



Session 3.3: Energy and Thermal Performance

INTERACTION BETWEEN PV-SYSTEMS AND EXTENSIVE GREEN ROOFS

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Abstract

On the cultural Center of the Ufa-Fabrik in Berlin Tempelhof, various extensive green roofs were installed in the 1980s. On a few of them in 1998 a first PV-power plant was installed with 53 KW_{peak} . Initially, a second one with a main focus on research was added in 1999 with a capacity of about 19 KW_{peak} . The main focus of the research was to enhance the PV-Technology. Test variables included the types of PV-Cells, inverter, and the influence of the exposure of the cells to the cooler ambient temperatures provided by the green roof. Fixed installation and three tracking systems were tested and compared.

Voltages characteristic depends on temperature levels. Lower temperature means better PV efficiency. In this research the PV cells over a green roof were compared with cells over Bitumen roofs.

The energy output of PV-panels depends on several factors. In this survey of over approximately 5 years of data, the effect of the green roof has been estimated at an average 6% increase in yields (2). But the green roof is only one factor in enhancing the efficiency of PV-panels. The total range of increased energy output varies between 1 and 10%.

PV over green roofs can be mounted on fixed frames. The costs are lower in comparison to the tracking systems, which follow the sun.

Under the PV panels, a variety of extensive green roof vegetation can be grown. In the case of UFA it was originally a Sedum roof but this was subsequently changed to include a wide variety of plantings.

Minimum garden roof maintenance is required to reduce taller growing plants. The PV – cells must be without shade.

The estimated benefit of a higher Power output from a green roof can help to offset the cost of green roof installations.

Key words:

Extensive green roofs, Berlin, Photovoltaic, PV panels, Greenhouse Gas Reduction.

1. Introduction



Sustainable Architecture has increased worldwide during the last years. In the 1990s there was discussion in Germany on whether it was better to implement extensive green roofs or photovoltaic panels (PV) on roof spaces. Both technologies seemed to be competing on the same roofs.

Until recently, about 5% of all the roofs in Germany were extensive green roofs. In several regions of Germany up to 14% of green roof projects are on new buildings (see: Haemmerle, 2002, 1). A general questionnaire to get detailed information of all Cities with more than 50.000 inhabitants, the National Green Building Association (FBB had been sent out last December; see: www.FBB.de). The number of PV power stations on roofs until now has been too small to calculate in percentages (own survey). There is also a high potential for both technologies, by combining them.

On the roofs of the Ufafabrik (see www.ufafabrik.de) there was the opportunity to test both technologies, separately and together. The European Union (EU), the German Federal government, Berlin Senate, supplied funding for this research and the citizens of the ufa-area donated many volunteer hours themselves. Two different PV-power plants were installed in the first stage. One with about 19 KW_{Peak}, was installed in 1999 as a research PV-Power plant and another one with a maximum of 53 KW_{Peak} was installed one year before to produce a reasonable quantity of electricity (12). This bigger PV-Plant in the following text called "A" was installed on Bitumen roofs next to the research one. Both plants got a mixture of fixed and flexible panels, which were able to be oriented at the best angle to catch the sun.

The smaller one is partly installed above an extensive green roof. Both PV-plants together were about 5 years ago the largest PV-installation in Berlin. The cost of the 19 KW project was about 500,000 €. In the first 5 years 80.000 KWh of energy was produced generating a refund of nearly 40,000 €. Wiartralla calculated the annual reduction of CO₂ – Emission of this PV power plant at about 33.000 kg per year. (see: www.ufafabrik.de/en/nav.php?pid=n27).

The market for rooftop PV panels has increased rapidly in the last few years. Germany and Japan lead the household rooftop solar PV Market with a combined 250,000 installations to date (10).

From research, conducted by Krauter and Ochs (2002, 3) it is known that lower temperatures can have a positive influence on the efficiency of PV-panels. Krauter and Schmid (1999, 4) and Wachsmann (2000, 11) conducted experiments to cool down the panel's surface. They had two strategies; the first was to mount the cells on a water tank, the water will become warmer over summer days and loses the temperature through the night. This tank offers an additional chance for solar thermal use. The second strategy was, to use a thin water film floating over the cells to cool the surfaces. This water film on the cells also has a cleaning effect. (Information about these types are available on the internet: http://www.rio02.de/proceedings/pdf/101_Krauter.pdf, and http://www.rio02.de/proceedings/pdf/101_Krauter.pdf) Krauter (3) calculates the increase of the electrical yield between 9 and 12%.

The buildings of the cultural center Ufafabrik were renovated in the 1980s and fitted with about 4000 m² of extensive green roofs. These roofs were part of grassroots activities by the citizens of the cultural center. The additional long time technical research of these green roof



infrastructures began in 1992. The species richness of these roofs is part of a long time research program in green roof technology of Berlin (5, 6, 9).

As the authors know, this was the first field experiment to test on a long-term basis the combination of both PV and green roof technologies together.

