Energy and water, a decentralized approach to an integrated sustainable urban development

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Abstract Environmental changes in urban areas include reduced evapotranspiration of precipitation and the transformation of up to 95% of net incident radiation to heat. 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.
The Institute of Physics in Berlin- Adlershof is a research and office building that features a combination of sustainable water management and energy conservation techniques, including the use of rainwater. Compared to urban areas where rainwater disappears into sewer systems, all of the precipitation from the roof will be used to cool the building and for the infiltration into the groundwater in one of the courtyards. The project includes ongoing monitoring of 1) water consumption by different plant species, and 2) the rate of evapotranspiration which influences the energy balance of the building. This information will be valuable in planning future projects, which is the primary objectiveof the Department of Ecological City Construction of the Berlin Senate which is organizing and financing this innovative project.

Key words: green building architecture, green façades, evapotranspiration, evaporative cooling, rainwater harvesting, urban heat island effect

1. Introduction

Worldwide, the reduction of energy consumption for cooling and ventilation installations is becoming increasingly important. The increased use of air conditioning systems, in particular, will require conservation strategies in the building sector (Schmidt, 2003). In the last years, the energy consumption for heating decreased due to insulation and energy efficiency strategies. In the same time, the cooled-floor area increased 12% per year in Germany (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 that features several sustainable measures. The building combines sustainable water management and reduced energy consumption for cooling and ventilation. The evaporation of water is the cheapest and most effective way to cool a building. A cubic meter of water evaporated consumes 680 kWh. The water used in this project is harvested from the roofs and stored in 5 cisterns. The rainwater is used to supply a façade greening system and central air-conditioning systems.

The building is a result of an architectural competition held in 1997. Construction of this experimental building for the Humboldt- University of Berlin started in the year 2000, and ended in 2003. The building has a total floor area of 19 000 m² . It was honored with the Berlin Architectural Award in the year 2004.

2. Methods

At the request of the Berlin Environmental Ministry, researchers at the Technical University of Berlin, the Humboldt University, and University of Applied Sciences Neubrandenburg have monitored the overall benefits of this building. This research has three foci: 1) reduction of operating costs, 2) improvement of the functionality of the systems, and 3) development of new applications.

The project includes permanent monitoring of the water consumption of different plant species and 8 climatization units. The façade greening system is evaluated to determine the importance of evapotranspiration and shading on the overall energy performance of the building. This project is controlled and monitored by an internet-integrated computer system (for more detailed information see http://www.gebaeudekuehlung.de). Temperature and radiation measurements are included. Data collected from this project is used to calibrate simulations that are designed predict performance and benefits in range of different climatic conditions.This work will inform the design of future projects.

The investigated measures will be divided into three main topics:

- Passive and active building climatization
- The façade greening system
- Rainwater harvesting and decentralized stormwater management

The general project structure is divided into 5 different phases:

- Phase I : Optimization of the planning assumptions (2001-2002)
- Phase II : Construction management (2002-2004)
- Phase III : Monitoring (2004-2007)
- Phase IV : Optimization of the project (2005-2007)
- Phase V : Model construction, performance prediction for future projects (2007)

2.1 Passive and active building climatization

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 (Schmidt, 2005).

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.

Figure 1 façade greening system, Institute of Physics, Berlin-Adlershof

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. Energy savings will be extrapolated through radiation measurements at the institute.

Although in the natural landscape most precipitation is evaporated or transpired, in urban areas, evapotraspiration is greatly decreased and rainwater is instead swiftly directed into the sewer system and to receiving waterbodies. At the institute stormwater runoff is collected and used to irrigate 150 planters on nine different façades. The planters, which are located at each floor of the building, are irrigated by a water content maintained at a constant level. Evapotranspiration of the plants has an immediate feedback to the water supply.

2.2 Rainwater based adiabatic cooling systems

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 $30^{o,}$ indoor temperatures are maintained by a conventional cooling system. This system is is supplied with cold water from two absorption chillers, powered by hot water derived from a combined heat and power unit (CHP).

Figure 2 adiabatic exhaust air cooling in seven air conditioning systems

2.3 Rainwater harvesting and decentralized stormwater management

A main goal of rainwater harvesting in Berlin is the retention of rainwater to reduce stormwater flows into combined and separated sewer systems during rain events. This reduces the peak load and avoids an overload of the systems, which could cause flooding and serious health problems (Diestel, Schmidt, 2004). The Institute of Physics has no connection to any rainwater sewer. Rainwater is stored in 5 cisterns in two courtyards and will be used for irrigating the green facade system and to supply adiabatic cooling systems in 7 climatization units. Stormwater events with heavy rainfall will be managed by an overflow to a small constructed lake in one of the courtyards inside of the building. The institute is located in a groundwater protection area close to groundwater supply wells of the city's drinking water supply station. To protect the ground water quality, only natural surface infiltration is allowed.

Figure 3, 4 constructed lake with natural surface infiltration inside of a courtyard

3. Results

Table 1 Results for the year 2005 and expected values (simulation during the planning process)

	Simulation	2005	MWh
Used Water	1608 m³	269 m³	
Rainwater	864 m³	267 m³	
Tap water	744 m³	1,6 m³	
Evaporative cooling systems	536 m³	75,9 m³	51,6
Facade greening systems	1072 m³	146,2 m³	99,4
Tap water absorption chiller	1415 m³	7488 m³	
Infiltration	1146 m³	2430 m³	

The retention pond in Adlershof has a size of 1,5% of the annual precipitation. This is a very low percentage, especially considering its role in water storage for both irrigation and cooling purposes. Many unknown factors – including the amount of water which will be used by the green facade and the adiabatic cooling systems – meant that assumptions had to be made in the planning process. Monitoring of this project provides information on these subjects that can be used for the planning of future projects.

