PHOTOVOLTAIC-PANELS ON GREENED ROOFS

POSITIVE INTERACTION BETWEEN TWO ELEMENTS OF SUSTAINABLE ARCHITECTURE

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Abstract The cultural center “UFA-Fabrik” in Berlin-Tempelhof has been known for years for its use of ecological technology. The original structures were completely renovated in 1984 and fitted with greened roofs at that time. Today the entire complex includes ca. 4,000 m^2 of greened roofs. Since 1992 a monitoring program has tracked development of the vegetation, microclimate and retention of precipitation. The first solar panels were installed on the UFA Factory in 1998. A year later, an array consisting of ten 2 kW_P photovoltaic panels was added on a greened roof. One part of the monitoring includes tracking the efficiency of fixed versus steered panels; another regards the interaction between the greened roof and the photovoltaic panels.

While this is a preliminary report, several tendencies seem clear: the tracked solar panels are generating ca. 10 – 15% more electricity than the fixed ones. The greened roof is notably cooler than conventional bituminous roofs: While lower temperatures lead to higher voltages at silicon based photovoltaic panels, the electricity generation of PV on green roof is higher than on conventional roofs. We are in the process of quantifying that fact. Due to construction activity accompanying the installation of the array it was difficult to evaluate the vegetation during the first year; however, from the second year on investigation of the vegetation under the panel indicates significantly improved growth of the species relative to plant height and foliage density. There also appears to be a change in species from small plants (e.g. Sedum) toward larger ones such as Artemisia.

1. INTRODUCTION

In Europe, greened roof technology has become increasingly important within the last 20 years (Koehler et al., 1993). “Skyrise Gardens”, as they are called in Asia, are one way to return open space to paved and sealed areas of the inner city. Such roofs become important for residents in areas of high urban density. However, such greened roofs provide benefits far beyond their aesthetic component. A number of groups (Koehler et al., 2001) have pointed out that greened roofs offer energy savings as well, contributing to sustainable urban development. In temperate climates a greened roof functions as additional insulation against temperature extremes, resulting in a reduction of energy consumption in heating and cooling. In the tropics, greened roofs play an important role in cooling the building. Soil on the roof retains rainwater, which is in turn evaporated by the plants of the roof garden, removing heat from the building through enthalpy. One of the big problems of growing urban areas is the creation of “inner city heat islands”. Greened roofs can help alleviate this problem. One of the major projects of the Brazilian – German group is the quantification of this effect.

Figure 1 (left side): PV mounting structure on the greened roof in November 1999. Figure 2 (right side): Photovoltaic array with solar tracking ("Traxle") in Summer 2001.

Photovoltaic cells are one of the most promising technologies in the continuing struggle to reduce carbon dioxide emissions. They are available in a variety of panels, and have been tested in various array densities and solar angles over the last few years. If we are considering changing the paradigm of urban architecture toward an increasing exploitation of solar energy, why not consider combining the best of both technologies: photovoltaics and appropriate ecology. This paper suggests that there is a positive interaction between both.

- The efficiency of a photovoltaic panel increases as it is cooled; a typical non-greened roof is very hot, increasing the temperature of the PV-modules;
- The vegetation of greened roofs benefit from increased shade. Both aspects need to be investigated in conjunction with each other, in the tropics as well as in temperate climates. Our group would like to present the results of its first two years experience in Berlin, Germany.

2. RESEARCH AT THE UFA FACTORY (BERLIN)

Located in Berlin-Tempelhof, the UFA Factory was an important center of the German film industry until the end of World War II. Nearly 20 years ago, an enthusiastic group of young people established a cultural center in the old buildings. Cultural and, increasingly, ecological projects have been tested there and have gained considerable renown.

2.1. Research on Extensively Greened Roofs

In 1984, the first extensively greened roofs were installed over decrepit asphalt roofs. By now nearly 4,000 m^2 of greened roofs have been established. Extensively greened means, that a soil layer of 10 cm receives seeds from typical plants from dry meadows. These seeded areas were watered during dry periods for the first few years until vegetation was well established. For the last few years rain was the only responsible for the irrigation. Since 1992, selected roofs have been included in a vegetation-monitoring program. Climate and run-off data have likewise been collected (preliminary results are shown in Table 1).