A first introduction to this PV installation on the extensive green roof of Ufa as well as some facts on the green roof infrastructures were presented at the PV - conference RIO02 (4) http://www.rio02.de/proceedings/pdf/151_Koehler.pdf).

2. Research

2.1 PV Panels

The efficiency of PV panels depends on a number of factors, like:

- Type of PV – cells, each cell has a different capacity;
- Type of inverter to transform Direct Current (DC) in Alternating Current (AC),
- Installation details such as inclination, shade and reflections from the surroundings,
- Fixed installation or tracking systems,
- Local climate: temperature, wind, radiation, direct influence of rain, as well as annual differences in climate factors,
- Surface materials like Bitumen or Green roof structures under the panels
- Frequent maintenance, to reduce failures.

The PV-Power plants on the Ufa-roofs:

The 53 kW-PV-Plant “A” was installed only on Bitumen roofs of the Ufafabrik in 1998 with very little monitoring ability. The main aim of this first Installation “A” was, to produce a maximum of electricity. From “A” monthly results are registered in real kWh, and some values will be presented in table 2. The second PV plant “B” with a potential Efficiency of 19 kW was installed in 1999 for research fields to test various details in PV-technology. The focus was on types of Cells, inverter technology and last but not least, the influence of the green roof structure, as well as fixed and moving cells with the different sun angles. About half of these cells are mounted above the green roof. The others are also on the Bitumen roof (see fig. 2).

Description of the research PV-plant “B”

Table 1 as well as **figure 1** explains the 12 different blocks of PV cells and inverters on the research PV-power plant “B” - roof. The variation is in the types of cells (Manufacturer), different construction, fixed with an angle of 8 or 30 degrees to the sun, or with a tracking system, following the best angle to the sun. Also different types of inverters were tested.

PV cells with the field names follows the types of inverter: NEG 1, 2, 3, 4, 5, 6 and 11 are mounted on a bitumen roof. No 5 has the same angle as the fixed ones above the green roof



but it is situated behind the 8-degree PV-systems, so sun reflection reaches these cells and has the best results.

NEG 8, 9, 10 are PV arrays with different types of solar tracking modes, mounted on the green roof. They look like sun umbrellas on the rooftop with a dimension of about 4 meters above the roof. The Fields NEG 7 and Sunny 12 are above the green roof and are fixed at an angle of 30 degrees to the sun.

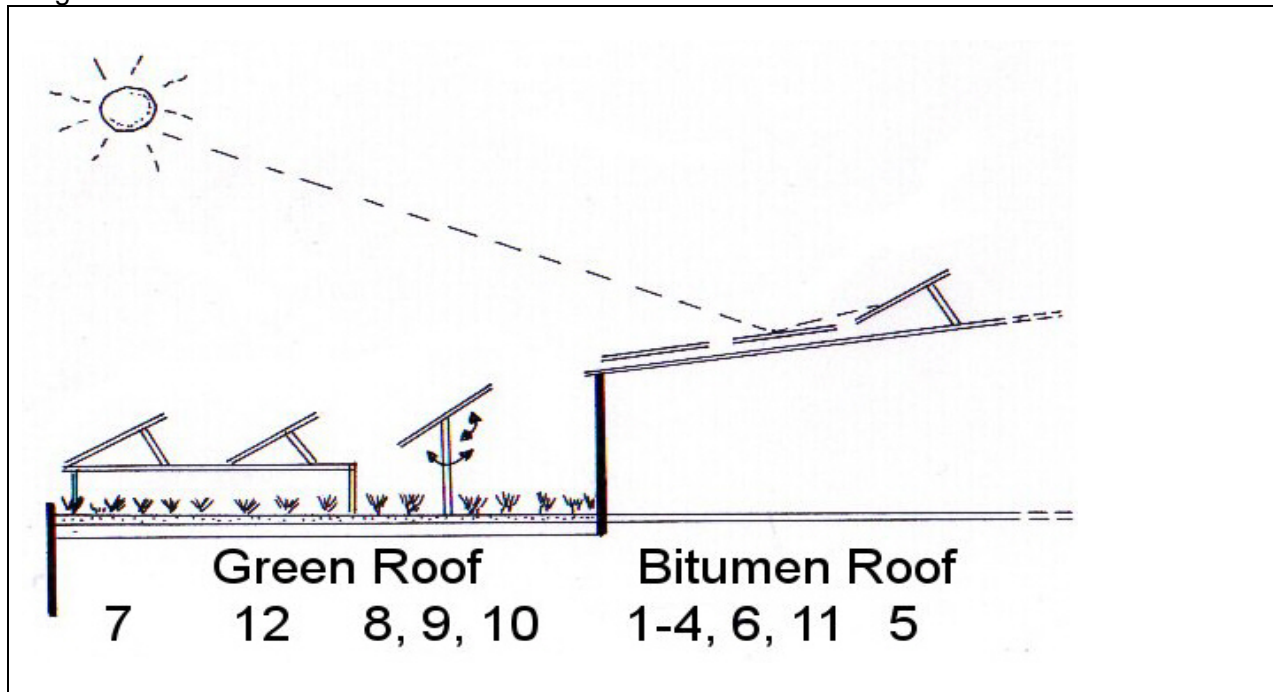


Figure 1: Principal cross section of the Research PV-power plant “B” with “field names and numbers”. Number 7, 12 as well as the tracking systems 8, 9 and 10 are mounted on top of the extensive green roof. 1 – 4, 6, 11 and 5 on the bitumen roof.





