrete roof without vegetation as reference roofs and one fibre cement roof and one concrete roof with substrate and vegetation each.

The objectives of the research project are:

- Measurement of the difference of the surface temperatures on the underside of the different roofs (the indoor side), in order to find out the impact of green roofs on the indoor comfort of low cost houses in the hot & humid tropics
- Measurement of the run-off in order to quantify the effect of green roofs as a buffer during tropical storm water events.
- Identification and testing combinations of plants and substrates for the specific climate of Rio de Janeiro with dry winters and very humid summers.

Keywords: tropical climate, extensive green roofs, thermal comfort, run-off reduction

1. INTRODUCTION

While green roofs are already quite common in countries with temperate climate like Germany, especially extensive green roofs are still an exception in tropical climates.

In the last decades a fast growing of urban agglomerations could be observed. In most cases it was accompanied by serious environmental degradation of the urban environment. Especially the sealing of urban soil causes flooding and inner city heat islands, reducing significantly the well being of urban dwellers. A lack of green areas is recognized as a major problem in many cities. All this facts are leading to a growing consciousness for quality of urban spaces and environmental issues. Amazing improvements in the economy of many tropical countries and a growing middle class are preparing the terrain for concepts and technologies improving the environmental balance of cities. One important item will be the green roof technology. Until recently research and development was concentrated mainly in Germany. So solutions were tailor made for German climatic, economic and technical parameters. In tropical locations like Rio de Janeiro some parameters are significantly different: due to its tropical climate there exists an a 12-month growth period, 2 – 3 times as much rain, higher temperatures, higher relative humidity and higher solar radiation. Also the building technology is different, as there is no frost or even low

temperatures and no legislation on energy efficiency in buildings.

The expected advantages for tropical locations are even greater than in temperate climates:

As there generally is no thermal insulation on roofs, the effect of direct evaporative cooling on roofs improves the comfort in the building

Inner city heat islands may even have some positive aspects in temperate climate, as they reduce the need for heating and provide longer seasons for street cafes. In a tropical city they are a problem during the whole year, increasing significantly the need for air conditioning in buildings and reducing the thermal comfort in the streets and places. So the improvement of the microclimate is a major challenge for tropical cities.

Storm water events are more frequent in tropical cities, as are flooding (also due to a lack of efficient urban drainage systems for storm water events). Green roofs are decentralized and integrated systems and not end of the pipe solutions like sewer systems. Therefore they are easier to implement.

The idea of this research project was to give concrete information on possible benefits of green roofs under tropical conditions. It also was supposed to provide the necessary experience in order to realize green roof projects on a larger scale in the near future. Former experiences from Germany [1] and Brazil [2] have been integrated in to this research project.

A long tradition in intensive green roofs, featured by Burle Marx, makes Rio de Janeiro a perfect place to start research on green roofs in the tropics.

2. THE RESEARCH PROTOTYPES

The experiment was set up on the roof of the indoor swimming pool of the Maracanã-complex. In the past the Maracanã district was known as a low-density urban neighbourhood with many trees and a pleasant microclimate. Today this district is being considered one of the hottest spots of Rio de Janeiro, suffering frequently from floodings, due to a high sealing rate of the urban soil. The chosen location is rather unshadowed, only very early in the morning and very late in the afternoon surrounding hills and buildings shadow the test plots. The plots are on top of an wooden, white painted supporting structure, which is thermally neutral. The surrounding surface – the roof of the indoor swimming pool – is weathered concrete with an albedo of 0.1 – 0.2.



Figure 1: Test plots in Rio de Janeiro

Four test plots were installed in the beginning of 2004. Two test plots are simulating fibre cement roofs, which are still very common even for residential buildings in Rio de Janeiro. The other two test plots are simulating a concrete roof with a thickness of 9 cm, a common value. One of each roof types was then covered with a growing medium (the concrete roof protected with a waterproof plastic foil, while the fibre cement roof was sealed with silicone at the overlapping). The substrate consists mainly of sand, with a small portion of organic material. The thickness of the substrate on the concrete roof is 10,2 cm, on the fibre cement roof it is in average 8,9 cm (min. 4,0 cm, max. 13,0 cm). Each test bed is 1,0 m wide and 4,0 m long. The inclination for all roofs is 2%. Two wings of 50 cm on both sides of the prototype reduce the influence of the roof-edges on the airflow.

Each greened test plot has been visually divided in eight triangles of the same size in order to facilitate the observation of the plant growth of diverse species. About 40 species are actually being tested (start: January 2004).

The idea behind the composition of the prototypes was an adaptation of the green roof technology to the climatic and economic parameters of Brazil.

