EVALUATING 5-YEARS PERFORMANCE MONITORING OF 1 MW BUILDING INTEGRATED PV PROJECT IN NIEUWLAND, AMERSFOORT, THE NETHERLANDS

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ABSTRACT:
The performance of about 400 decentralised PV systems has been evaluated for a period of five years (2001-2006). The systems are situated in the urban area Nieuwland in the town of Amersfoort in the Netherlands and are part of one of the largest decentralised PV projects in the world. The evaluated systems are situated in eight sections and are characterized by different architectural designs, tilt and azimuth angles. In six of the sections the majority of the systems perform well. Data indicate that in those cases there is no substantial lowering of the performance during 5 years. However, several individual systems in those sectors do not perform well. Often defects in the PV system or changes in the roof construction are the cause. For example, string errors are not recognized as such and as a consequence not repaired. In two other sections the performance of the systems is insufficient, but no clear explanation could be found.
Keywords: PV system; performance; monitoring

1 INTRODUCTION

The development of the 1 MW building integrated photovoltaics (BIPV) project in Nieuwland, Amersfoort started about 10 years ago [1]. It is the first and also one of the largest large-scale decentralised PV projects in a newly built living area. More than 500 photovoltaic systems with a total power of 1.3 MWp were installed on residential houses, apartment blocks, schools and a sport hall. The installations were completed in 1999-2001. More than 450 of these systems were monitored during the first years [2-4]. This paper will focus on the evaluation of 5 years of performance monitoring of the Nieuwland project. This work was carried out within the PV-UPSCALE project, supported by the Intelligent Energy Europe programme, in which experiences and lessons learnt on urban applications of PV are collected and disseminated.

Monitoring the performance of PV systems is relevant for both the owner of the system as well as the PV community. The owner of the system could prevent energy and economic losses if he/she is timely informed about a failure or problem with the PV system. It is relevant for the PV community to be informed on the performance of PV systems, especially in the case of Nieuwland, which was one of the first large-scale decentralised building integrated PV projects. Experience from past projects can help to improve the quality of new projects and to avoid problems in current and future large-scale projects.

In 2001 the installation of more than 1 MW PV in the newly built area “Nieuwland” in Amersfoort, the Netherlands was completed. The PV project (as part of the overall housing development by the municipality of Amersfoort) was initiated and carried out by the energy company ENECO (formerly REMU) with financial support of SenterNovem and the European Commission [4].The Nieuwland project consists of building integrated and grid connected PV installations, with different

Figure 1: Systems in Section K1 [5]

Table 1: PV systems installed on houses in Nieuwland; 486 systems totaling 1.321 MWp [5].

Sector	Nr of syst.	Size (kWp)	Total size section (kWp)	Tilt Angle
K1	99	3.49 3.93 4.36	377	23
K2	38	2.14	88	20
K3	36	3.04	97	25
K4	32	2.73	87	20
N2	125	2.00 2.28	258	25
N3	24	0.81	32	90
N4s	96	2.66	255	70
N4r	23	2.05	47	20
$O^{schools}$	10	2.57	26	23
O^{other*}	*3*	-	*54*	-

* not considered

architectural and system designs in each of the sectors. Figure 1 shows an overview picture of one of the sectors. The systems have different architectural designs, installed power ranging from 0.8 to 4.4 kWp per house and tilt angles ranging from 20 to 90 degrees. In Table 1 the number of systems in different sections, their sizes and tilt angles are listed. Section O consists of school buildings, while all the other sections listed consist of family houses. Almost all of these systems are monitored with the Eclipse monitoring device [5]. Installations on other utility buildings are not shown. The systems in the O and K sectors are owned by Eneco, while in the N sectors the house owners own the systems.

Our analysis consists of two parts. Firstly, the developments over time of systems that do not have any defects are analysed. The trends in performance ratio are discussed. Secondly, the causes for the unsatisfactory performance of part of the systems are briefly identified. There are simple reasons, like shading or a high tilt angle, but also more complex reasons. We will examine and discuss the underperformance of the systems.

The methodical approach will be described in section 2. In section 3 the results will be presented. Conclusions and recommendations are shown in section 4 and 5.