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Figure 2a (left hand): Experts are discussing the benefits of PV-installation on the green roof of Ufafabrik (from left to right: Ulrich Porsche (Krefeld, Germany), Karsten Jarmer (Thailand), Manfred Köhler (Neubrandenburg, Germany), Melissa Keeley (USA) and Steven Peck (Toronto, Canada).

Figure 2b (right hand): Extensive green roof structure under the fixed PV panels of “Sunny 12”. (Images: Koehler; source: http://www.gruendach-mv.de/en/research_topics.htm#8)

Field – name	PV power installed, (W_{Peak})	Manufacturer – brand name – type	Installation: inclination of the panel	Tracking system	Green Roof mounted	Inverter
NEG1	1572 W	Solarwerk Status 200	8°	No	No	NEG 1600+
NEG2	1572 W	Solarwerk Status 200	8°	No	No	NEG 1600+
NEG3	1439 W	Astropower 1206	8°	No	No	NEG 1600+
NEG4	1439 W	Astropower 1206	8°	No	No	NEG 1600+
NEG5	1838 W	Solarwerk Status 115	30°	No	No	NEG 1600+
NEG6	1764 W	Siemens SM 110	8°	No	No	NEG 1600+
NEG7	2013 W	Solon alpha	30°	No	Yes	NEG 1600+
NEG8	1838 W	Solarwerk Status 115	20°	Yes with sensor	Yes	NEG 1600+ NEG 1600+
NEG9	1838 W	Solarwerk Status 115	Follows the sun	Yes, time system	Yes	NEG 1600+
NEG10	1838 W	Solarwerk Status 115	30°	Yes, passiv with liquid	Yes	NEG 1600+
NEG11	450 W	Antec Solar ATF 50	8°, 30°	No	No	NEG 500
Sunny12	2013 W	Solon alpha	30°	No	Yes	Sunny 2000

Table 1: The research variables and design of PV-power plant “B”. The Number 7 and 12 are the fixed “green roof cells. They are mounted about 50 cm above the Green roof. (Pay attention also to pictures, fig. 2a and b.

2.2 Extensive Green roofs on Ufa

The extensive green roofs with about 10 cm growing media were constructed over several years. The experimental extensive green roofs were established in the mid 1980s. In the first years there was some irrigation and low maintenance.

The extensive green roof of the Ufa fabric is an ongoing monitoring program by the author since 1992. Twice a year a complete data list is taken of the presence and distribution of all plant species. The roofs are dominated by Sedum species. In the last 30 years about 5% of all buildings in Berlin have extensive green roofs. Now the green roofs of the Ufafabrik have the highest variety of species in Berlin (see 6, 9).



3. Results

Since 1999 a large amount of data has been collected; mainly hours of energy production and the sum of the output. In the following, some important questions shall be answered by representative data selection: as follows. This is the first publication of this data set. A complete statistic interpretation must be done later.

- 3.1 Comparison of the efficiency of a “typical PV-installation” with a “sophisticated research Installation; Method: Summer – Winter results of selected month of Power plant “A” versus “B”,
- 3.2 What about the annual influence of variation in climate differences though the years; as an example: 2001, selected month: “cold temperatures low sun” and the “high radiation values” in 2005,
- 3.3 Electrical yield output of exactly the same installation above a green roof by using different types of inverter (NEG, see: <http://www.wuseltronik.com/lewr.htm> and Sunny <http://www2.sma.de/index.php?id=1346&Dokumentenart=Short%20description>),
- 3.4 Electrical output of the green roof installation versus installation on a Bitumen roof, same angle of 30 degree and different angle of 8 degree,
- 3.5 The efficiency of a fixed green roof PV- panel system versus several high end tracking systems,
- 3.6 PV systems as umbrellas against direct sunshine,
- 3.7 Vegetation dynamics under PV – Installation on a green roof.

3.1 PV Efficiency

General compare of both types of PV-plants:

Table 2 displays the real energy output of both PV-power plants for selected months in summer and winter. The question was; are there differences in the relation of energy production during summer and winter months of these two power plants? The potential relation is 53 to 19 kWh that means a difference of about 35.8%. The real values in MWh real energy output in summer months is about 37% and in winter month 40%. As a result, the research power plant “B” has a slightly higher efficiency in energy production than the bigger one “A”. There could be several reasons for the differences. The tracking system, the better inverter as well as the greenery could be a mixture of these reasons. The higher efficiency in winter month is an effect of the tracking systems that offers better orientation to the sun.