A set of two data loggers registered different parameters:

- The precipitation with three different rain gauges, working with different resolutions (2 x 1 mm, 1x 0,1 mm)
- The run-off from the “nude” fibre cement roof and the two green roofs with tipping-bucket units
- The air temperature inside and outside the prototypes, the relative humidity inside and outside, the temperature of the plastic foil sealing the concrete roof, the surface temperatures of the underside of each roof

3. THERMAL COMFORT

In Rio de Janeiro the bio-climatic approach seems to be very promising – in only 3% of the year would air conditioning be necessary [3]. This is definitely not the perception of the majority of the inhabitants of Rio de Janeiro. Most “Cariocas” use air-conditioning for long periods. Even in slums 20% of the buildings already use air conditioning [4]. The difference between scientific theory and actual perception is mainly based on the difference between air temperature and thermal radiation from surfaces. While the air temperature in Rio de Janeiro in fact is not extremely high – for this reason well planned buildings provide good comfort without air conditioning -, in many cases the building envelopes are heated up by solar radiation. Some simple and low cost solutions have been already suggested for walls [5].

Table 1. Albedo of test plots

Surface	Albedo
Concrete	0.31
Concrete Greened (substrate)	0.13
Fibre Cement	0.41
Fibre Cement Greened (Substrate)	0.18

While a low albedo value on conventional roofs means thermal discomfort, green roofs do generally have even lower albedo values without causing problems. For roofs on lower buildings they even have the huge advantage of not reflecting solar radiation and not emitting thermal long wave radiation on surrounding façades.

Over 10 month the albedo of the concrete roof became 27% lower, of the fibre cement roof 20%. Older roofs are almost black with an albedo as low as 0.1. This means an even more pronounced temperature difference between green roofs and traditional roofs.

Figure 2 shows the indoor air temperature and the underside surface temperatures of the concrete and the greened concrete roof on a typical summer day in Rio de Janeiro.

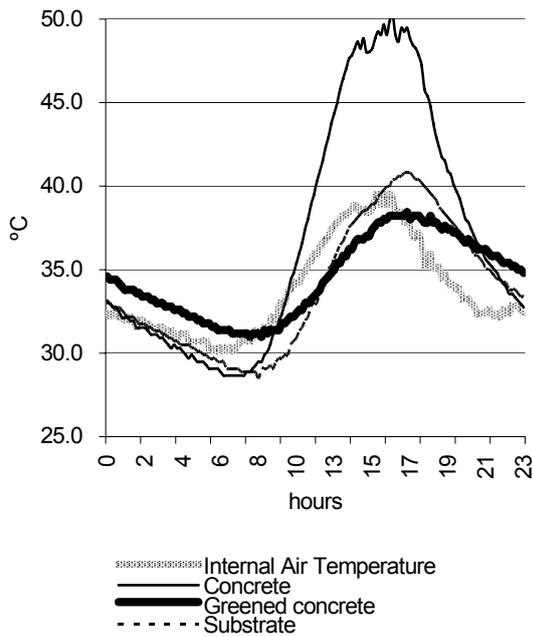


Figure 2. Surface temperatures of concrete - 9th of January 2005

Table 2. Temperatures in °C - 9th of January, 2005

	Indoor Air	Concrete (inside surface)	Greened concrete (inside surface)	Substrate
Max	39,5	50,0	38	40,8
Min	30,3	29,0	31,0	28,9

The maximum underside surface temperature of the concrete roof reaches 50°C, while the underside surface of the greened concrete roof gets 38°C warm, which is lower than the inside air temperature of 39,5°C. This value is close to the average human body temperature of 37°C. The surface of the sealing foil, protected by substrate (sensor between foil and substrate), gets 40,8°C warm. That means that even with a relatively new concrete roof with an albedo of 0.31 the temperature difference is already 12 K.

The minimum underside surface temperature during night time gets down to 29°C at the concrete roof and to 31°C at the green roof. The substrate blocks the long wave heat exchange of the greened concrete roof with the cooler night sky, for that reason the "nude" concrete roof gets cooler at night.

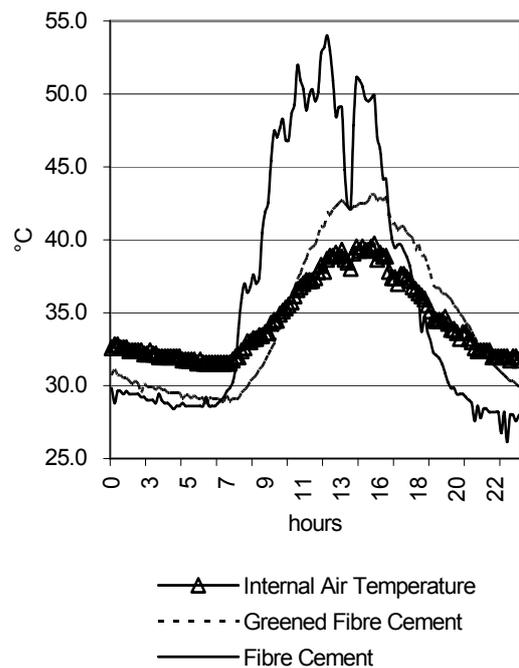


Figure 3. Surface temperatures of fibre cement - 7th of January 2005

Table 3. Temperatures in °C - 7th of January, 2005

	Indoor Air	Fibre cement (inside surface)	Greened Fibre (inside surface)
Max	39,7	54,0	43,0
Min	31,6	26,0	29,0

The underside of the fibre cement roofs gets 54°C hot, while the greened fibre roof reaches 43°C. The temperature difference of 11K will increase significantly over the time, due to a decrease of the albedo of the fibre cement, which after only one year is already down to 0.41 (from 0.51). The difference of the night temperature is similar to the concrete roofs and can be explained through the same effect.

