Urban Water Retention by Greened Roofs in Temperate and Tropical Climate

Manfred Köhler (1), Marco Schmidt (2), Friedrich W. Grimme (3), Michael Laar (3), Fernando Gusmão (4)

Institutions

(1) University of Applied Sciences Neubrandenburg, Dep. of Landscape Architecture and Environmental Planning, Germany, www.manfred.koehler@fh-nb.de

(2) Technical University of Berlin, Institute of Landscape Development, Dep. of Applied Hydrology, Germany

(3) University of Applied Sciences Cologne, Institute of Technology in the Tropics, Germany

(4) CEFET, Rio de Janeiro, Brazil

First published on the 38th IFLA World Congress (International Federation of Landscape Architects), Singapore 2001

Abstract

The authors of this paper are working on the ecological effects of greened roofs. What are the ecological functions of plants growing on roofs? Are there any benefits for the inhabitants of cities?

Urbanisation is increasing worldwide. As more and more urban areas are paved over, precipitation increasingly runs off directly into surface waters. This does not only change the flow of the waters but also increases the level of nutrients and contaminants led into them. By greening roofs it is possible to reduce such environmental impacts. Green roofs contribute as well to a better microclimate through evapotranspiration, filtering off dust from the air and decreasing temperatures at the rooftop and in the surrounding area.

This team's aim of cooperation is to transfer knowledge of greened roofs of Central Europe to the tropics. This project is supported by DAAD (Germany) and CAPES (Brazil) since 2000. Long-term studies in Germany have pointed out water retention by greened roofs. Nowadays, water retention is one important aspect of modern ecological architecture. Retaining rainwater has a lot of further positive effects in the cities of Central Europe, i.e. to improve the urban climate. The above-mentioned scientific group pointed out some first results based on these European studies for tropical countries.

Keywords: greened roofs, evapotranspiration, Brazil, water retention, ecological architecture

Image 1: Intensively Greened Roof in the City of Rio (MEC), designed by Burle Marx in the 1940s

1. Introduction

Green roofs have a long tradition. The "hanging gardens" of Semiramis are one famous example. One has to distinguish extensively and intensively greened roofs. Intensively greened roofs, also called roof-gardens, can sometimes be found on representative buildings to add additional space (3). The roof-gardens of Roberto Burle Marx are one example. In order to build roof gardens special structural prerequisites are necessary. Roof gardens can then be developed with a high variety in gardening to create a high-quality green space as shown in image 1, the Ministry of Education and Culture (MEC) in Rio de Janeiro.

Extensively greened roofs are different from roof gardens. They have just a thin layer of soil, usually up to approximately 10 cm (~3“), adding an extra weight of water saturated approximately 100 kg/m². Extensively greened roofs only require little maintenance during the first years, after which they develop without additional care. Depending on the regional climate, only dryness-adapted and robust plants can survive. In 1753 the Swedish botanist Carl von Linné already assigned to some plants in his "Species plantarum" the species name "tectorum" as they grow on walls and roofs spontaneously. These species are a good selection to be used on extensively greened roofs. A typical extensively greened roof was created in 1984 on a common apartment house in Berlin, being the reference-object of the authors (14).

Ecologists, landscape architects and technicians have spent more than 20 years developing guidelines for extensively greened roofs regarding ecological, planning and technical aspects. Meanwhile, a number of standards exist in Germany, for example for waterproof roof sealing layers, the selection of substrate, the choice of plants etc. (see www.FLL.de). It is now safe and easy for architects to include green roofs in their design because they can offer the same lifespan as conventional tile roofs. In Germany, companies give a guarantee of 30 years on their green roofs. Nowadays, the extensively greened roof is technically equal to the conventional tile roof while offering ecological advantages.

