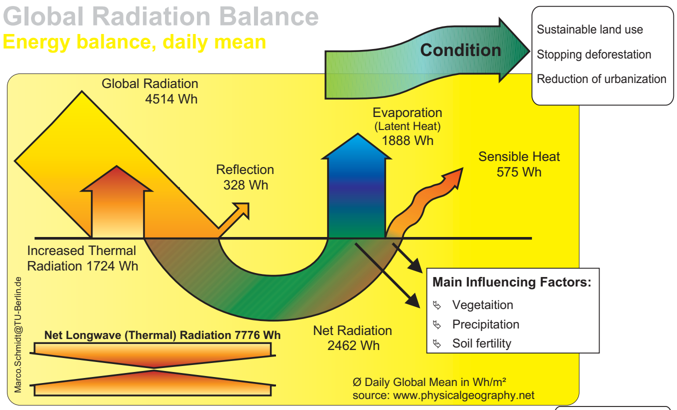
Rainwater harvesting and evaporation for stormwater management and energy conservation

Marco Schmidt *1, Brigitte Reichmann *2, Claus Steffan *1
1: Technical University of Berlin, Institute of Architecture, Section Building Technology and Design
2: Berlin Ministry for Urban Development, Department VI, Section Building and Ecological Construction

1. Introduction

Environmental changes in urban areas include reduced evapotranspiration of precipitation and the transformation of up to 95% of net incident radiation to heat (compare fig. 1 global radiation balance and fig. 2 urban radiation). As a result, air temperatures inside buildings also rise and lead to discomfort or increased energy consumption for climate management. A logical solution to create more comfortable air temperatures inside and outside of buildings is to green their facades and roofs, thereby „consuming“ this energy by evapotranspiration.



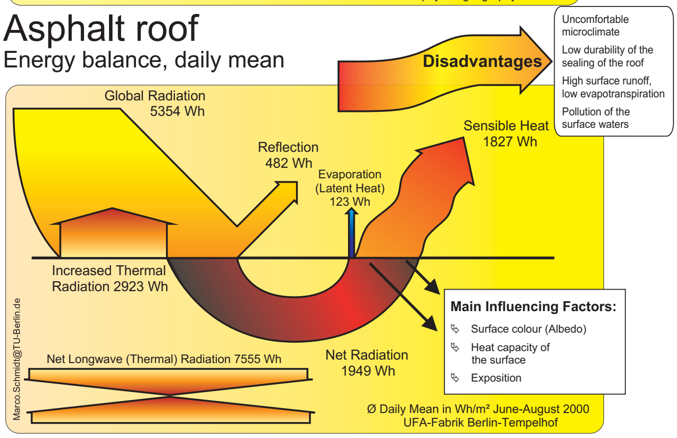


Fig. 1: Global daily radiation balance as annual mean (after: www.physicalgeography.net)

Fig. 2: Radiation balance of a black asphalt roof as an example for urban radiation changes

Worldwide, the reduction of energy consumption for cooling and ventilation installations is becoming increasingly important. While political agreements announced the reduction of CO_2 emissions for Germany by 30% until the year 2020, CO_2 emissions due to cooling are estimated to increase by 250%, mainly because of the increased use of conventional air conditioning systems (Fig. 3).

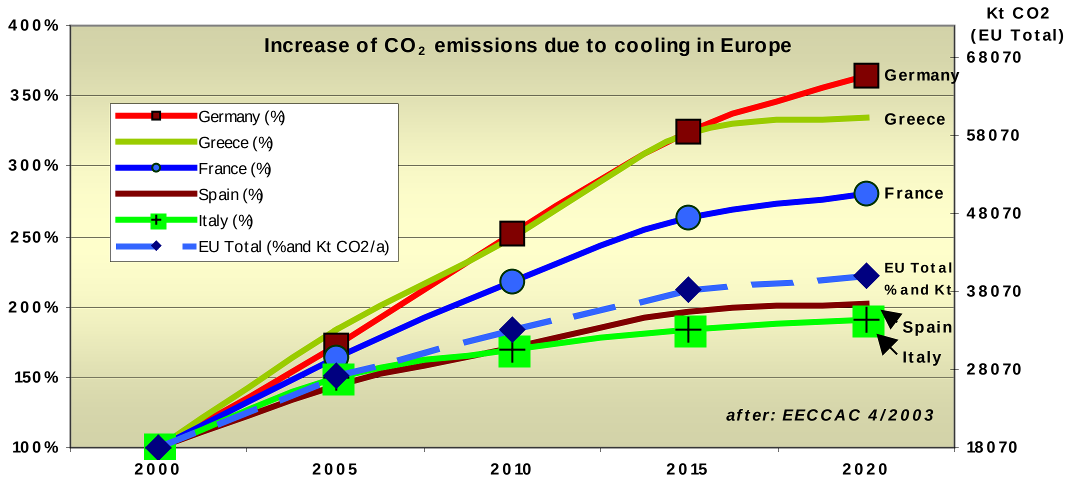


Fig. 3: Increase of CO_2 emissions due to cooling in Europe (after EECCAC 2003)