4. REDUCED RUN-OFF & EVAPORATION COOLING

Flooding is a permanent problem in many cities. Due to a high sealing rate of urban soil the rain water can't be infiltrated into the soil, runs off to lower areas and causes flooding. In tropical cities this causes a second problem: due to the fast draining of the rain water, urban areas lost the ability to take advantage of the evaporative cooling through the rain water stored in unsealed soil and vegetation. The potential of evaporative cooling – the rain water – is lost due to the fast run-off. The difference in temperature of green areas and densely populated areas with sealed

urban soil is huge. So heat islands are a mayor problem in cities like Rio de Janeiro.

The measurements of the precipitation and the run off started in May 2004 and went on until February 2005, when due to the Pan-American Games in 2007 mayor renovation projects of the Maracanã-complex made a move of the prototypes to another location necessary. The new site has a significantly different microclimate; therefore the new measurement cycle will be object of a separate future publication.

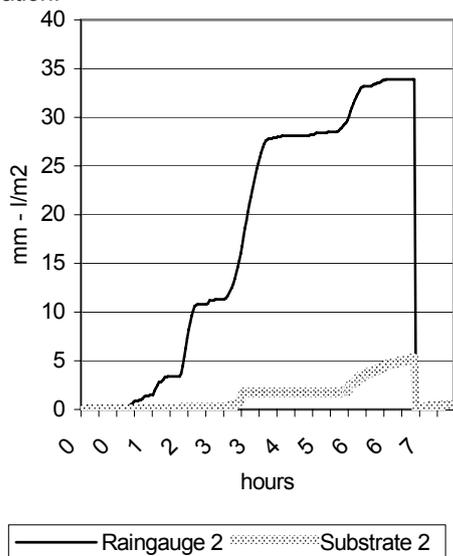


Figure 4. Precipitation & run-off in the early morning of 11.01.05 (0.00 – 8 am)

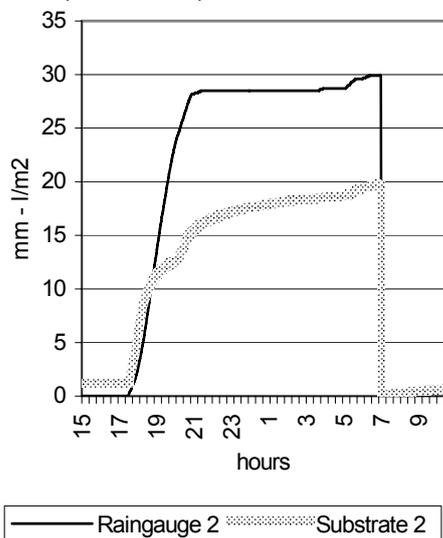


Figure 5. Precipitation & run-off in the afternoon of 11.01.05 (3 pm – 10 am)

The results of the measurements show an average reduction of the run-off for the 9-month period of 60,3%. The total precipitation in measured period was 556 mm, which is relatively low due to an uncommonly dry winter period. The result can be considered satisfying, considering the typical torrential rainfalls, which inevitably cause saturation of the substrate and subsequently lead to run-off.

The figures 4 and 5 (the curves represent accumulated values, zeroing every 24 hours at 7.30 am) show a typical situation in the rain season in Rio de Janeiro with a monthly rainfall of 210,4 mm in January 2005 [6]. In the early morning of January 11th, the run-off is reduced in 85% (substrate 2), creating also a considerable delay in the run-off (figure 4). The reduction in the afternoon is down to 35%, due to the saturation of the substrate (figure 5). The total reduction of the run-off in this 32-hour period with a total precipitation of 63,8 mm is 61%. That means that 38,8 l/m² were hold back, creating cooling through evaporation and evapotranspiration.

Evaporation and evapotranspiration of 335 mm in this nine-month period produced 228 kWh of cooling per m² on the green roof.

5. CONCLUSION

The first results are very promising. As expected, the advantages are even more significant than in countries with temperate climate. A couple of new solutions have been found in order to adapt the green roof technology to local parameters.

Research on plants and substrate requires some more attention and will be extended in a next step. Another important task will be the improvement of the retention rate.

Due to a huge reconstruction of the Maracanã-complex in preparation for the Panamerican Games in 2007 the measurements had to be interrupted after 9 month. The prototypes were moved to another site outside Rio de Janeiro and the measurements have been started again.

In the medium and long term the tropics can be considered a huge field for the implementation of green roofs.

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