HORZONTAL PV SYSTEMS AND CONTAMINATION OF MODULES, 1.5 YEAR EXPERIENCE WITH FRAMELESS MODULES IN "PV NORD"

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ABSTRACT: Horizontal PV systems become more and more important in the Built Environment. Several PV projects with (near) horizontal pv arrays, realized between 1995 and 2003 in the Netherlands have been examined by visual inspection, while in two projects the energy production was monitored before and after cleaning of the modules. In Rijswijk the 65 kWp Shell PV Pergola is in operation since December 2003. In the final horizontal design of the PV array it was possible to install 63% more modules and to produce 38% more kWh/m2 compared with the first conventional 'saw tooth' design. During 1.5 year of operation no effect was measured of contamination and of cleaning of modules on the energy production of this horizontal system. Also other systems confirm that the effect of contamination on horizontal (or with a low tilt angle) PV systems is very low, if glass laminates are used and if rain has access to the modules. Based on visual inspection is turns out better not to use or to be very careful with the use of module frames or profiles in horizontal PV systems as contamination accumulates and grows near the lower profiles. In transparent pv systems contamination at the back-side of the modules might be an esthetic problem.
Keywords: Module integration, Optical losses, Shading.

1 INTRODUCTION

The purpose of this study[1], which was carried out within the EU-supported PV NORD project, is to contribute to the knowledge about contamination of modules as a function of the tilt angle of PV arrays in the Built Environment in NW Europe, with a focus on horizontal or almost horizontal PV systems.

In Rijswijk (near The Hague) Shell International Exploration and Production b.v. has built a 65 kWp PV Pergola on the roof of one of her office buildings in the beautifully refurbished Shell Rijswijk Campus. For this PV Pergola the question how much energy will be lost by the increasing filth due to rain and pollution will be answered and what is the effect of yearly (or more often) cleaning of the modules.

In this study also several other PV projects with horizontal or near horizontal PV arrays, realized between 1995 and 2003 in the Netherlands will visited and studied, among others:

- Fire station in Houten
- Powerlight system at Madurodam, The Hague
- BP fuel station in Utrecht
- PV system at the Gemeentearchief Rotterdam
- One family house in Utrecht with both framed and frameless modules
- ECN office

Most PV systems have been examined by visual inspection only, while in the PV Pergola and the latter project the energy production has been monitored before and after cleaning of the modules.

[1] Important remark: This small study has been done in a limited time of only weeks; though the results are very interesting, they should be taken as indicative.

2 HORIZONTAL PV SYSTEMS

Horizontal PV systems become more and more important in the Built Environment. Depending on the location in Europe the production per kWp (& per square meter) PV is only 10-20% less than for an ideally tilted south oriented PV array. It is possible to install more PV and produce more kWh per square meter ground area. Also several problems connected to shading, wind load, water tightness, costs, esthetics of PV on flat roofs etc. are solved more easily than with tilted PV systems. Therefore it is relevant to study horizontal PV and issues connected to this, such as the degree of contamination, as well as innovative solutions such as the use of special films to avoid contamination.

Indicative calculations, changing parameters relevant for horizontal PV solutions, have been done with the simulation program "PVsyst". We looked into:

- the energy production per square meter for several tilt angles as well as horizontal and for several collector/ground ratios;
- the energy production per square meter with the back side of the PV modules ventilated, lightly ventilated and not ventilated;
- the energy production per square meter with the backside of the PV modules insolated;
- the energy production per square meter related to the mass of the PV module (glass/Tedlar versus glass/glass.

In the Netherlands and middle Germany the energy production per square meter decreases from the maximum at a tilt angle of about 40 degrees (south) to 86% for a horizontal surface. The collector/ground ratio at the same time may increase to 100% for horizontal (because there is no shading between the modules). In middle Europe for tilt angles of 30 to 40 degrees often a collector/ground ratio of 50% is chosen as optimal. For such a system with a maximum production per Wp (=**per square meter collector surface)** it is now easy to calculate the production **per square meter ground or roof surface**. For the Netherlands and middle Germany this is only 58% of the maximum possible energy

production (if the the ground or roof surface was covered for 100% with horizontal PV modules).

Or to resume it the other way around: a horizontal PV system in the Netherlands and Germany has an energy production of about 86% of the maximum possible per Wp (=square meter collector surface), but can have (compared with the same tilted system) over 70% (=1/0.58) more energy production per square meter ground or roof surface, if the horizontal surface is completely covered with PV modules (which is almost never the case).