	53-KW- PV-Plant Monthly efficiency in MWh “A”	19 KW- PV-Plant Monthly efficiency in MWh “B”	Monthly B – A - ratio in percentage	“Summer” B-A-ratio In percentage	“Winter” B-A-ratio
May 2001	5.8	2.3	40		
July 2001	5.5	2.2	40		
August 2001	5.6	1.9	34	38	
<i>Jan. 2002</i>	<i>1.7</i>	<i>0.4</i>	<i>24</i>		



Feb. 2002	1.6	0.6	38		
March 2002	3.5	1.1	31		31
May 2002	6.4	1.8	28		
July 2002	5.5	1.6	29		
August 2002	3.9	1.8	46	34	
Jan. 2003	1.7	0.2	12		
Feb. 2003	0.9	0.8	88		
March 2003	3.5	1.3	37		46
May 2003	6.2	2.2	35		
July 2003	5.7	1.9	33		
August 2003	5.4	2.0	37	35	
Jan. 2004	0.7	0.3	43		
Febr. 2004	1.2	0.6	50		
March 2004	2.8	1.1	39		44
May 2004	4.8	1.9	40		
July 2004	2.9	1.2	41		
August 2004	6.8	2.8	41	41	
Jan. 2005	0.6	0.2	33		
Feb. 2005	1.2	0.5	42		
March 2005	2.9	1.2	41		39
Av. Ratio; in %				37 Summer	40 Winter

Table 2: Comparison of real energy output of both PV-power plants for selected months in summer and winter

3.2 Annual influences of PV-efficiency

Figure 3 explains the peak variables between two years. The output depends on the sun hours, climate conditions and the absence of any disturbance to the system. The variation between the years can vary by 20%.

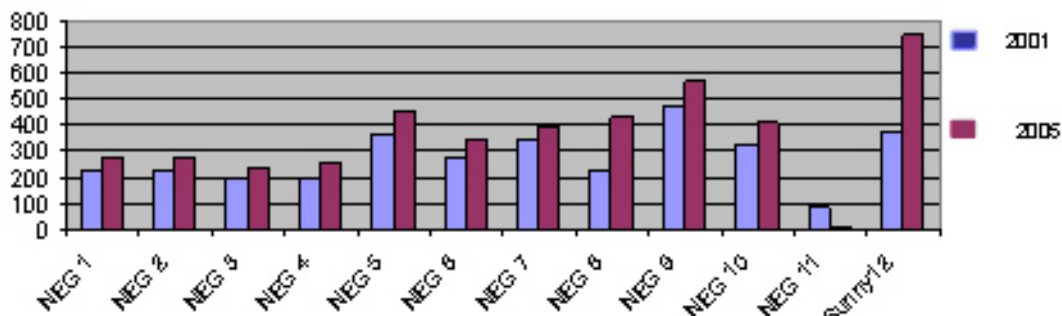


Figure 3: Comparison of the different fields of the PV-research power plant by month for the years 2001 and 2005 in kWh. The higher sun input 2005 is one reason for the higher efficiency of that year. You can also see a breakdown of NEG 11 in 2005. A significant better relation can be seen on the Green PV – panels “Sunny 12”.



3.3 Electrical yield output on the green roof

As an example of a complete data set of two PV-power installations with exactly the same power shows differences in some month (see Fig. 4). A similar picture can be taken also from the other years. Inside of the PV-technology are some weaknesses included, which must be solved by the services. NEG 7 had some troubles in July, Sunny 12 in August. Looking over the years, the Sunny 12 inverter was better suited to be used here of the two PV-panels “Solon alpha” (compare with Table 1).

