Water management to save energy, a decentralized approach to an integrated sustainable urban development

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1. INTRODUCTION

Urbanization is increasing worldwide. Urban centers are characterized by negative environmental impacts including escalated flood risks, polluted surface waters, modification of the urban climate and increased water and energy consumption.
The increase of water-impermeable surfaces forces to give high priority to decentralized measures of rainwater retention. Multiple techniques have been developed to reduce these impacts.

These techniques include:

- greening yards and roofs,
- greening facades,
- partly permeable surfaces,
- artificial lakes for water retention,
- active infiltration systems and
- rainwater utilization systems.

Photo 1: Greened roof system established 1984 in Berlin-Kreuzberg

There are two main goals of rainwater harvesting. The first goal is to **replace drinking water** by rainwater for toilet flushing and other purposes. The second is the **retention** of rainwater to reduce inflow into sewer systems in order to either avoid overload in combined sewers or reduce contamination in seperate sewer systems [7]. Treated rainwater is also useful for **climatization** of buildings.

The risk of flooding is increasing in many cities due to the increase of water-impermeable surfaces such as buildings, asphalt and concrete. Annual floods of three German rivers: the Rhine, the Mosel and the Main, show that high priority should be placed on decentralized measures of rainwater retention. Land use practices that reduce the retention, infiltration, and evaporation of rainwater throughout a watershed are a main cause of the floods which periodically damage settlements and infrastructure built along rivers. The most recent flood in Germany in September 2002 caused damages of more than 9 Billion Euro (see: http://www.umweltbundesamt.de/index-e.htm).

2. DECENTRALIZED APPROACHES FOR URBAN GREENING

2.1 Evaporation by greening roofs

Most of the precipitation in the natural landscapes is evaporated. For example, in the natural environment of the Spree and Havel watershed surrounding Berlin, approximately 80% of precipitation is evaporated or transpired by plants. 20% leaves the catchment area as basic runoff via the river flow. On the other hand the direct surface runoff in urban areas is high and as in most cases also the groundwater recharge. Missing vegetation reduces evapotranspiration dramatically. Groundwater recharge increases by semi permeable surfaces, application of infiltration systems and also by broken sewers.
Missing evapotranspiration increases the thermal radiation caused by higher surface temperatures of hard materials like concrete and the ability of such surfaces to store heat (Fig. 1). New innovative rainwater projects focus on the necessity of evapotranspiration rather than infiltration. If possible, rainwater can be used for toilet flushing and irrigation of greened areas.

First project, established in the beginning of the 80th, is the **Cultural Center UFA-Fabrik** in Berlin-Tempelhof. The former UFA-Film factory was built in1920 and used as a copy center for German film studios. The factory has since been turned into a site of various urban ecology projects (see: www.ufafabrik.de). Besides innovative energy systems, an integrated rainwater management project was established. As a first measure, most of the roofs have been greened in 1983 to 85. In 1994, a rainwater harvesting system was integrated. The water of the green and conventional roofs together with the runoff of the streets is stored in a former underground waterworks station.