The effect of ventilation at the back side of the PV modules is calculated to be relatively low. On a sunny day in middle Europe the difference of a well ventilated module versus a not-ventilated module is calculated (by PVsyst) to be maximal 10 degrees; this means a reduction in power of less than 4%. The energy production on a yearly base is maximal 1 to 2%. Light ventilation, such as under some PV roof-tiles are possible, will lead to energy production loss on a yearly base of less than 1% compared with a well ventilated system.

The effect of an increase of the mass of the PV module with a factor of two (as a model for the replacement of glass/Tedlar modules by glass/glass modules), while other parameters stay exactly the same, result in that the average temperature during the daytime is lower for the PV module with a higher mass. This means that the module with higher mass (say the glass/glass module) will have a higher energy production per Wp. The effect is much smaller than 1% on a yearly base.

3 SOME HORIZONTAL SYSTEMS IN HOLLAND

Before 1995 it was more or less ‘not-done’ to built:

- horizontal PV systems
- PV systems with east or west orientations
- several orientations combined in 1 system
- systems with not-ventilated modules or even insolated modules
- and a bit longer ago PV systems with laminates only.

Anno 2005 the theoretical advantages and disadvantages of horizontal systems as partly described above are mentioned by several authors in the past decade. Several systems have been built.

Not only there is clearly more potential due to a higher energy production per square meter ground surface, which raises in the end even the technical potential in a country, but also there are more market opportunities for PV in the Built Environment, such as:

- PV parkings
- on Dormer roofs,
- other roof types such as low tilted shed roofs
- it is possible to hide PV (camouflage architecture).

Owners of large horizontal roofs tend to have a preference for horizontal PV, see e.g.

- Blijdorp Zoo Rotterdam
- Several BP filling stations in Europe

Horizontal PV systems can add furthermore practical and cheaper solutions to wind load and water tightness problems. There is no shadowing between the modules; costs for BOS can be much lower while the underlying roof material is protected from UV light. And of course the architectural esthetics of horizontal PV is different from e.g. PV on tilted racks on horizontal roofs. Several horizontal systems in the Netherlands have been visited. Visual inspections and data-monitoring have been done during (yet only 1,5 year) on:

- 65 kWp Shell PV PERGOLA in Rijswijk
- Several pilot systems (~10 kWp) of framed and frameless modules Utrecht

and visual inspection only on:

- 175 kWp Gemeentearchief Rotterdam
- 24 kWp Fire station Houten
- 25 kWp Powerlight system in Madurodam
- ~18 kWp BP fuel station Utrecht

4 SHELL PV PERGOLA, RIJSWIJK, HOLLAND

The PV Pergola in Rijswijk was built as a sub-project of the so-called PV NORD project by Shell International Exploration and Production b.v. as a pergola on the roof of the central office building in the new Shell Campus. The PV array is 65 kWp and 742 m2, while the frameless PV modules have a 2 degrees tilt. In more detail:

- 318 Shell Solar S105 glass/white Tedlar modules (105Wp)
- 398 Saint Gobain/Shell Solar glass/glass modules (80Wp)
- Inverters: SMA Sunny Boy 21 x 2500W and 3 x 1700W
- Mounted horizontally as a ‘Pergola’ on the roof (design: Van den Broek en Bakema)
- PV modules and cells: Shell Solar
- PV Construction: Oskomera
- Mounting and DC installation: Oskomera
- AC installation: GTI

Photo 2: Shell PV Pergola in Rijswijk, Netherlands

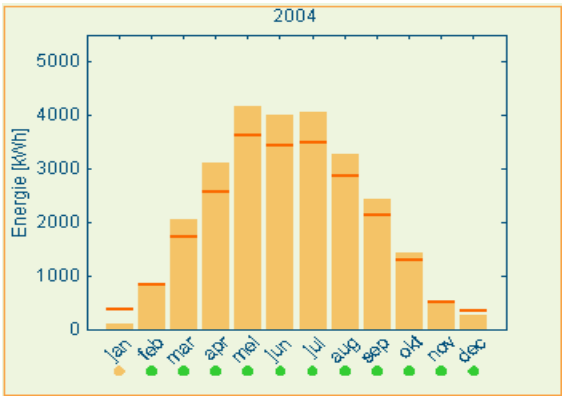
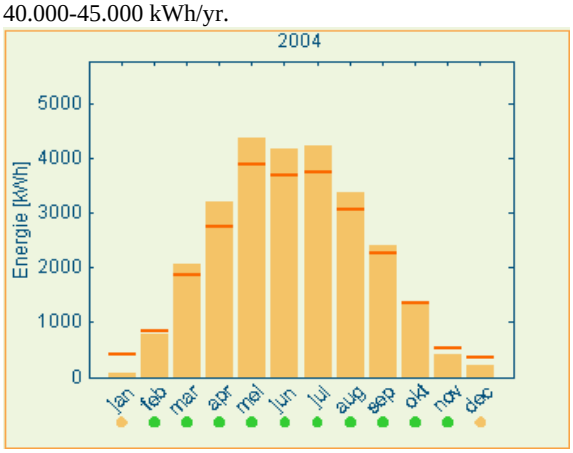