Table 1 shows the estimated results of a simulation for the planning process. Up to now the real water consumption was much less than the estimated values (coloumn 2005). The main factor was the underdeveloped vegetation of the façade greening system in the first years of it's implementation. 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.

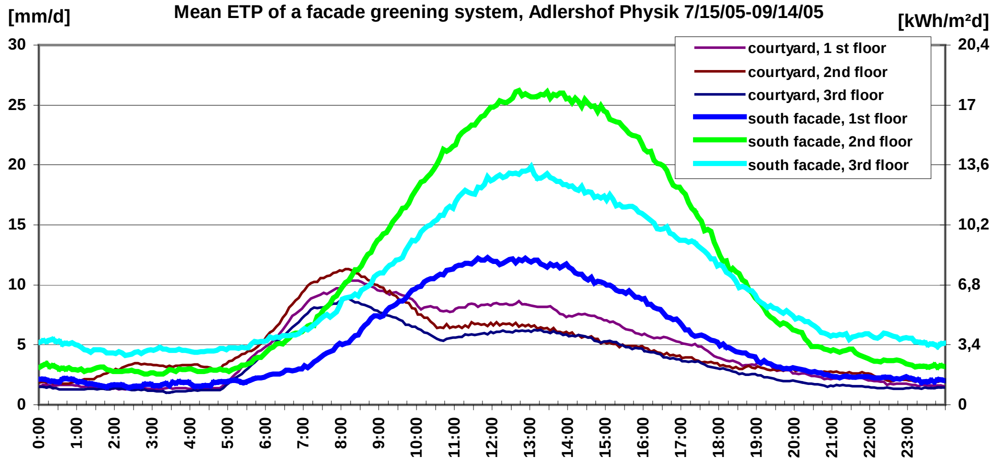

Figure 5 mean evapotranspiration of the façade greening system in mm/day and correspondent cooling rates

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.

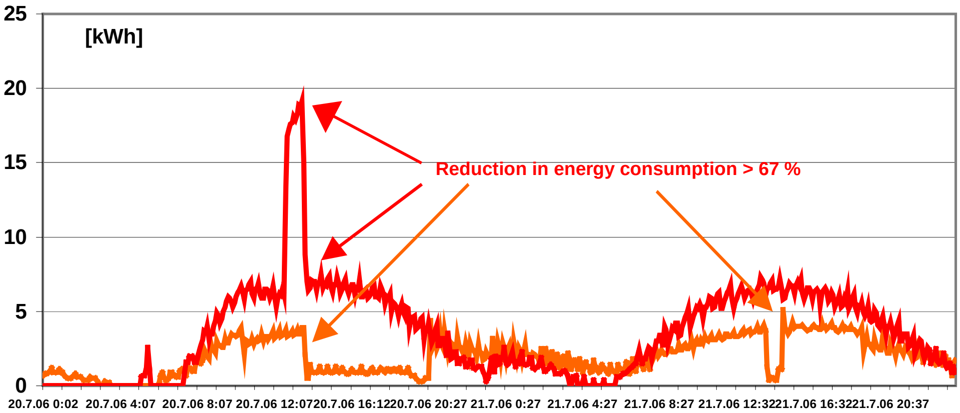

Figure 6 difference in energy consumption with and without evaporative cooling

Figure 6 shows the difference in energy consumption of two adiabatic exhaust air cooling systems that were switched on and off as the outside air temperatures reachedup to 35 °C. Energy consumption decreased from 19.0 to 6.0 kWh. Up to 30°C outside air temperature no additional energy is used.

4. Conclusions

Passive and active evaporation of water is an inexpensive and effective means to climatize a building. The evapotranspiration of a cubic meter of water consumes 680 kWh of heat. Greening a building's roof and façades results in significant additional evapotranspiration, which has a high potential to reduce the building's surface temperatures and to improve the climate inside and around the building. Both the potential and the real evapotranspiration rates are high due to high temperatures caused by the urban heat island effect and the low humidity of urban areas.

Evapotranspiration is the most important environmental benefit of green roofs and green façades in urban areas. It influences urban hydrology, reduces surface temperatures and improves stormwater management.

The combination of rainwater harvesting with the climatization of a building has been successfully implemented. The adiabatic cooling systems have a higher efficiency than expected. Goals for future projects will include utilizing knowledge gained from this research to design climatization systems that can completely substitute rainwater-based approaches for conventional technical cooling facilities

Additionally, evapotranspiration is can be an important tool to decrease global climate change. The process of evapotranspiration converts short wave radiation from earth surface to latent heat which than is transported into the atmosphere. In Germany, on average, natural landscapes convert 86% of the net incident radiation into latent heat.

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.

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

Schmidt, M. (2006) Rainwater harvesting for stormwater management and building climatization. Proceedings RWHM Workshop, IWA 5th World Water Congress and Exhibition, Beijing, China, pp 132-138.

SenStadt (2002) Maßnahmenkatalog zur Reduzierung der Wasserkosten im öffentl. Bereich

SenStadt (2003) Innovative Wasserkonzepte, Betriebswassernutzung in Gebäuden

http://www.gebaeudekuehlung.de

http://www.stadtentwicklung.berlin.de

http://stadtentwicklung.berlin.de/bauen/oekologisches_bauen

http://www.a.tu-berlin.de/gte

http://www.augustinundfrank.de

http://www.physik.hu-berlin.de

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