	Before PV-Panel-installation (1992–1999)	Northern part of the roof without PV-panels	Southern part with PV-panels (2001)
Av. number of plant species	**41**	**41**	**43**
Av. cover of all higher plant species (%)	**89**	**85**	**97**
Max. height of plants (cm)	**65**	**110**	**118**
Av. height of all plant species (cm)	**22**	**15**	**38**
Av. cover of the genus "Sedum" (typical for greened roofs) (%)		**48**	**27**
No. of plant species benefited by the shade of PV-panels			**7**

PV generator power installed Electrical energy output Relation Energy output/

Table 1: Results of covering by PV on vegetation
(Extensively greened roofs before and after installation of photovoltaic panels)

2.1. Types of photovoltaic panels

In 1998 the first photovoltaic panels were installed on a conventional, non-greened roof. In 1999 a. photovoltaic array of about 400 m^2 was installed on a greened roof. All together the photovoltaic panels have a maximum capacity of 53 kW_p, i.e. an average of 37,000 kWh/year. The equivalent carbon dioxide emissions would be approximately 33 tons/year, taking the European Energy Mix a reference. (see: www.ufafabrik.de).

Different types of photovoltaic arrays and systems have been monitored, as mentioned in Table 2. In order to distinguish the different systems in the text below, they will be named according to the type of inverter they are equipped with (see column "Inverter type" in Table 2) The condition of the old buildings made installation of the solar arrays a difficult proposition. Minimal static reserves dictated installation on the outside walls.

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PV generator power installed Electrical energy output Relation Energy output/ generator power (W_{Peak}) (kWh) (kWh/kW_{Peak})	Inverter type	Manufacturer - Technology
1572 4.480 2.8	NEG 1	Solarwerk - Glass,Tedlar
1572 4.511 2.9	NEG 2	Solarwerk - Glass,Tedar
1 440 2.808 1.9	NEG 3	Solarwerk -Astropower
1 440 3.939 2.7	NEG 4	Solarwerk - Astropower
1 840 6.283 3.4	NEG 5	Reference

Table 2. Energy production of different types of photovoltaic systems during a single day (09/09/01)

2.2 Types of PV mounting structures (fixed and tracked)

In opposite to fixed mounted systems, solar tracking systems adapt the angle of the solar generators to the sun continuously throughout the day. The angle of incidence should ideally be 90^0 to the surface of the PV-module throughout the day. Solar tracking systems ensure a significant increase in the percentage of direct solar radiation received over fixed panel operation, thus increasing energy production, particularly on clear days with little or no diffusion of direct sunlight.