2 METHODOLOGY

2.1 Method

The PV yield is recorded by ENECO using one Eclipse solar display for every system. The Eclipses record the power output of the PV systems on a daily basis [4]. Every year performance data are gathered from the Eclipses and reported by Ecofys. In the last five years data have been extracted successfully for at least 394 out of 465 systems with an Eclipse. The monthly energy yields and performance ratios from January 2001 up to February 2006 were used for the analysis.

The performance of the systems is evaluated on basis of the 'Performance Ratio'. The Performance Ratio (PR) is defined as follows:

$$PR = \frac{\eta_{sys}}{\eta_{stc}} = \frac{\dfrac{E_{fi}}{H_i \cdot A}}{\dfrac{P_{stc}}{G_{stc} \cdot A}} = \frac{E_{fi} \cdot G_{stc}}{H_i \cdot P_{stc}}$$

With:

η_{sys} = system efficiency
η_{stc} = efficiency at STC
E_{fi} = energy yield (kWh)
H_i = solar irradiation in plane-of-array (kWh/m^2)
A = area of system (m^2)
P_{stc} = nominal module power (Wp)
G_{stc} = irradiation under standard test conditions (= 1000 W/m^2)

The performance ratio is an indicator for the losses in a PV-system, which depend on modules, inverters, irradiation patterns and other factors like shading, cabling losses, etc.

Both monthly energy yields and in-plane irradiation data were provided by Ecofys. The energy yields were recorded by Eclipse solar viewers based on kWh-counters with pulse-output. The monthly in-plane irradiation was calculated by Ecofys on basis of global horizontal irradiation data from the nearest KNMI station (Royal Netherlands Meteorological Institute). It is calculated by an in-house computer program based on Perez [6] and Orgill and Holland [7]. The irradiation calculation does not include a correction for reflectance. The irradiation that reaches the solar cells is therefore approximately 6 % lower for the façade systems and 4 % for the other systems [8].

Due to a problem with the capacity of the data logger a large amount of measurement data between November 2004 and February 2005 is missing.

2.2 Accuracy of PR calculation

There are several sources of uncertainty in the calculation of the performance ratio. Firstly the energy yield is measured by kWh-counters with an accuracy of 2 %. The second cause for uncertainty is that the nominal module power may differ for different modules. Also some degradation may be present. The last but most import cause of uncertainty is the calculation of the in-plane irradiance. This is based on measured global horizontal irradiation data measured by the Royal Netherlands Meteorological Institute (KNMI) in De Bilt, which is approximately 20 km from Amersfoort. The error introduced by this conversion is approximately 3.6 % [9]. The conversion into in-plane irradiation adds even more uncertainty, especially for larger tilt angles. We compared the monthly in-plane irradiation measured with a reference cell with the simulated in-plane irradiation for the year 2001. The difference between measured and simulated in-plane irradiation was, after a rough correction for reflectance, between 4 % and 8 % on a yearly basis. A large share of this difference may be caused by a large systematic deviation of the irradiance measurements of the reference cells. The Eclipse monitoring still yields interesting and useful results and serves the purpose it was originally designed for: an operation and maintenance tool. However, for detailed performance analysis the accuracy is too low. Most results and conclusions will therefore be indicative.

3 RESULTS

3.1 Introduction

The monthly PR's for 394 PV systems in Nieuwland were available for our analysis. In general the PR's were lower than expected. Note that reflectance is not included in the irradiation used to calculate the PR, therefore the real PR is approximately 4 % larger. In two sectors the performance of the systems was insufficient. In the other six sectors the majority of the systems functioned reasonably well, but some problems with individual systems remained.

In section 3.2 we will describe the performance in sectors that perform well. In sections 3.3 and 3.4 the sectors in which insufficient performance is encountered are described. In section 3.5 we will give an overview of the results.