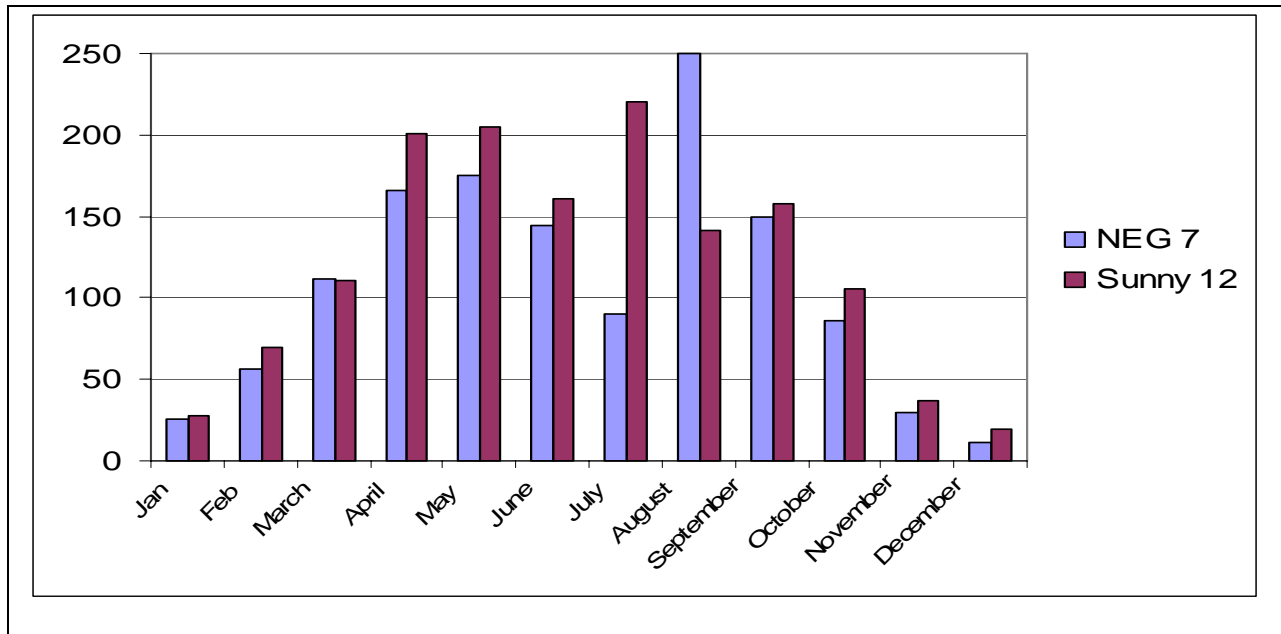


Fig. 4: Comparison of the yield electricity output in kWh in 2004 of both fixed PV-fields on the green roof. Both panels had exactly the same power installed at 1838 kW_{peak}. The difference is a result of the different inverter used here.

3.4 Electrical output of the green roof versus the Bitumen installation

In both the following graphs Fig. 5a and 5b, the Data set from the year 2000 will be given as an example. “Green” is the mean value of both “green installation NEG 7 and Sunny 12” together. In addition, all Bitumen panels are put together. For a better understanding, the values of the “Green” are put as an axis. So it is easy to see what works better. The Bitumen 30 degree (NEG 5 see table and fig. 1) has a relative better efficiency of about a few percentages. The Bitumen 8 degree – installation has 1 – 15 % less output than the green roof ones. In this year the effect was a 6.5 %, yield. The Bitumen 30 variable is benefited by the reflection on the cells just in front of them. So in 2000 the benefit was a mean of +1.5 %.