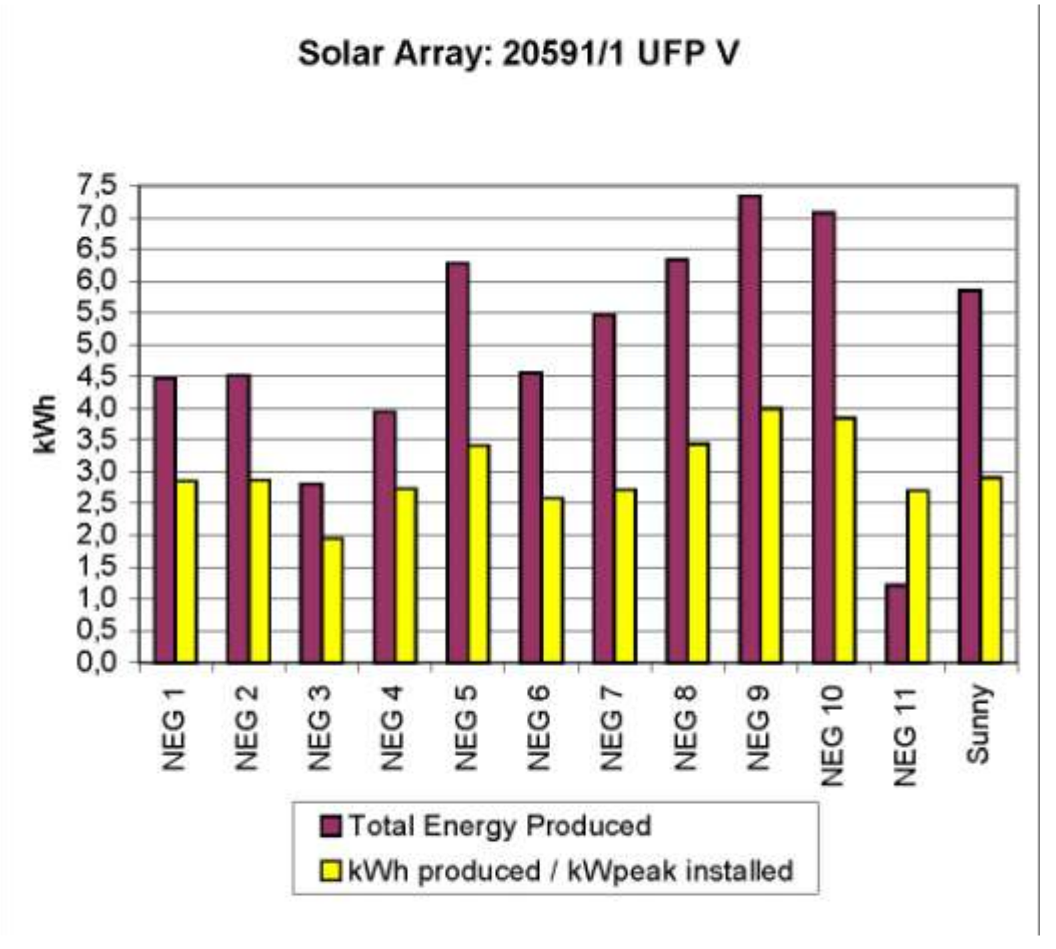

Figure 3. Absolute and relative electrical energy generation of the different PV-systems

2.2.1 Reference System: fixed mounting

The solar generators (Status 115) of the reference system are fixed and oriented due south at an angle of 30^0. This reference system is intended to provide a control to demonstrate the increased power generating capacity of solar tracking systems. The efficiency of various types of modules and switching techniques or direction changing systems is determined through direct comparison, as their mounting angles differs from that of the reference system. This could result in a divergence of around. 5%.

2.2.2 Photovoltaic arrays with solar tracking

EGIS System

This system uses the SolarTracker, a biaxial positioning mechanism manufactured by EGIS GmbH in Offenbach. It consists of an external and an internal unit. The external unit consists of a traversing and tilting rotor and mounting provision for a large mirror/reflector/panel. Modularized photovoltaic panels were mounted on this tracking system. The rotor has two separate 24 volt electric motors and can rotate the head with the attached panel horizontally by 180^0. The vertical tilt range is 65^0. Maximum balanced static load should not exceed 100 kg. The inner unit consists of a computer with a power source for the rotor. The electronics are contained in a small metal housing with controls and a 40 character LED display on its face. Connectors for the rotor cables are located on the rear of the housing.

Prior to starting the unit, the local geographic coordinates are entered into the computer via a keypad. Using this information in conjunction with the time of day and year, the precise location of the sun is determined.

ALTEC System

The ALTEC system, offered by ALTEC Solar Products in Schleiz, passively guides the solar generators around a tilted North-South oriented axis with a horizontal range of 54^0 East to 54^0 West. (Tilting axis) The mounting angle of the generator is set to 30^0. (Range: 5^0 – 45^0). This type of tracking is called “thermohydraulic” or “gravity tracking”. It utilizes a liquid with a low boiling point that is confined in two connected tank systems housed in the generator mounting. Any deviation from the optimum solar orientation results in a partial shading of the tanks as well as redirection of the impinging rays by reflector and shading louvres, causing differential warming of the tank systems. As the medium within the tanks expands, it moves into the cooler tank through the connecting pipes. The resulting change in the location of the centre of gravity of the module causes the module bounce in the direction of the sun, thus able follow the sun. As soon as the surface of the module is aligned with the sun again, both tank systems are warmed equally and the unit remains in this position, until one of the tanks is heated up a differentially from the other once again. If the sun’s rays are too weak, the system stays fixed At sunset the system remains pointed to the west, so that at sunrise the medium in the western tank must first be warmed by the sun to turn the system toward the east. For this reason the two tanks have reflector and shading systems that react at different speeds so that the system can follow the sun as soon as possible after sunrise. The system is constructed for wind loads up to 1200 N/m². Shock absorbers ensure that the solar array is not disturbed by strong winds and gusts.