1.1 Essential Advantages of Extensively Greened Roofs

Besides technical advantages, a green roof offers open-space-planning and ecological advantages. An overview of these effects is shown in the following literature (see 7-17). Prerequisites are sufficient building structures. Taking that into consideration, a green roof has the following aesthetic preferences and positive aspects on the protection of species compared to conventional bitumen- or tile roofs:

- Longer life and longer maintenance-intervals (19) show that in spite of higher construction costs the green roof will be less expensive after 40 years.
- Appealing view from the adjoining houses. This aspect has not been taken into account financially until now.
- Additional habitats for birds in the city; in Germany, rare birds can find new habitats on big green roofs that they would otherwise not have in the city.
- Rare and specialized plants find refuge on green roofs.

Regarding ecology and water, related further aspects are of importance:

- 10 cm of substrate showed an evapotranspiration of 90% of the summer precipitation and 75% of the annual precipitation.
- The evapotranspiration of precipitation lowers the surface-temperature of the building and improves the microclimate of the open space.
- Roof-greening decreases the runoff during storm water periods, reducing the times of sewage system overflow which leads to untreated sewage finding its way directly into the surface waters.

The last points have been research subjects of different working groups all over Germany for approximately two decades. Some essential results regarding water retention are firstly published in this essay. A general overview has already been given by the Association of Landscape Construction (5).

The effect of lowering the surface temperatures of buildings is getting more and more important for regions in warm climates, e.g. in Southern Europe. In tropical regions with higher annual rainfalls and higher evaporation rates this effect might be more important than in Europe. The summer data of water retention in Central Europe is used as a data base in this article.

Urban ecology was developed in Germany as a scientific topic with high priority, especially before the removal of the Berlin wall. Numerous scientific understandings resulted from these works and from the efforts of other research groups. The annual floods of the rivers Rhine, Moselle and Main show that there should be a high priority for decentralized measures to retain rainwater. Nowadays, a charge is raised in many German cities for the diversion of the precipitation into the sewage system. One sealed square meter costs about 1 Euro per year - an important monetary motivation to green roofs as owners can save this charge. Today, 7% of newly constructed flat roofs in Germany are already greened ones.

Green roofs are one element of ecological and sustainable building. Following the Agenda

21-process roof-greening is a simple technology which has however big effects. By combining green roofs with roof-terraces valuable urban space can be gained in the center of our cities with its widely sealed surfaces. The combination of greened roofs with photovoltaic panels, like demonstrated at the UFA-Fabric in Berlin-Tempelhof-Schöneberg (www.ufafabrik.de) leads to a modern system that combines the generation of energy and the protection of the urban environment against the negative effects of sealed surfaces (see image 2).

2. Measurements

2.1 Methods

Research on the retention potential of extensively greened roofs was started by the authors in 1985. At first, the weekly runoff was collected from permanent plots of approximately 1 m² each at the project "Englische Straße" in Berlin-Charlottenburg in comparison with the precipitation. This construction showed an annual retention rate of 75% of the entire precipitation as a median value of three years. The results were published in (9, 12). During the summer the retention increased to more than 90%. This value is applied to Berlin with a relation of precipitation to potential evapotranspiration of 550 to 650 mm.

More detailed measurements over 3 minutes take place at the plots of 2 m² each at the Institute of Landscape Development. These investigations are aiming at detecting the water movement in the soil/ substrate to prove positive aspects in the decrease of the runoff-intensity and the runoff-delay.

The latest steps have been measurements on complete roofs, one at the cultural centre "UFA-Fabrik" in Berlin Tempelhof and one at the University of Neubrandenburg of 360 m² each. These examinations show the relation between evapotranspiration and the water content in the soil before a new precipitation. The target is to transfer the measured parameters into a simulation in order to cover long time-periods and to gain a better understanding of the saturated and unsaturated soil water movement in thin substrate layers. The measurements of these installations serve simultaneously as a model for measurements as they were proposed for new locations, i.e. in Rio de Janeiro.