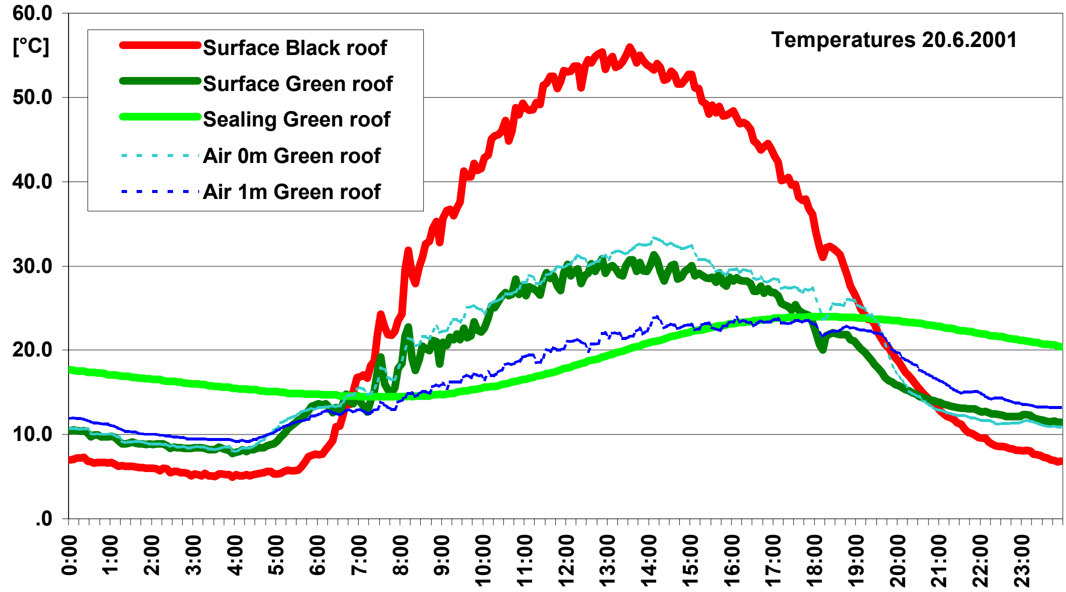


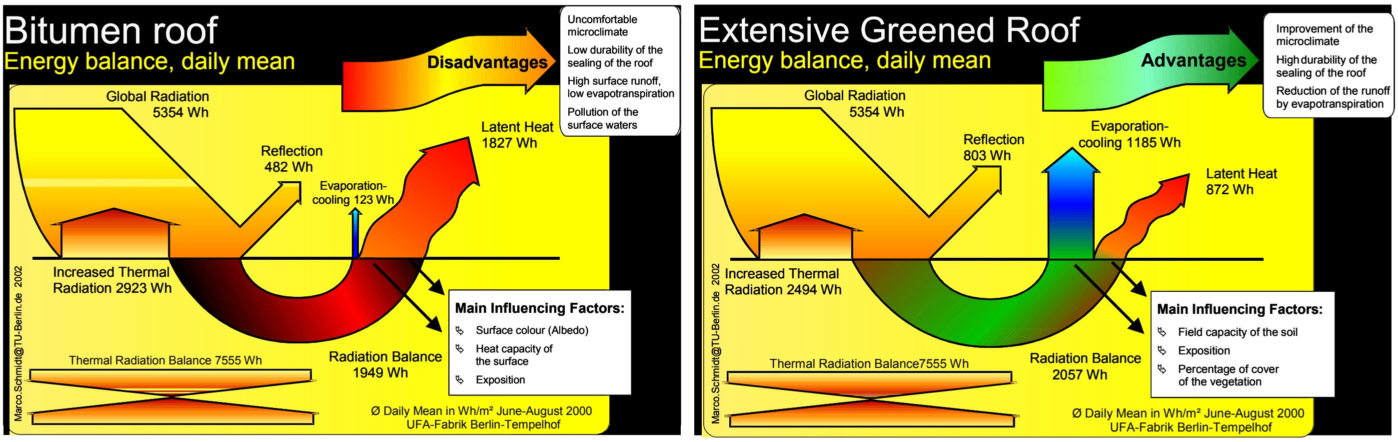
Fig. 1: Reduced surface temperatures of a greened roof compared to a conventional tarboard roof (Infrared measurements) [5]

The rainwater system has a total storage capacity of 240 m³ in two cisterns. This is equivalent to 40 mm or 6,7% of the annual precipitation. The system collects primarily "first flush" stormwater, the water that is the most highly polluted. The capture of pollutants and nutrients provides an increased ecological benefit. The collected rainwater is treated in a modified constructed wetland. The rainwater is used to flush toilets and for irrigation. 72% of water used in the community for irrigation and toilette flushing is rainwater provided by the storm water detention system, only 38% is from the public drinking water supplier (see: http://www.id22.de/english.htm).

Tab.1: Project data UFA-Fabrik Berlin Tempelhof [7]

Project data	UFA-Fabrik Berlin Tempelhof	
	rainwater cistern	240 m³ (39 mm)
	total daily water use	6,3 m³ (3-11m³) = 1,04 mm
	percentage of drinking water	36 %
	proportion of total precipitation used	72 % (Simulation)
	reduction of nutrients and heavy metals	> 90 % (estimated)
	constructed wetland for rainwater treatment	25 m²

Measurements have shown that green roofs can evaporate 60 to 75% of annual precipitation. The intensity of stormwater runoff from greened roofs is 80% lower than from conventional flat roofs, depending on the soil layer and the saturation of the soil [1,3]. In separated sewer systems greened roofs avoid nutrients and heavy metals to runoff into the rivers and streams.