TRAXLE System

As with the ALTEC unit, the TRAXLE system is a single-axis unit that rotates the solar generators around a tilted North-South oriented axis (Tilted axis). The TRAXLE device, made by Poulek Solar, Ltd. (CZ), is an active self-tracking system. It needs electricity to drive a DC motor, but the energy is generated by two small PV modules switched in a anti-parallel (parallel, but with inverted polarity), which are mounted in perpendicular to the main PV generator., each facing in the opposite direction. If the irradiance incidences in non-perpendicularly way, one of the small modules will receive more irradiance than the other, resulting in a voltage at the driving motor which begins to turn the panel towards the sun. The anti-parallel switched solar module that is attached to the rear of the tracking module permits the axis of rotation to adapt to any position of the sun. This allows the array to return to East for daybreak from any position. The integration of the two anti-parallel units makes the system more compact, reliable and saves costs. The system takes only a few minutes to adjust from evening to morning position. The additional solar module needed to power the rotor takes up about 1% of the surface of the solar array. The tracking range is ca. 120^0, while the mounting angle of the array is 20^0, as per the manufacturer’s recommendations. Installation of this unit is quite easy due to its relatively low weight (ca. 7 kg/m²). At the same time, transport costs are relatively low. Care must be taken to position the solar array symmetrically and well balanced to ensure the lowest possible turning moment for the system (less than 1 Nm).

2.3 Evaluation of power generated

The measurements taken on September 1, 2001 indicate: (NEG 6) 24% more; (NEG 1 & 2) 17% more; (NEG 7) 20% more power generated than by the reference system. The results for (NEG 3 & 4) by Astropower differ considerably, despite identical systems. This is due to a tree located near the building, which partially shaded NEG 3 in the early evening. This tree

should be thinned appropriately. Similarly, tall herbaceous plants on the greened roof should be cut back annually.

Figure 4: General overview of the different types of roofs (July 2001)

3. RESULTS

Positive interaction between greened roofs and photovoltaic panels:

- Green roofs reduce operation temperature of the PV system, thus increasing efficiency and energy yield
- PV array offers shading for green roof, thus improving growth of plants and increasing number of species.

The well-shaded vegetation of the roof with the photovoltaic panels is significantly higher than on those roofs without the panels. Indeed, occasionally the vegetation must be controlled to ensure that the panels are not getting shaded. Plants of a height of ca. 40 cm cover the entire roof, providing good protection of the roof and acting as a natural cooling system. Based on an installed capacity of 20 kW_P, fixed installations can be expected to produce ca. 14,000 kWh/year, while solar tracking systems can be expected to produce around 16,800 kWh/year. In terms of carbon dioxide, this means a reduction of about 15.1 tons/year (Reference: European Energy Mix). Determining the effect of the interaction between photovoltaic panels and greened roofs on energy production requires long-term measurements of identical systems on greened and conventional roofs. The positive effects of greened roofs, such as evaporative cooling as well as a reduction of surface temperatures, are achieved through greening measures alone. The cooling effect by the plants and the resulting increase of electrical energy yield of the PV system (see Krauter and Hanitsch 1996) not determined during this experiment. This task will be carried out in the next phase as well as the measurement of reduction of radiation onto the roof surface. Further on new ideas for cooling of PV panels will be implemented (see Krauter and Schmid 1999). Maintenance measures necessary to ensure the efficiency of the photovoltaic panels – cutting back vegetation annually in the late summer, a measure not necessary on customary greened roofs – represents a minimal added expense.

In any case, the observations suggest the need for further experiments, particularly under tropical conditions. The values of climatic parameters in the tropics - radiation, temperature and precipitation are approximately double as high compared to those prevailing in temperate zones such as Europe. Therefore the efficiency of photovoltaic panels is higher in the tropics. To date, there have been few studies of efficiency gains with artificial cooling of PV-modules (Wachsmann, 2000). It would be desirable to verify the preliminary results obtained in Germany with similar studies conducted in the tropics. COPPE at the Federal University of Rio de Janeiro (UFRJ) is already cooperating in such a project. First results on local plants under extensive conditions on roofs for Rio de Janeiro are already available (Laar et al, 2000). The results of the first Rio Conference in 1992 suggested the need for a change in architecture. Energy conservation is an issue of ever increasing importance. Our group has demonstrated a realistic approach to reducing primary energy use without an accompanying life-style trade-off for urban dwellers. A decade after the initial conference we need to implement all of these small steps to realize a definitive change of course toward the true solar city. (Droege, 2001)

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