2.2 Results

Year	Precipitation	Runoff	Runoff	pot. ETP	measured ETP	Cooling
	[mm]	[mm]	[%]	[mm]	[mm]	[kWh/(m²*a)]
1987	702	179	25.5	641	523	356
1988	595	157	26.4	696	437	298
1989	468	98	20.9	750	370	252

Tab. 1: Precipitation, Runoff, potential and measured Evapotranspiration and Evaporation Cooling of Greened Roofs

Image 2: (left) Extensively Greened Roof in Combination with Photovoltaic Panels, UFA, Berlin

Image 3: (right) Open Runoff System in the City of Rio – Maracana

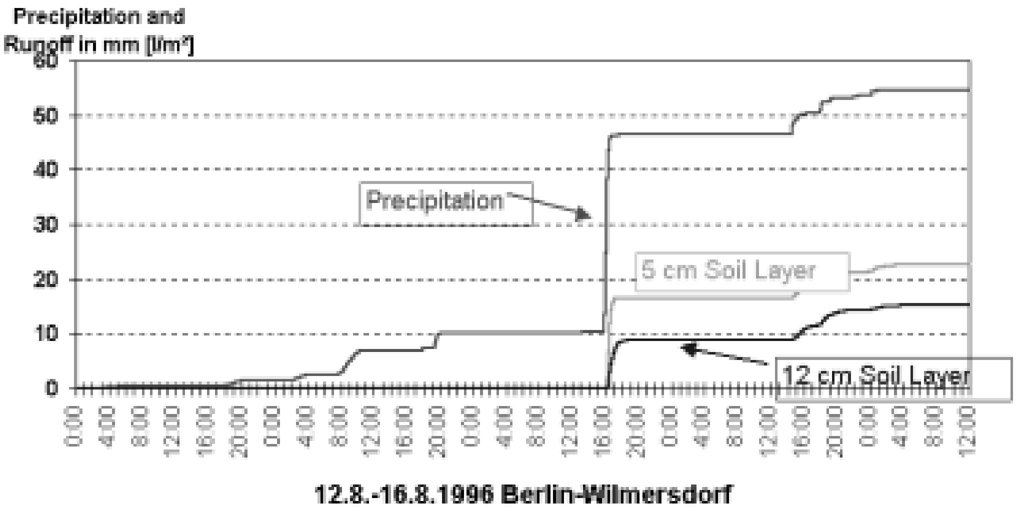

Fig.1: Reduction of Rain Runoff on Extensively Greened Roofs

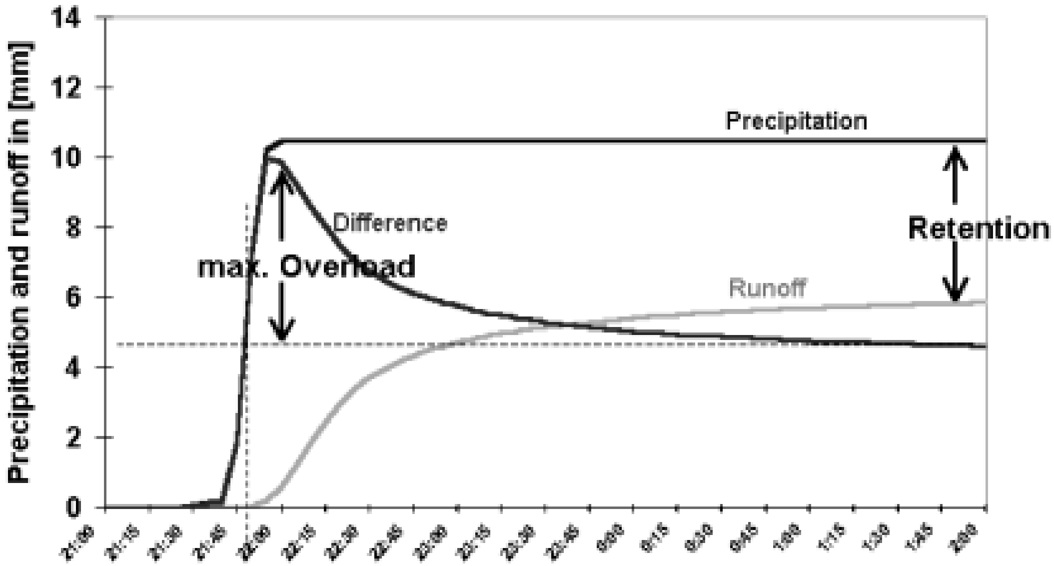

Fig. 2: Water Retention and Drain Delay of Greened Roofs compared with Flat Bitumen Roofs