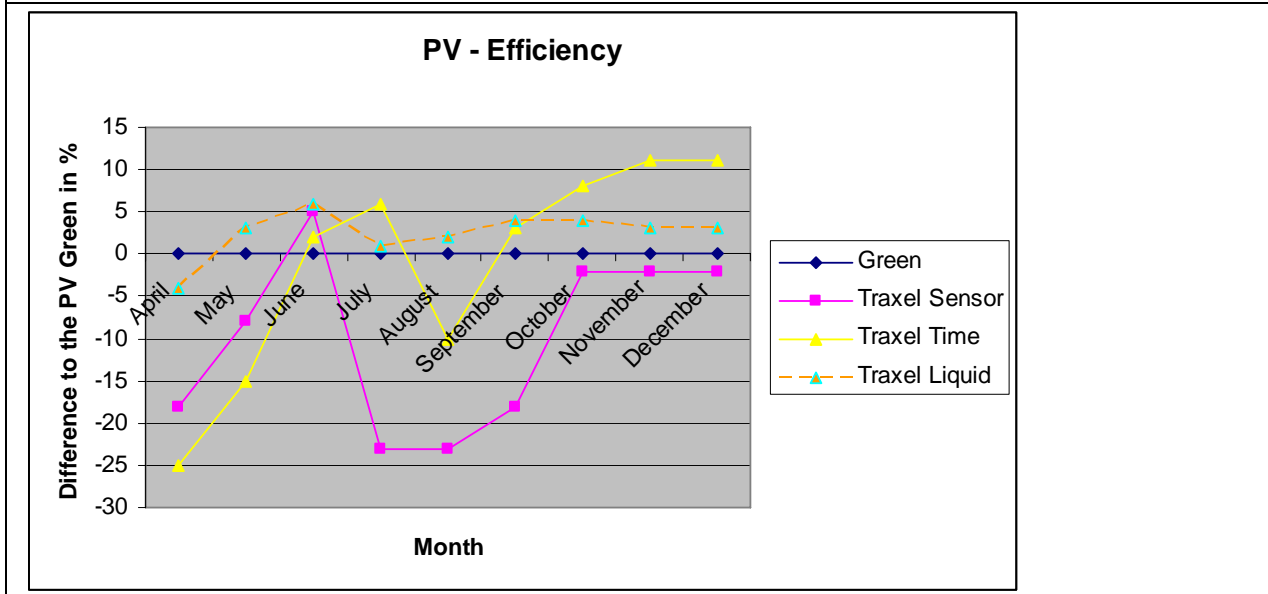
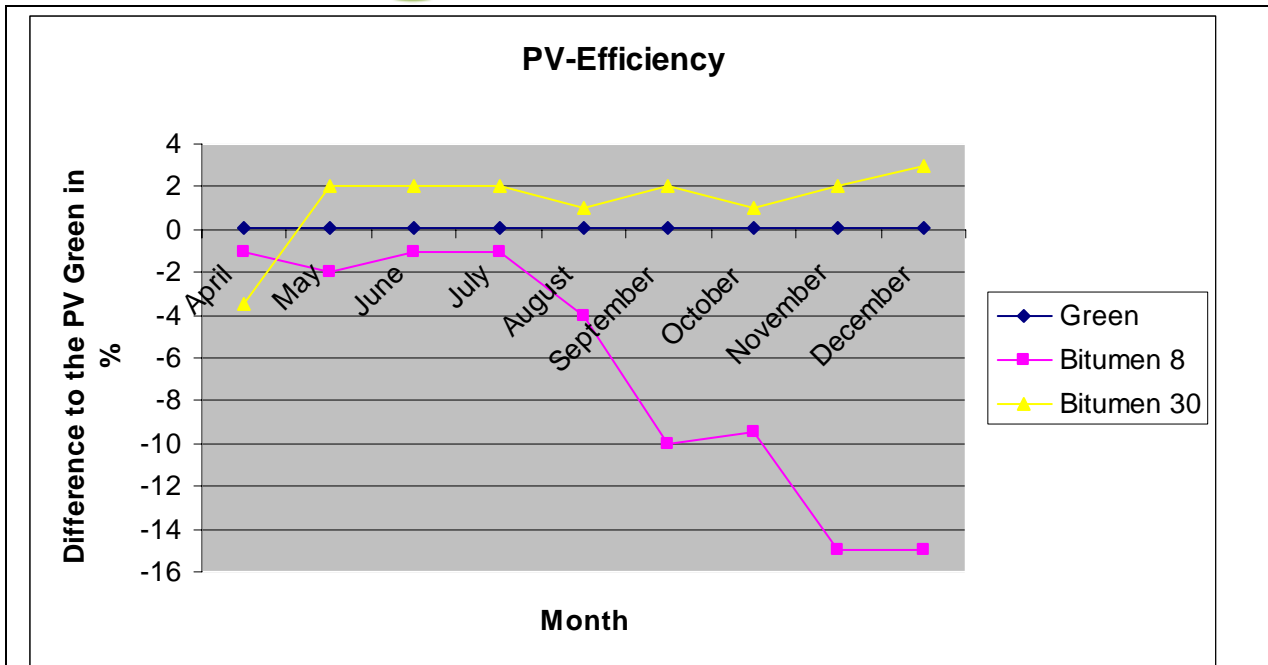


Figure 5a: Exemplary PV- Efficiency a: between both PV block NEG 7 and Sunny 12, called “Green” 4026 KW_{peak} and the Cells above Bitumen 8 degree angel (are all the fields NEG, 1,2,3,4,11) with 6472 KW_{peak} Bitumen 30: NEG 5 reflexion input 1838 KW_{peak} : benefited by various reflecting effects , (Data set from 2000)

5b: The same “Green” selection in comparison to the Tracking – Variation, Data from 2000 Traxel Sensor, NEG 8, Traxel Time; NEG 9 and Traxel Liquid NEG 10, each has 1838 KW_{peak} Power installed



Fig. 5b explains three different expensive systems that follow the sun. The system requires lot of maintenance, and is sensitive to any type of damages by storms. In winter these steered systems have advantages, but overall effectiveness and comparisons would need to be determined by an economic calculation.. These types of steered Panels are suitable for small PV-power plants.