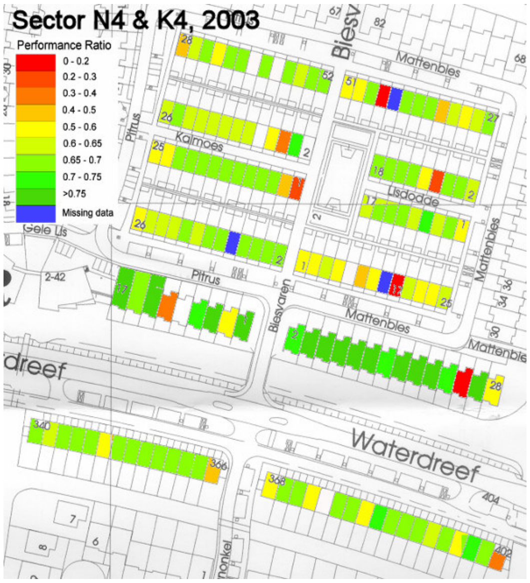

Figure 2: PR distribution in sector K4 and N4 for the year 2003.

Figure 3: Section K4

3.2 Sectors with a good performance

In this section we show examples of systems in the sectors N4, K4, K3 and O in Nieuwland. A large share of the systems in these sections is functioning quite well. An example of two sectors (K4 and N4) in which the systems are working quite well is shown in Figure 2 for the year 2003. A pseudo-colour map clearly shows that the majority of the systems have an average PR for 2003 larger than 0.65 (coloured green in Fig. 2). There are several systems that do not function well or that have missing data (coloured red in Fig. 2). Also, some systems have a lower PR than expected (coloured yellow in Fig. 2. Figure 3 shows a photograph of part of the sector K4.

An example of the PR development of 10 systems in section K3 is shown in Figure 4. There is a large variation in the PR over time. One can see a repeating pattern over the months per year. This may be caused by 1) the real variation of the PR with irradiation and temperature over the months, and 2) by a systematic error caused by the calculation and monitoring method. Note the following:

- Data for a lot of systems from October 2004 to February 2005 is flawed or missing, due to capacity issues with the data logger.
- The PR in several winter months is lower. The systems in K3 are installed in rows. The low sun in winter months causes shading. An additional effect could be snow for several days in winter.
- The performance ratio in September and October is larger than 0.7.
- PR = 0 could mean the system is not functioning or not connected, or that there is no data available.

There is a clear pattern in the data and we expect that a large part of the error in the PR is similar for the same months in different years. Nevertheless there is some variation in the PR's for the same month over the years. This variation is small for e.g. June (-1 % to + 1.6 % compared to the average PR for June over 5 years for the ten best performing systems) while it is much larger for e.g. May (-2 % to +4 %). This variation can be caused by temperature and irradiation variations and changing uncertainties over the different years. The trend does not show a deteriorating PR and therefore we do not think there is substantial dirt accumulation or loss of quality of the system.

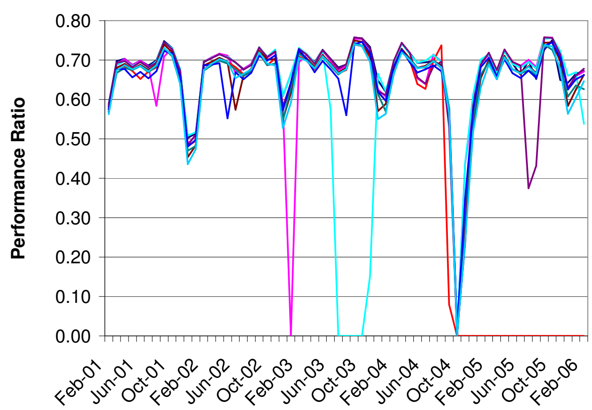

Figure 4: PR over time for 10 systems in Section K3

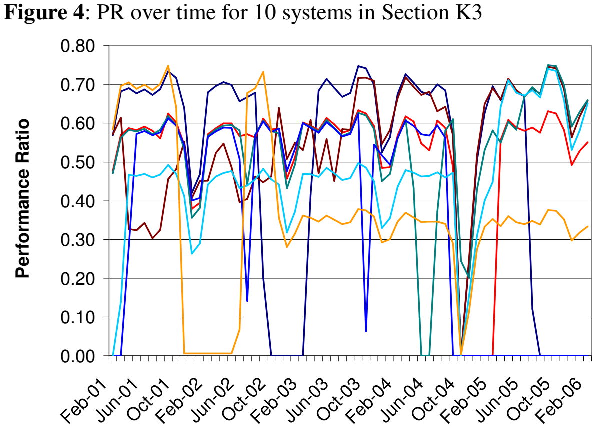

Figure 5: String errors in several systems in Section K3

Figure 6: School houses in sector O

In Figure 5 some systems with string errors are shown. The systems in section K3 have 6 strings. The reduction of PR by 1/6, 2/6, and 3/6 can be clearly discerned. The PV owner does not notice this, which results in significant and continuous energy losses.