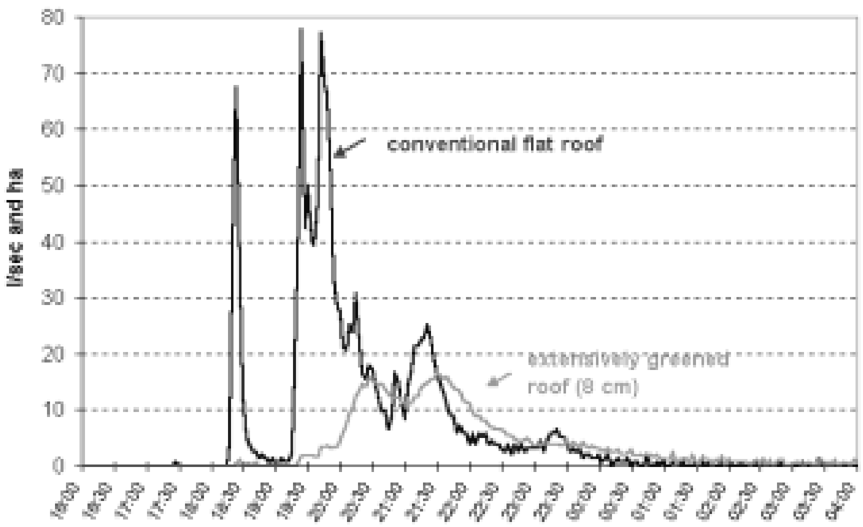

Fig. 3: Measured Precipitation and Runoff 21.5.97, UFA-Fabrik Berlin-Tempelhof (2)

Fig. 1 shows exemplarily the reduction of rain-runoff on extensively greened roofs. The first results, given by the measurements on small greened plots, show an enormous reduction of the runoff due to evapotranspiration of the vegetation and the substrate. The value up to 75% of the annual precipitation is applied to Berlin with a relation of precipitation to potential evaporation with 550 to 650 mm (see Tab. 1 and 2).

The first measurements on small greened plots showed a different retention rate compared to the latest measurements on real greened roofs. Especially during storm water events the big greened roofs have shown a much higher retention rate than expected. The runoff was reduced to 10% of the precipitation intensity (see Fig. 2). This aspect has a high influence on the size of sewage systems. Storm water, in particular, can overload the mixed sewerage systems, leading to untreated sewage finding its way directly into the surface waters. Separated sewerage systems have a negative environmental impact such as inundations of streets, basements and whole parts of the city.

The reduction of the runoff intensity is applied to the storage capacity of the soil, especially the temporarily storage capacity above the field capacity. In this example the maximum overload as the difference between the precipitation and the runoff was about 6 mm (see Fig. 3). The absolute maximum overload registered in 2 years was 15 mm.

1997	Precipitation [mm]	Runoff [mm]	Precipitation/ Runoff -ratio
Jan	8,1	7,0	0,86
Feb	58,5	55,8	0,95
Mar	22,6	6,4	0,28
Apr	33,1	6,2	0,19
May	75,9	29,8	0,39
Jun	41,6	2,5	0,06
Jul	84,0	38,3	0,46
Aug	37,4	20,0*	0.53*
Sep	8,9	0*	0*
Oct	33,7	1,6	0,05
Nov	18,1	15,0	0.83*
Dec	73,8	58,7	0,80
Sum/ mean	495,7	221.3*	0.49*