	Conventional [Wh/(m²*d)]	Green [Wh/(m²*d)]	Conventional [%]	Green [%]
Global radiation	5320	5320	274%	260%
Diff. thermal radiation	-2900	-2472	149%	121%
Reflection	- 479	- 798	25%	39%
Radiation balance	1942	2050	100%	100%
Evaporation cooling	-123	- 1185	6%	58%
Latent Heat	- 1827	- 872	94%	42%

Fig. 2: Change of urban Climate - tarboard roofs compared to green roofs, UFA-Fabrik Berlin [6, 4]

2.2 Green facades to save Energy

Impermeable surfaces influence the microclimate by creating a different energy balance than is found in greened areas. The main causes of this change are reduced evapotranspiration of the precipitation and the ability of hard surfaces like concrete to store heat. Energy is required for the evapotranspiration of water to proceed. This physical process generates the so-called “evaporation cooling” of 2450 Joule/g H_2O evaporated.

According to research in Hamburg, Germany in 1957, greened areas like meadows consume 86% of all radiation balance as a yearly average. According to measurements made at the UFA Fabrik in Berlin, extensive green roofs transfer 58% of the radiation balance into transpiration during the summer months [5]. The resultant cooling-rates are on average 300 kWh/(m²*a) in Germany. Hard materials in urban areas like concrete and bitumen roofs transform up to 95% of radiation balance to latent heat. As a result, air temperatures inside buildings also rises and leads to discomfort or increased energy consumption for climatization [8].

A new project, the **"Institute of Physics" of the Humboldt University in Berlin-Adlershof** features a combination of stormwater management with energy saving. The project combines natural cooling by green facades with technical adiabatic cooling systems. Both systems are supplied with rainwater. Rainwater is stored in 5 cisterns in two courtyards of the building. The plants which are irrigated with rainwater provide shade during the summer, while in the winter, the sun's radiation penetrates the glass front. In this project the water demand of the different plant species as well as the demand for the adiabatic cooling system will be monitored by the Technical University. Both the shade created by the plants and their evaporate cooling will influence the energy consumption of the building.
Stormwater events with heavy rainfall are managed by overflow to a small urban lake in the courtyard. To protect the ground water quality, only the natural surface infiltration is allowed. No rainwater sewer has been constructed, the runoff is managed completely inside of the building complex. The cooling effect by using treated rainwater has been calculated. With 1 m³ Water for facade-plant irrigation the saving for costs of climatization is about 100 € (in energy prices of Germany in 2004 = 1,30 € per kWh).

Photo 2: Pond in the yard of the Institute of Physics, HU-Berlin for retention and infiltration (right)

Tab. 2: Project data Institute of Physics Berlin HUB - Adlershof [8]

Project data	Institute of Physics Berlin HUB - Adlershof	
	Storage capacity:	40 m³
	Adiabatic cooling systems:	8
	Irrigated Green Areas:	151
	Connected roofs:	4700 m²
	Pond in the courtyard:	225 m²

2.3 Harvesting and utilization of rainwater

The **DaimlerChrysler Area at the Potsdamer Platz, Berlin**, in 1996 -1998 the largest building site in Europe, was built under very strict stormwater management conditions. The construction of the complex demonstrates the importance of the integration of all aspects of ecology in the planning process This project was implemented using an integrated ecological concept and included diverse sustainable techniques such as energy efficiency, environmental-friendly building materials, and a water-management system.

In order to avoid an overload of the existing combined sewerage system, the building permit issued by the city council stated that the new complex could drain rainwater into the sewerage system at a rate of no more than 3 l/sec /ha, or 1% of flows during storm events. To comply with this regulation, the following techniques were implemented for the management of 23.000 m³ of rainwater which fall annually on this complex of 19 buildings:

- extensive and intensive green roofs
- collection of roof-runoff for toilet flushing and plant irrigation
- an artificial lake for rainwater retention and evaporation

The project was completed and handed over to the public in October, 1998.