In sector O 10 'school-houses' have been built with integrated PV systems. These systems have been monitored from July 2003 to February 2006. In Figure 7 the performance ratios of the 10 systems are depicted. For several systems no data was available for certain monitoring periods. Nearly all systems perform well with a PR of circa 0.7. The variation in PR is caused by the uncertainty in the irradiation (larger effect) and temperature effects (smaller effect). One system has a PR that is about 18 % lower than for other well working systems. The systems have 5 strings, so it is safe to assume that one string has been defective since the installation of the system. Also for this systems it is visible that there is no deteriorating trend in the performance.

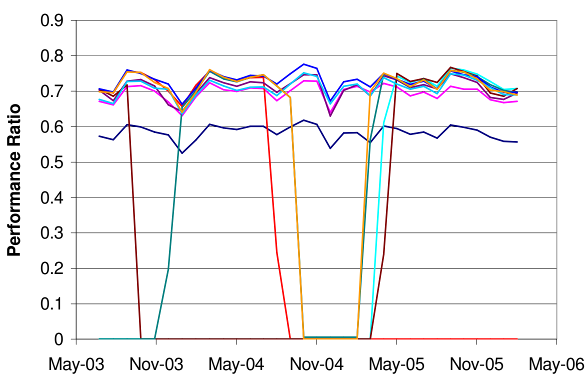

Figure 7: PR of systems in Section O

3.3 Problematic sectors

In Figure 8 the PR distribution of the 97 systems in sector K1 for the year 2005 is shown. It is clear that only a very small fraction of the systems have a PR that is larger than 0.65. A research report from Ecofys in 2005 pointed out that several strings are not always working properly. It is suggested that corrosion of the connectors are causing this problems [10]. More research is needed to evaluate these problems.

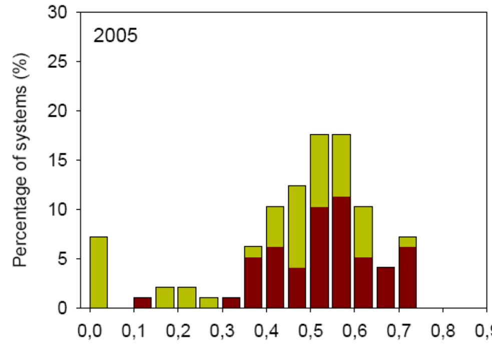

Figure 8 The 97 systems of section K1 are grouped into Performance Ratio ranges, which run from 0 to 0.05, 0.05 to 0.1 etc. The systems that have been operating for the entire time frame are shown in brown, those that have data missing for several months (monthly energy yield is less than 5 kWh) are shown in green. The shift of the distribution to the left as well as the relatively high portion of green indicate the existence of severe problems. The considered time period runs from January 2001 to February 2006.

3.4 Analysis with the help of Google Earth

The systems on the houses in sector N2 consist of seven rows of three modules. Originally these rows were placed some distance apart as can be seen in the middle three houses shown in Figure 9. Also in this sector the PR graphic plots and PR distribution table showed the existence of defects and/or other causes for a low PR. Here the comparison of old aerial photos with Google Earth maps showed clearly the main cause. An extra floor was added for several houses. The PV systems have been relocated on this added roof, of which the area is smaller than the original roof area: increased shading is the result. Also the higher roofs shade the lower adjacent roofs significantly as can be seen in the photograph for the situation in the morning. The result can be found in the measurement data.