3.5 The Efficiency of a fixed green roof PV-panel system versus several high end tracking systems

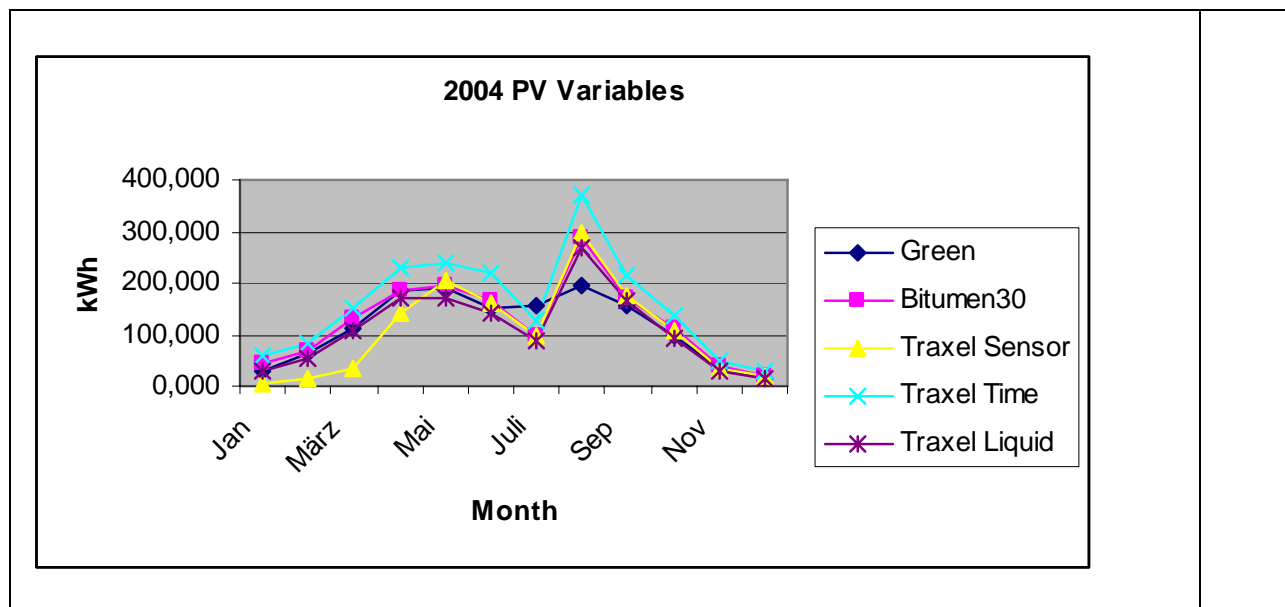


Figure 6: Monthly energy output in kWh 2004



In figure 4 the Energy output of a complete year was displayed as an example. About $11\text{kW}_{\text{peak}}$ are represented in the selected five variables. Both Green power strings NEG 7 and 12 called “Green”, the effective NEG 5, called “Bitumen30” and the three tracking systems 8 (Sensor), 9 (time steered) and 10 (Liquid steered) from table 1 are here in the graph. In 2004 these cells had produced 8820 kWh that means a monetary result of about 4145€. The well-known Bitumen 8-cells had -6.5% less than the PV Cell on the “Green”. The best tracking cells, with the time steering has had about + 6% more Energy output than the fixed one. In July there was for a short time trouble in the technique and there was a decrease in energy production. The “Green” has moderately good values, so at least it is an economic decision, 6% of 1900 kWh of the best tracking systems means on the existing price of the electricity market, about plus 48.00 € per year. The construction of the sum umbrella – carries the construction with the 16 modules on an area of about 4m^2 . On the other hand 6% more efficiency by a green roof infrastructure on an area of about 4m^2 each year is a good profit. The amortization of the additional costs of the green roof will be refinanced after less than 5 years.

3.6 PV systems as umbrellas, air temperature on the rooftop under the PV cells

In the following picture the infrared-technology had been used to get temperature data of a full image. This technology had been adapted for measurements of living walls and green roofs (7, 8). In the figure 5 the temperature distribution on the roof at high rise sun on July 6th, 2004 is visible. The Bitumen roof, white colour in the centre of the picture, has a maximum temperature of about 38 degree C. The green roof surface is cool, with only 22 degree C. Under the PV – Cells in the shade, there are only 19.5 degree C. The dark blue colour of the PV-cells is the reflection of the sky temperature on the mirror like surface of the PV-cells and cannot be used here. The difference in the surface temperature of about 20 degrees between Bitumen roof and on the green roof, especially under the PV – cells is significant. In the back ground the tracking PV array – Cells.



all Vascular plants plant species (%)					
Av. height of all plant species (cm)	65	110	70	118	90
Av. cover of the genus "Sedum" typical for extensive green roofs (in %)	22	48	46	27	25
No of plant species benefited by the shade of PV – panels				7	17

Table 3: Information on the change in the flora on the extensive green roof 1999 – 2006 with and without PV panels

The species richness increases over the years. The number of plant species benefited by the green roof increased from 7 to 17. These are for example the following plant species (scientific names): *Erigeron annuus*, *Hypericum perforatum*, *Linaria vulgaris* and *Melilotus albus*. These plants grow all on the roof, but in the shade of the PV- the biomass is significantly higher. The typical *Sedum* species decreases in the slight shade. Close to the PV-panels a lot of working trails had influenced the vegetation structure.

4. Discussion

Green roofs and PV- technology can be used together. The panels shade parts of the roof and thereby reduce the sun exposure and high evaporation rates normally experienced on extensive roofs. Thus, this will reduce the drought stress for plants.

Direct sun on building surfaces ages conventional roof top materials. PV – panels need direct sun: so the installation of PV panels has a lot of benefits, like:

- If there is a green roof under the PV-panels there will be a wider range in vegetation stands; from full sun to half shade with shifting sun spots.
- The quantity of rainfall is the same on a roof with or without PV panels. However, PV panels add another distribution of the rain on the roof
- The growing media stores the rain and evaporates this water over time. This evaporation has a cooling effect, which in turn helps to cool the PV cells.