A new European parliament directive on the energy performance of buildings (2002/91/EC), strongly encourages the implementation of passive cooling techniques to improve indoor climatic conditions as well as the immediate microclimate.
The Institute of Physics, a project of the Architects Augustin and Frank (Berlin), is a research and office building featuring several measures of sustainable architecture, incorporating elements combining decentralized water management and reduced energy consumption for cooling and ventilation. Rainwater is stored in cisterns and used to irrigate a façade greening system and ventilation units using evaporative cooling. Extra water is collected in a pond in the building's courtyard which allows the water to either evaporate or drain into the ground.

2. Methodology

At the Technical University of Berlin, section of Applied Hydrology and section of Building Technology and Design, evaporation measurements are combined with radiation measurements. Focus is he hydrologic change in urban areas compared to naturalistic landscapes. Lysimeter measurements of the real evapotranspiration of a meadow are completed through measurements on semi permeable surfaces, greened roofs and green wall systems. Evapotranspiration measurements are placed into relation to longwave and shortwave radiation measurements (Schmidt 2005).
Evapotranspiration of a cubicmeter of water consumes about 680 kWh. This energy is transported as latent heat into the atmosphere and released as longwave radiation when the water vapour condenses as clouds. Parts of the longwave radiation is lost to space, an important global energy loss for the received shortwave radiation from the sun. A reduction of evapotranspiration in urban areas results in higher surface temperatures and higher longwave emission. Second effect is a higher sensible heat flux. The relation between sensible and latent heat flux is expressed as the bowen ratio. The bowen ratio increases by reduced evaporation rates.

The project in Berlin-Adlershof includes an ongoing monitoring of the water consumption of different plant species of the façade greening system and of resulting evaporative cooling and the effects on the energy balance of the building. Temperature and radiation measurements assist in identifying the economic and ecological benefits of the investigated climbing plants and ventilation units.

3. Results

3.1 Rainwater harvesting and stormwater management

Rainwater harvesting becomes an important issue. Until 2020 another 1 billion people will live in cities (UN/ DESA 2003). The increase of urban areas forces to give high priority to decentralized measures of rainwater retention and new strategies in water supply and wastewater management. Although in the natural landscape most precipitation is evaporated or transpired, in urban areas, evapotranspiration is greatly decreased and rainwater is instead swiftly directed into the sewer system and to receiving waterbodies. The Institute of Physics Building is not connected to rainwater sewers, as one main goal of the decentralized rainwater harvesting is a retention of rainwater in order to reduce stormwater flows into sewer systems.

Rainwater is stored and used for the irrigation of the facade greening system and adiabatic cooling systems. Storm water events with heavy rainfall are managed with an overflow to a small constructed pond in one of the courtyards, from which the water can evaporate or drain into the ground. To protect the ground water quality, this drainage is only allowed through surface areas with vegetation. Some of the roof surfaces are also extensively greened to assist in retaining and treating water.

Fig. 4 and 5: façade greening system (left), adiabatic exhaust air cooling in air conditioning systems (right)

3.2 Green Facades

Impermeable surfaces like roofs and streets influence urban microclimates through radiation changes. As a result of these changes, air temperatures inside buildings also rise and lead to discomfort or increased energy consumption associated with climate management. A logical solution to create more comfortable air temperatures inside and outside of buildings is to green façades and roofs, thereby „consuming“ this energy by evapotranspiration. According to measurements taken at the UFA Fabrik in Berlin, extensive green roofs transfer 58% of net incident radiation into evapotranspiration during the summer months. The annual average energy consumption is 81%, the resultant cooling-rates are 302 kWh/(m²*a) with a radiation balance of 372 kWh/(m²*a) (Schmidt 2005).

A more demanding solution is a façade greening system which has a higher direct effect on the energy performance of a building than a greened roof. Green façades were implemented at the Institute with two objectives: 1) to passively climatize the building through shading and solar radiation and 2) to harness evapotranspiration to improve the microclimate inside and around the building. Plants provide shade during summer, while during the winter, when the plants lose their foliage, the sun’s radiation is able to pass through the glass-front of the building. In the summer month July until September 2005 the water consumption for the well developed *Wisteria sinensis* increased up to 420 liter per day for 56 planter boxes. This represents a cooling value of 280 kWh per day for one of the courtyards.