1998	Precipitation [mm]	Runoff [mm]	Precipitation/ Runoff -ratio
1	54,8	54,5	0,99
Feb	12,9	5,4	0,42
Mrz	62,6	61,0	0,97
Apr	31,8	4,1	0,13
Mai	24,5	0,4	0,02
Jun	91,8	25,4	0,28
Jul	60,5	23,5	0,39
Aug	63,2	17,7	0,28
Sep	53,2	29,4	0,55
Okt	76,1	35,0*	0.46*
Nov	20,2	15,0*	0.74*
Dez	39,9	24,4	0,61
Sum/ mean	591,5	245.8*	0.50*

Tab. 2: Monthly and Annual Rain and Green Roof Drain Values for the Year 1997 and 1998 [2]

2.3 Conclusions

Until now only a few greened roofs have been investigated scientifically. Further research is necessary concerning the annual change of the precipitation/ runoff-ratio and different types of soil and vegetation. The retention rate differs from the local conditions regarding the relation and distribution between precipitation and potential evaporation.

A second essential parameter for the precipitation/ runoff-ratio is the storage capacity (field capacity) of the soil/ substrate and the vegetation. At the demonstration roofs a field capacity of 10-30% was measured, at 10 cm of substrate the calculated storage capacity is until 30 mm, that means 5% of the annual precipitation.

As long as urbanization continues as in recent years, decentralized strategies and measures will be taken against the environmental impacts of paving. Greening roofs and facades are two possibilities. Other decentralized measures are rainwater-reuse-systems, partly unsealed surfaces and active infiltration systems. The Administration of Berlin, the Senate of City Development, has started projects in cooperation with the Technical University to combine these measures to completely substitute the rainwater sewerage system.

3. Application of Green Roofs in the Hot and Humid Tropics – Case Study Rio de Janeiro

There are some striking differences in the parameters to be observed in the tropics:

3.1 ..The storm water events are much more common in the hot and humid tropics compared with temperate climates. What is considered as a hundred-year-event in temperate climates is an annual event in the tropics (see table 3)

This has several consequences for its application in the tropics:

- Erosion on freshly implemented green roofs has to be avoided.

Quicker saturation of the substrate has to be considered.

3.2. Higher temperatures throughout the year, a 12-months vegetation period

- The gain of biomass is higher (especially when urban air pollutants via rain water fertilize the roof): that might complicate the drainage function of the substrate, but will presumably increase the retention rate of the roof due to the larger surface of the plants.
- The roof might become a habitat for dangerous animals, principally insects like mosquitoes (dengue, malaria, yellow fever etc.). A careful check of possible plants has to be carried out. Bromelias, for example, should be avoided to open water retention capacity.
- The evaporation rate is higher, evapotranspiration works all year long.

Station	mm/hour	Date	Hour
Campo Grande	116.2	19/03/2000	00:08
Grajaú	90.3	16/02/2000	23:01
Sumaré	81.3	02/04/1998	23:49
Tanque	78.3	09/01/1997	18:42
Tijuca	78.2	17/02/1998	15:15
Vidigal	72.5	15/12/1998	17:43
Cachambi	72.4	28/03/2001	22:17
Tijuca	71.5	07/01/1998	19:00
Anchieta	71.0	28/03/2001	21:23
Madureira	71.0	31/01/1997	19:17

Table 3: The 10 heaviest rainfalls in different parts of Rio de Janeiro/ Brazil from 1997 until March 2001 [4]

At the moment, 5 prototypes of roofs are under construction in Rio de Janeiro. 4 of them are green roofs, 1 is a blank reference roof. The green roofs vary in the thickness and the composition of the substrate. Possible plants are being tested under extensive conditions since October 2000. First results are being published in Brazil during ENCAC 2001 [22].