Figure 1 &2: Total production in 2004 in kWp per month for sub system 1 of 31,8 kWp of glass/glass modules (398 modules of 80 Wp), and sub system 2 of 33,4 kWp of glass/Tedlar modules (318 modules of 105 Wp). The red line indicates the expected production of 40.000-45.000 kWh/yr.



5 CONTAMINATION OF PV MODULES

The PV Pergola has been monitored before and after cleaning of the modules, while most other PV systems have been examined by visual inspection only. Especially for the Shell PV Pergola the owner of the building was very interested whether the system can do without any regular cleaning, as the cleaning of modules was expected to be very expensive due to stringent safety regulations on the Shell Campus.

After the first visits it became clear that some of the disadvantages of horizontal surfaces, such as the easy collection and long stay of leaves and snow, but especially bird droppings makes it necessary to clean the modules at least sometimes. Bird droppings on PV probably have a simple co-sinus relation with the tilt angle, which shows that also tilted PV systems have to be cleaned every now and then. Also when rain has no free access to the PV panels, filth can accumulate very quickly, as was reported in another PV NORD project.

5.1 Cleaning PV modules at the PV Pergola

In this limited study the effect of contamination was simply evaluated by cleaning 5 strings of modules (out of in total 24 strings) of the PV Pergola:

- comparison of the production of each of the 5 strings before and after the cleaning
- comparison with other strings after the cleaning
- visual inspection of modules and cleaning cloth

The conclusion is rather simple but also interesting:

No effect on the energy production could be measured. Of course one has to remember that we are looking only at 1.5 year of operation and longer term effects are not clear yet.

The cleaning of the PV Pergola, 65 kWp and 750 m2, will take for one person only 3 to 4 hours.

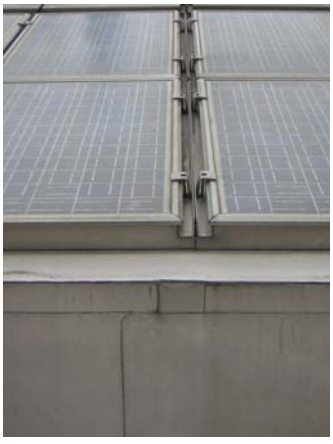
This conclusion is confirmed during the visits to the other projects. There is almost no effect on the energy production (SolTile project in Utrecht) and there are only limted effects on visual contamination of modules in all projects where frameless modules were used and where the rain water flow on modules were not hindered by other aluminum profiles.

Photo 3: SolTile2 PV roof integration without modules frames or aluminum profiles (Utrecht-1, Netherlands)

As all the projects were relatively young this still does not mean that there are no long-term effects.
In all projects glass/Tedlar or glass/glass modules/laminates were used, which means that the above is only valid for glass modules/laminates.
The above is in line with the experimental study of TNO [ref.1]. This study shows that a clear relation between the contamination of PV module glass and the tilt angle of the glass could not be found, while the effect of contamination on the transmission of the glass was less then 3% during a one-year period in the Netherlands, and the effect on energy production of a float glass PV panel would be less than 2%. The study also indicated that the relation between tilt angle and contamination for plastic foils was existing while the effect on the transmission could be as high as 7%. The study paid also limited attention to the effect of structured and anti-reflection glass and to the effect of coatings.