The vegetation of the extensive green roof under the PV panels changes from a *Sedum Acre* and *Album* dominated roof to one with a great variations in plant cover and size. The vegetation



changes from succulent vegetation stand to a vegetation type more commonly found along typical dry roadsides.

The Panels needs more maintenance than an extensive green roof. More pathways on the roof mean also more trampling disturbance of the vegetation.

The efficiency of PV-panels depends on various factors, as described here. At least there must be attention paid to details. For example, shade for several hours a day can reduce the efficiency significantly. The environmental cooling is one of these factors (3). Green roofs offer such a cooling effect to PV-panels. The number of the cooling rate can be measured like here, or calculated by the annual retention rate of the rain and the evaporation cooling of the green roof. The effect of the direct shade effect of the Cells can be measured, see as an example the infrared picture. PV cells are similar to umbrellas in a City street and reduce the direct influence of solar radiation and aging surfaces.

What about the higher efficiency of PV Panels on a green roof? The results of this first survey of combining both technologies summarized this effect with a mean of 6% yield. But there will be a range and lots of effects will be overlapping. PV technology and green roofs need detailed knowledge in both technologies. It will be good to continue these researches as well as getting results from other research sites to verify the results.

During the last five years about 80,000 kWh electrical energy output had been produced here on this project. In Germany the energy suppliers pays 0,457 € per kWh for the Energy to the private producer (see: www.bmu.de : renewable Energy source act). Everyone can calculate for himself what additional profit this combination means for him personally.

The layout of an optimized PV-power plant is a play with a lot of components. This presentation explains, that green roof technology is one of these components to play with. As well PV panels are components for sustainable roofscapes. PV panels are also a new challenge for Landscape architects and planners to find solutions for each project to combine these possibilities in the best way for each project. The opportunity to work with PV-cells can be on the one hand “design elements” on the other hand they can be purely functional and be placed on the roof in a way just to have maximum electricity output. There will be very different solutions if the intent is to produce a maximum of solar energy on an extensive green roof or if it is part of a roof garden structure with only some PV panels to get a decentralized opportunity to illuminate the roof or provide energy in the building. A close cooperation between several specialists will be helpful to find the right solutions. PV technology is fascinating, but it includes a huge number of details, which can be done in a wrong way.

This study explains, that the tracking PV construction can have much higher efficiency than the same PV-cells on a green roof have. But the costs for this tracking array as well the risk of wind disturbance is high, which means that tracking systems will only be a cost-effective approach in very few situations.

PV technology is not a must on a green roof like a roof garden - but under optimized PV – power plant green roof offers a better economy.



In most project situations the additional costs for the extensive green roof will be recovered by the higher electric power output over the first few years following installation. The PV cells are a long lasting technology, which will last for decades.

But in comparison to the calculated effects of Krauter (3, 4) with more than 10%, more experiments and much more monitoring must follow. If these results can be reproduced over longer time frames, green roof and PV installation for all Arabic countries will be one of the future markets in this combined Technology.

The vision of PV shaded roof gardens in Arabia is a vision and a challenge for enthusiastic green roof planners for the near future.

Acknowledgement:

Thanks to the peer reviewer, who spent a long time with draft versions of this contribution. Thanks also to the team of the Ufabrik, which is responsible to the well ongoing power production on the roofs, as well to the maintenance of the green roof as a green island in the City of Berlin and in supporting ongoing research

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www.ufafabrik.de

www.sonnenseite.com (Journalistic german site with a wide range of PV and environmental information)

www.bmu.de/english/renewable_energy/doc/6465.php (The renewable source act)

Types of inverter:

<http://www.wuseltronik.com/lewr.htm>

<http://www2.sma.de/index.php?id=1346&Dokumentenart=Short%20description>

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Bio-Information:

Manfred Köhler: Study and PhD in Berlin, Institute of Ecology, Technical University Berlin; Degree in Landscape Architecture. Since 1980 his scientific work is focused on Green building technology. He is Professor of Landscape Ecology at the University of Applied Sciences in Neubrandenburg since 1994.

Manfred Köhler is a Member of the German FLL (Guideline group “Green roofs”), FBB – Executive Board Member for foreign affairs, Vice president EFB, Member of GRHC and chairman of the World Green Roof Infrastructure Network, since 2005 (see www.worldgreenroof.org)

Werner Wiartalla: Dipl.-Ing. Physics. Since the very beginning in the 1980^s Werner W. is the responsible technical manager in the Ufafabrik. He has implemented a lot of sustainable technical solutions or has adapted these to the Ufafabrik. Examples are the Bio filter system, heating solutions and electric power saver. He is responsible for the development of the PV-project on the Ufafabrik.

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