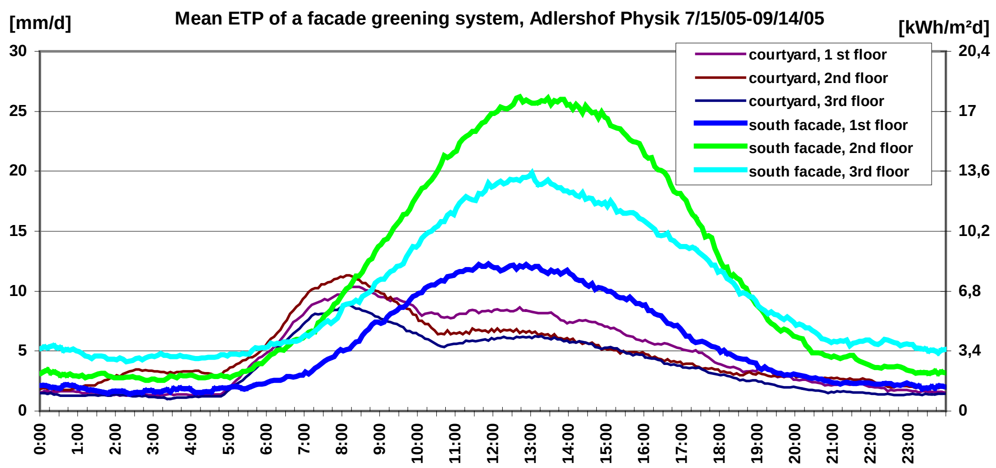


Figure 6: mean evapotranspiration of the façade greening system in mm/day and correspondent cooling rates

The mean evapotranspiration between July and August 2005 for the south face of the building was between 5.4 and 11.3 millimeters per day, depending on which floor the planters were located (Figure 5). This rate of evapotranspiration represents a mean cooling value of 157 kWh per day.

In selecting the climbing plants an emphasis was placed on types that can grow in the extreme conditions of planter boxes. Of the various plants tested the Wisteria sinensis has proven to do the best. In addition a special system of irrigation and different substrates have also been applied and studied. A factor in the selection was an adequate capillary rise of the water through the irrigation and substrate systems. Another aspect studied was the providing of a layer of insulation to some of the planter boxes, to compensate for large shifts in temperature and especially to help protect against very low winter temperatures. This comparison revealed that insulation can lead to significant differences in plant growth.

3.3 Evaporative exhaust air cooling

Air conditioning in the Institute of Physics is achieved through seven adiabatic climatization units. These units use rainwater to cool air through the process of evaporation. This is a two step process. First, the rainwater is evaporated to reduce the temperatures of the air leaving the building. In a second step, fresh air entering the building is cooled as it passes across a heat exchanger with cooled air on its way out. This process is sufficient to maintain indoor temperatures of 21-22 °C with outside temperatures of up to 30 °C. When outside temperature exceed 30°C, indoor temperatures are maintained by a conventional cooling system.

4. Conclusions

Reduced evaporation is the main hydrological difference between urban and rural areas. Missing evapotranspiration increases the thermal radiation caused by higher surface temperatures and increases the sensible heat. New innovative rainwater projects focus on the necessity of evapotranspiration rather than infiltration.

This research is designed to generate recommendations for an optimal and economical management of the building’s mechanical systems, emphasizing an innovative and sustainable relationship with the resources water and energy as well as the reduction of operating costs. The evaluation, optimization and documentation of the project results is expected to provide a basis for the long-term implementation and further development of innovative and economic technologies. Practical findings are incorporated into simulations designed to understand the transferability of these techniques to different climatic conditions and to determine applications for future projects, concerning the fields of design, construction, operation and maintenance.

The urban and global climate change is mainly resulted due to reductions in evapotranspiration. The increase in urbanization continues at a rate of 1 km² daily in Germany. The global daily loss of forests are 350 km² (GTZ 2007). This represents 1.3 % of annual loss of the remained 30% of forests worldwide. The latent heat flux and it’s importance on the temperatures seems to be absolutely underestimated in all climate models.

5. References and Links

EECCAC (2003) Energy Efficiency and Certification of Central Air Conditioners. REPORT for the DGTREN of the Commission of the E.U, 2001, Volume 1, 52 pp.

GTZ 2007: Reducing Emissions from Deforestation in Developing Countries. Deutsche Gesellschaft fuer Technologische Zusammenarbeit, Eschborn. 32 pp.

UN/ DESA (2003): World Population Prospects: The 2004 Revision, World Urbanization Prospects. UN, Department of economic and social affairs.

Schmidt, M. (2003) Energy saving strategies through the greening of buildings. Proc. Rio3, World energy and climate event. Rio de Janeiro, Brasil 2003. http://www.rio3.com

Schmidt, M. (2005) The interaction between water and energy of greened roofs. Proceedings World Green Roof Congress, Basel, Switzerland, 15.-16.9.2005

http://www.gebaeudekuehlung.de
http://www.a.tu-berlin.de/GtE/forschung/Adlershof
http://www.stadtentwicklung.berlin.de/bauen/oekologisches_bauen