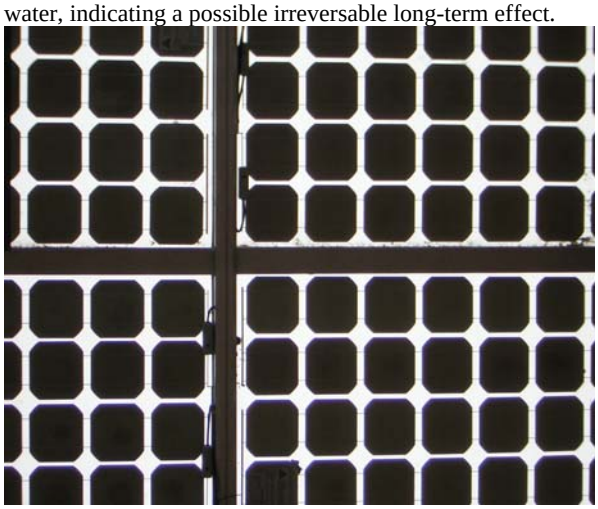
5.2 Effect of module frames and profiles

In all projects with framed PV modules (Utrecht-2, Rotterdam) or where aluminum profiles for the integration of PV in the façade were used (Petten, Houten), there was a clear contamination visable. In Utrecht no clear effect on energy production was measured yet, indicating that the



effect on the energy production is low.

In the case of the Gemeentearchief Rotterdam the panels are placed between exactly horizontal and about 1% tilt: this means that due to the module frames rain water can not flow away at all, and it is a wonder that the effect is not much more. During the visit of this oldest of the 8 visited projects, on the one hand the filth was less than I expected on the other hand it was difficult to remove some of the dust with a dry towel or with normal water, indicating a possible irreversable long-term effect.



In the 3 other cases the filth very clearly accumulated near the lower part of the module frame or profiles (see picture). In Utrecht-2 it could be also observed that the accumulation of filth was growing above the water level connected to the upstanding edges of the module frames.

5.3 Frost and condensation

One other interesting effect was discovered during early mornings in the PV Pergola and Utrecht projects. Both the upper and the back sides (especially of the glass/glass modules) were suffering from frost and condensation due to thermal radiation to the 'cold' nightly sky. On the outside of the module the frost and condensation evaporates or flows away, while the next rain can clean the glass again; at the back side of the module the condensation can only evaporate leaving filth behind. This was confirmed in all projects with (semi-) transparent PV. The effect is not massive but very visible. Of course this does not affect the energy production. But one can conclude that 'See-through' PV systems will make you seeing also filth accumultated both on the outside and inside of the façade. Cleaning of the inside can if wished depend on the frequency in which the windows are cleaned, but as the requirement for windows are much stringer, once per year should be far enough for a see-through PV system.

6 CONLUSIONS AND RECOMMENDATIONS TO MANUFACTURERS OF PV BUILDING COMPONENTS AND PV SYSTEM OWNERS

For horizontal PV systems is can be concluded that:

- the advantages are bigger than disadvantages
- there are more applications and therefore more potential in the Built Environment
- one can install 60-100% more kWp PV and produce 35-70% more kWh per m2 roof or ground area
- there is on the short term no contamination measurable
  - if a glass laminate is used
  - if no module frames or profiles are used
  - if rain has access to the PV array
- the cleaning can be done in 0.5 - 1 person.day per 100 kWp or 1000 m2.
- no or low correlation is found between the tilt angle and the accumulated filth in the projects.

Again under the restriction that the results of this study should be seen as qualitative and indicative the following recommendations can be made.

For horizontal PV building components it is recommended:

- to develop PV building components/modules for horizontal (roof) systems without frames / profiles (upstanding edges are 'forbidden') or to develop new frames without these problems
- to develop horizontal or almost horizontal PV integration concepts with at least 50% more PV per m2 roof
- to investigate and develop 'Walk-over' modules, e.g. with stronger thicker glass, as up to 100% more PV can be place on a flat roof. An example is Powerlight
- to use glass, as this is for the time being the preferred material. More research is needed on the important interesting subject of plastics.
- to be careful with anti-reflection glass. The effect of anti-reflection glass (Rotterdam) and a clean shield coating (no projects visited) is unclear. Ref.1 claims only a limited correlation with the contamination. More research is recommended here.
- to read the TNO-study/experiment 'Influence contamination on the energy production of PV elements' (2003, in Dutch)
- to take in account that there is room in the market place for new PV building components/products both
  - horizontal (1-2 degrees) such as Powerlight
  - almost horizontal (3-10 degrees)
- to clean a horizontal PV system at least yearly, as it can be done very quickly, as long as the long-term effects of not-cleaning are not clear yet. During this yearly cleaning at the same time a visual inspection can be done, while leaves, bird droppings and other can be removed. For NW Europe (depending on rain and irradiation) it is recommended to do the cleaning in May or June every year.

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