4. Aspects for City-Planning in the Hot and Humid Tropics

Flooding and water erosion can be especially vehement under hot and humid tropical conditions. In Rio de Janeiro, like in other Brazilian cities, these problems are commonplace, causing death and destruction regularly [4, 5]. There are mainly two reasons for that: first, the frequent and violent storm water events and second, the high soil-sealing rate of urban areas. Even huge sewer and canalization systems are overloaded by the peak storm water load. The average of the 10 biggest storm water events from 1997 to 2001 (see table 3) is 80,3 mm. The green roof can be considered as a very welcomed possibility to cut the peak load: using porous substrate and calculating with a retention rate of at least 0.8, a significant cut of the peak load is to be expected. Regarding results of several German studies [2, 6, 15, 21], the temporarily retention rate during storm water events was always at least 90% of the precipitation intensity. This value applies to the overload of the soil layer (see 2.3), theoretically up to the absolute pore space of the soil with ~75% (at 10 cm of soil layer up to 75 mm).

The annual retention rate for Germany is 50-75% of the total precipitation. This value differs depending on local conditions from the relation and the distribution between precipitation and evaporation (see 2.2). In tropical climates the absolute evapotranspiration of greened roofs is comparatively higher. An annual retention rate of probably 65% (about 900 mm [=l/m²]) of the precipitation is expected for Rio.

The analysis of aerial photography of the Maracanã district in Rio de Janeiro, where the research project is located, shows a sealing rate of approximately 80%. The area has a size of 142 ha [16]. A district of similar density in Berlin has a potential for extensively greened roofs of 20% of the total surface [1]. Considering an annual evapotranspiration of 900 mm one can expect a retention of around 1800 m³/ ha. This value is applied to a cooling of the inner city climates of 6 Mio kWh per ha and year (see table 1).

5. Final Conclusion

Roof-greening means more than just another type of surface of buildings. The scientific work gives a better understanding of the situation and influence of urbanization on the local water and energy cycles and of the change of the habitat function. Also aspects like the retention of pollutants are arguments for the greening of roofs.The research on the effects of greened roofs in temperate climates is far developed and has already found applications in urban relations. Specialized firms in Central Europe already carry out thousands of square meters annually, guaranteeing a quality and longevity comparable or even better than conventional roofs. Research on this topic is only beginning in the tropics. The theoretical considerations show a huge potential for this technology. Now this consideration has to be proved practically. The cooperation project between Germany and Brazil is a first and important step toward it.

6. Biographies

Manfred Köhler, Prof. Dr., Landscape Architect BDLA. Since 1981 several long term studies of urban ecology, especially plants in contact to buildings and their ecological effects. Professor of Landscape Ecology since 1994

Marco Schmidt, Dipl.-Ing., Master in Landscape Planning. Studies on urban water cycles, rainwater management and ecological functions of urban surfaces

Friedrich Wilhelm Grimme, Prof. Dr.-Ing.; Several studies all over the world in the area of bio-climatic architecture

Michael Laar, Dr.-Ing., Architect, M. Eng.; Main topic of work: the bio-climatic architecture in the tropics.

7. Bibliography

1. Bartfelder, F., Köhler, M. 1987. Experimental studies on the function of greened facades. (Experimentelle Untersuchungen zur Funktion von Fassadenbegrünungen).Thesis, Free University of Berlin, 612 p.

2. Bustorf, J. 1999. Simulation of the precipitation/ runoff-ratio of greened roofs. (Ansätze zur Simulierung der Abflußbildung von extensiv begrünten Dächern und deren Bewertung als dezentrale Regenwasserbewirtschaftungsmaßnahme) Master, TU Berlin, 108 p.

3. Cerver, F. A. 1994. Business and Corporation Parks. Roof gardens, Barcelona, 255 p.

4. Geo Rio, 2001. Data of the 10 precipitations with the highest Intensity since 1997. (Letter).

5. Globo online, Chuvas in Rio, 22.02.2001

6. Hoffmann, T. u. W. Farby 1998. Rain water management – of course by greened roofs.

(Regenwassermanagement – natürlich mit Dachbegrünung.) GaLaBau Service, Bad Honnef, 35p.

7. Köhler, M. 1990. The living conditions of plants on the roof of buildings. In: Sukopp et al. (ed.) Urban ecology. SPB Academic Publishing, The Hague 195-207pp.