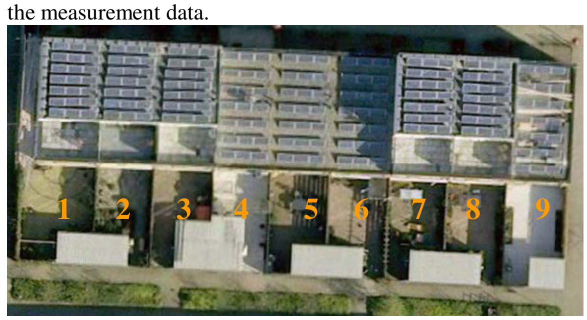

Figure 9: Extra floors in Section N2, image from Google Earth.

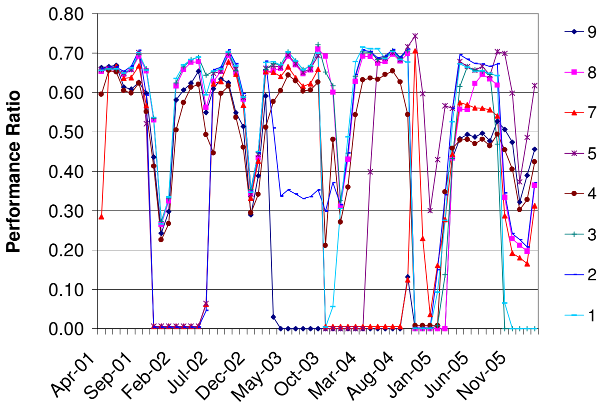

Figure 10: PR over time for systems shown in Figure 9. Values in the winter 2004-2005 are partly missing. In winter 2005-2006 it can be seen that systems 2, 7 and 8 have a lower PR due to increased shading, since the rows of PV modules are closer together. Systems 4 and 9 have a lower performance in summer, probably due to increased shading in the afternoon from neighbouring systems.

3.5 Overview results

Table 2: Results

Sector	Perfor-mance
K1	-
K2	-
K3	+
K4	+
N2	+
N3	+
N4s	+
N4r	+
O[schools]	+

An overview of the results of all the systems for the years 2002 to 2005 is shown in Figure 11. These figures illustrate that a lot of systems do not operate very well. A large share of these systems are in the sectors K1 and K2 and may be due to problems with the connectors. Furthermore most also well operating sectors have several systems with string errors. The error bar with PR is 0 may be due to either missing data or broken systems. Please keep in mind that the reflection is not included in the irradiation, therefore the real PR is approximately 4 % larger.

4 DISCUSSION

The Nieuwland 1 MW PV project was a 'first of its kind' in the world; never before had a BIPV project of such a scale been implemented. From an architectural point of view, the project was a big success. Many visitors from all over the world have visited the site. As of today, the project is receiving visitors from all over the world. For the Dutch government the Nieuwland project especially was done to encounter possible architectural, urban planning and grid bottlenecks. Especially with regards to this goal the project was very successful. Despite all expectations there were no major bottlenecks: all architects and urban planners could easily work with PV as a building component if they can have access to sufficient information to carry their work professionally.
However, the after-care of the systems has been more time consuming than anticipated and it looks like the growing pains are not over yet. It looks like the connector problems are causing significant part of the underperformance [10]. Part of the connectors causing