Tab. 3: Project data Potsdamer Platz, Berlin

Project data	Rainwater management Potsdamer Platz, Berlin	
	extensive and intensive green roofs	44.000 m²
	Rainwater cistern	2550 m³ (69 mm)
	Artificial lake	13.000 m²
	Constructed wetland for rainwater treatment	1900 m²

Advanced technology provides a constantly high water quality in the lake. 19 pumps and 2 filters are found in 2 underground control stations below the DaimlerChrysler Services building. The water is additionally cleaned and filtered through natural processes in the constructed wetland which is planted mainly with Phragmites [7].

The water circulates continuously with maximum filtering capacitys ranging from 30 m³/h to 150 m³/h for the different parts of the lake. Additionally, there are multi layered filters through which the water can be fed by 3 pumps in the control stations with a maximum combined capacity of 125 m³/hr. The water has a low nutrient concentration and a high transparency year round [by DCI, 7].

Photo 3: Belßstr. in Berlin Lankwitz

The Housing Development at **Belßstreet/ Lüdeckestreet**, a redevelopment of a building complex of the 60 ies, includes a system to collect and treat rainwater in order to supply 87 flats with water for toilet flushing as well as for limited irrigation. Enough rainwater can be collected from the roofs and public streets to provide one third of the residents with water for toilet flushing.
The rainwater is stored in the basement of one of the buildings. The existing storage capacity of 180 m³ corresponds 15 mm or 2.6 % of the annual precipitation. The rainwater is treated in a modified constructed wetland inside of the building. Although the constructed wetland is only 2,5 m², it has a treatment capacity of 10 m³ water per day and a treatment period of only 40 minutes. The water is subjected to **ultraviolett radiation before use** [7]. In contrast, UV radiation is not used at the UFA Fabrik project, as the water there is treated for 24 hours.

Tab. 4: Project data housing development Belß-/ Lüdeckestreet

Project data	The housing development at Belß-/ Lüdeckestr.	
	Start of the project:	March 2000
	Storage capacity:	180 m³
	Total daily water use:	9,9 m³
	Proportion of total precipitation used:	31 %
	Constructed wetland for rainwater treatment	2,5 m²
	Number of flats supplied with rainwater:	87
	Irrigated area:	1100 m²
	Connected roofs:	7325 m²
	Connected streets and parking lots:	4450 m²

3. COMPARISON OF THE FOUR PROJECTS

The Potsdamer Platz project is the biggest rainwater management project based on decentralized measures in Germany.
Shown in the table below is the comparison of the storage capacity of all projects. This calculation does not include the storage capacity of the greened roofs. The calculation of stormwater-management capacity the field-capacity of the soil of the greened roofs has to be added. As a general rule of thumb, green roofs with a soil layer of 10 cm have at least a 35 mm storage capacity. This figure includes a temporarily overload during heavy rainfalls.
The cistern in Adlershof has only 9 mm of storage capacity, this is 1.5% of the annual precipitation. This is a quite low percentage, especially considering its role in water storage for both irrigation and cooling purposes. In comparison with the DaimlerCrysler at Potsdamer Platz project with its 69 mm and additionally 84 mm in the urban water, the planning assumption for projects is not yet assured. Many unknown factors - including the amount of water which will be used for irrigation and cooling systems - ment that assumptions had to be made in the planning process. Monitoring of projects will provide information on these subjects that can be used for the planning of future projects.

Tab. 5: Project comparison

Project comparison		CA	RG	Consumption		Cistern size			Stormwater retention	
		[m²]	[%]	[m³/d]	[mm/a]	[m³]	[mm]	[%AP]	[m³]	[mm]
	HU Physik Adlershof	4700	6,4	5,1	412	40	8,9	1,5	180	40
	Belß/ Lüdeckestr.	11.773	< 2	9,9	311	180	15	2,6	-	-
	UFA-Fabrik	7600	34	6,3	380	240	40	6,7	-	-
	DCI Potsdamer Platz	44.000	27	?	?	2550	69	11,7	3100	84

CA: catchment area RG: percent green roofs
AP: Size of pond as a percent of annual precipitation *(8/2004)*

4. ACKNOWLEDGEMENTS + LINKS

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