8. Köhler, M. 1990. Ed. Of the proceedings of the symposium greened roofs. (Herausgabe des Ergebnisbandes über das Symposium "Extensive Dachbegrünung"). Schriftenreihe Landschaftsentwicklung und Umweltforschung 76: 1-110 pp.

9. Köhler, M. 1990. Abiotic Factors and plant grow. (Abiotische Faktoren und Pflanzenwuchs). Landschaftsentwicklung und Umweltforschung. 76: 14-27 pp.

10. Köhler; M., Schmidt, M. 1991. The Importance of roofs covered with Vegetation for the Urban Ecology, Biotic Factors. Ravera, O. (ed.) *Terrestrial and aquatic ecosystems: Pertubation and recovery.* Ellis Horwood Ltd. (Chichester). 5. Europ. Ec. Sym. Siena 1989. 153-161 pp.

11. Köhler, M. 1993. Greened facades and roofs. (Herausgeber und Verfasser des Fachbuchs Fassaden- und Dachbegrünung), Ulmer, Stuttgart, 329 p.

12. Köhler, M., Schmidt, M., Diestel, H. 1993. Greened roofs in Cities. (Funktion begrünter Dächer im städtischen Raum). BBaubl. (9) 729 – 734 pp.

13. Köhler, M. 1994. Research on extensively greened roofs in Berlin. (Untersuchungen an extensiven Dachbegrünungen in Berlin. Landschaftsarchitektur, 24 (2): 29 – 32 pp.

14. Köhler, M., SCHMIDT, M. 1997. Greened Yards, facades and roofs. (Hof-, Fassaden- und Dachbegrünung. Ergebnisse einer zwölfjährigen Begrünungsutopie). Landschaftsentwicklung und Umweltforschung 105: 1 – 158 pp.

15. Köhler, M., SCHMIDT, M. 1999. Long-term studies on greened roofs. (Langzeituntersuchungen an begrünten Dächern in Berlin). Teil I: Klimatische Wasserbilanz und Auswirkung auf das Pflanzenwachstum. DACH+GRÜN 8 (1): 12-17 pp.

16. Köhler, M., SCHMIDT, M. 1999. Research on greened roofs, plant species. (Untersuchungen an extensiven Dachbegrünungen in Berlin.) Teil II: Erfahrungen mit Pflanzenarten. DACH + GRÜN 8 (3): 18 – 24 pp.

17. Köhler, M., SCHMIDT, M. 1999. Research on greened roofs, retention of nutrients and heavy metals (Untersuchungen an extensiven Dachbegrünungen in Berlin). Teil III: Stoffrückhalt DACH + GRÜN 8 (4): 9 – 14 pp.

18. Prefeitura da Cidade do Rio de Janeiro 2000: Annual Statistics. (Anuario Estatistico. Instituto Municipal de Urbanismo Pereira Passos. Rio de Janeiro.)

19. Radbruch, R. 2001: Systems for greening pre-produced buildings. (Versuch der großflächigen Bauwerksbegrünung an Plattenbauten). Master Neubrandenburg.

20. Joint International Project Agribusiness- Environmental Protection – 3 (Ed.) 2000: Information about materials and methods for greened roofs. (Material didactica del curso „Naturación de Areas Construidas y Desarollo Sustenable de Ciudades). Humboldt Univ. Berlin. Program of the EU.

21. Knoll, S. 2000: The runoff of extensively greened roofs (Das Abflußverhalten von extensiven Dachbegrünungen). IWAWI-Mitteilung Nr. 136, Technical University of Berlin.

22. Souza, C. et al 2001: Applied Studies about plants on extensively greened roofs in cities of tropic climate. (Estudo de Aplicação de plantas em telhados vivos extensivos em cidades de clima tropical). ENCAC 2001, São Carlos, Brazil.

Links

www.FLL.de (State of the art in many topics of landscaping techniques, advice for architects and owners) www.tu-berlin.de/~Wasserhaushalt (further information and links)