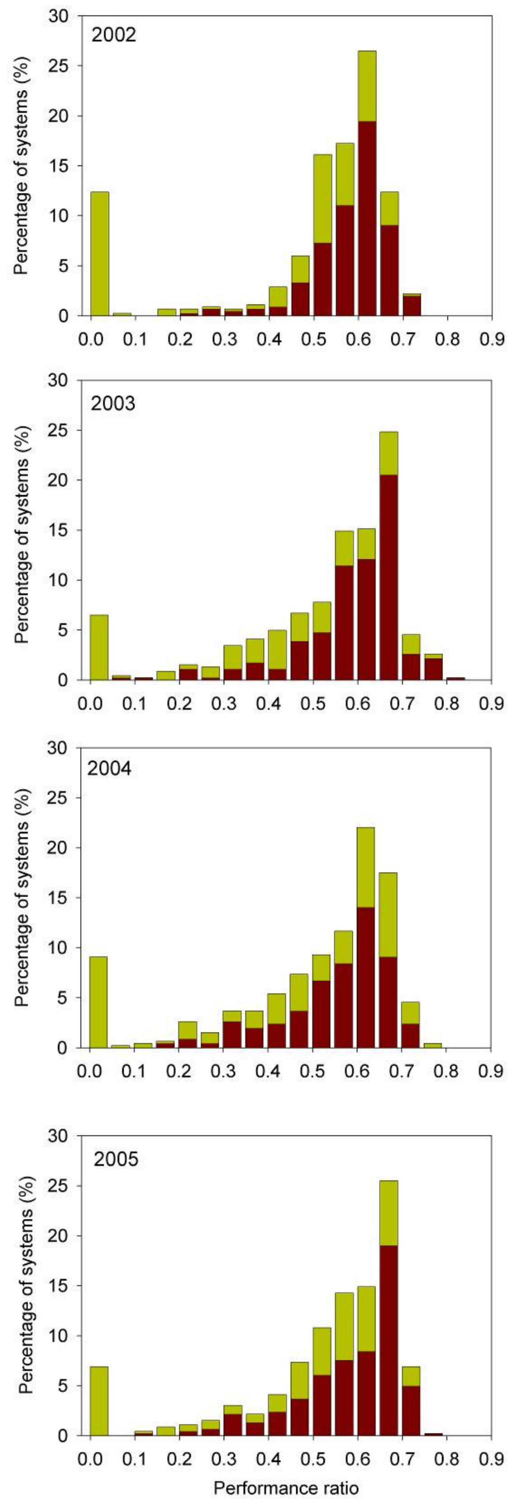

Figure 11: More than 350 systems are grouped into performance ranges over the years. The systems that have been operating for the entire time frame are shown in red, those that have data missing for several months (monthly energy yield is less than 5 kWh) are shown in green. The considered time period runs from January 2001 to February 2006.

the string problems have been replaced, but it looks like this has not been sufficient. This should be investigated, but this will be difficult and time- consuming because it requires panels to be lifted from the roof.

Utility Eneco owns 45 % of the systems (55 % of peak power) and has an agreement with home and PV-system owners to take care of the other 55 % of the systems. It turns out that yearly monitoring and inspection rounds (the current practice in this project) has not been sufficient to keep system outage down to an acceptable level. Eneco has offered inhabitants of the PV-homes tools to check the performance of their system, either through a display in their homes, the Eclipse [11] or through the 'Sundial' internet service to keep track of the performance of their system [12]. However, this has not resulted in any significant error reporting by inhabitants. Lack of ownership and feeling responsible (they did not make the investment) and lack of substantial financial repercussion (no high feed-in tariffs) are likely causes of this behavior.

5 CONCLUSIONS

We have presented an overview of monitoring results for one of the largest building integrated PV projects realized in the urban area Nieuwland of Amersfoort, the Netherlands. Our conclusions are the following:

- In the majority of sectors the majority of systems perform well, this holds for sectors K3, K4, N2, N3, N4 and O.
- In the above-mentioned sectors there is a significant amount of systems that do not perform as expected. Several of these have string errors. System failures causing partial energy loss are often not noticed and/or repaired and can linger on for years.
- The systems in sector K1 and K2 do not live up to the performance expectations, problems with connectors are expected to cause a large part of this problem.
- For systems without a clear defect there is no substantial degradation or lowering of the PR visible over the 5 year period. Although the uncertainty in the PR is large, we expect a large share of the error to be systematic. By comparing the PR in months with high energy yields in sequential years, we feel we can exclude a large part of this systematic error.

On the approach we conclude that:

- the calculation and monitoring method used has led to a systematic error in the PR values that was too large to detect subtle effects like system degradation
- nevertheless the plotting of PR graphics can indicate and identify many defects and others problems or changes (the purpose for which it was originally designed)
- the presentation of PR distributions is also a helpful instrument to indicate the existence of problems
- while the use of aerial pictures such as nowadays easily available through Google Earth of Google Maps is an ideal instrument to identify problems and causes related to BIPV aspects.

An in-depth analysis to establish the causes for the underperformance of many systems clearly is needed, and is presently conducted. It can be concluded that (1) a project like this either needs remote monitoring, enabling a more adequate response to malfunctioning, or requires more involvement from inhabitants (2) attention should be paid not only to robustness and quality of PV-modules and inverters, but also to more mundane parts like connectors.

6 ACKNOWLEDGEMENTS

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