Performance evaluation of the 1 MW building integrated PV project in Nieuwland, Amersfoort, the Netherlands

January 2001 – February 2006

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Project: PV-UP-SCALE

Disclaimer
The limited timeframe available for conducting this research did not allow for a full analysis of the causes of the underperformance of a part of the systems in Nieuwland. We therefore would like to treat this report as confidential, until a full analysis has been conducted.

Contents

Acknowledgement

We would like to thank Adriaan Kil and Edith Molenbroek of Ecofys for providing the measurement data.

Summary

The performance of 463 decentralised PV systems with a total installed peak power of 1.2 MWp, 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.

An overview of the results of all the systems for the period 2002 until 2005 is presented in the graph below. This figure illustrates that a lot of systems do not operate very well. A large share of these systems are located in two sectors: K1 and K2. It is suggested that corrosion of the connectors are causing the problems. Furthermore there are several systems with string errors in sectors that function well. Please keep in mind that the reflection is not included in the irradiation, therefore the real PR is approximately 4 % larger.

For this period 92 % of the monthly energy values were available; 14 % of these monthly energy values were zero. Because data has not been extracted successfully from several dataloggers 8 % of the monthly values are missing. For more than 70 % of the systems a PR of 0.7 was expected and for 95 % of the systems a PR of 0.65 or higher was expected. Only a very small part of the systems has a PR higher than 0.7 and between 15 and 32 % of the systems have a PR of 0.65 or higher. Furthermore, we found that in several sectors the frequency distribution of the performance is very broad.

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. However, the after-care of the system has been more time consuming than anticipated and it looks like the growing pains are not over yet. 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 (Molenbroek, 2000) or through the ‘Sundial’ internet service to keep track of the performance of their system (Molenbroek, 2002). 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.

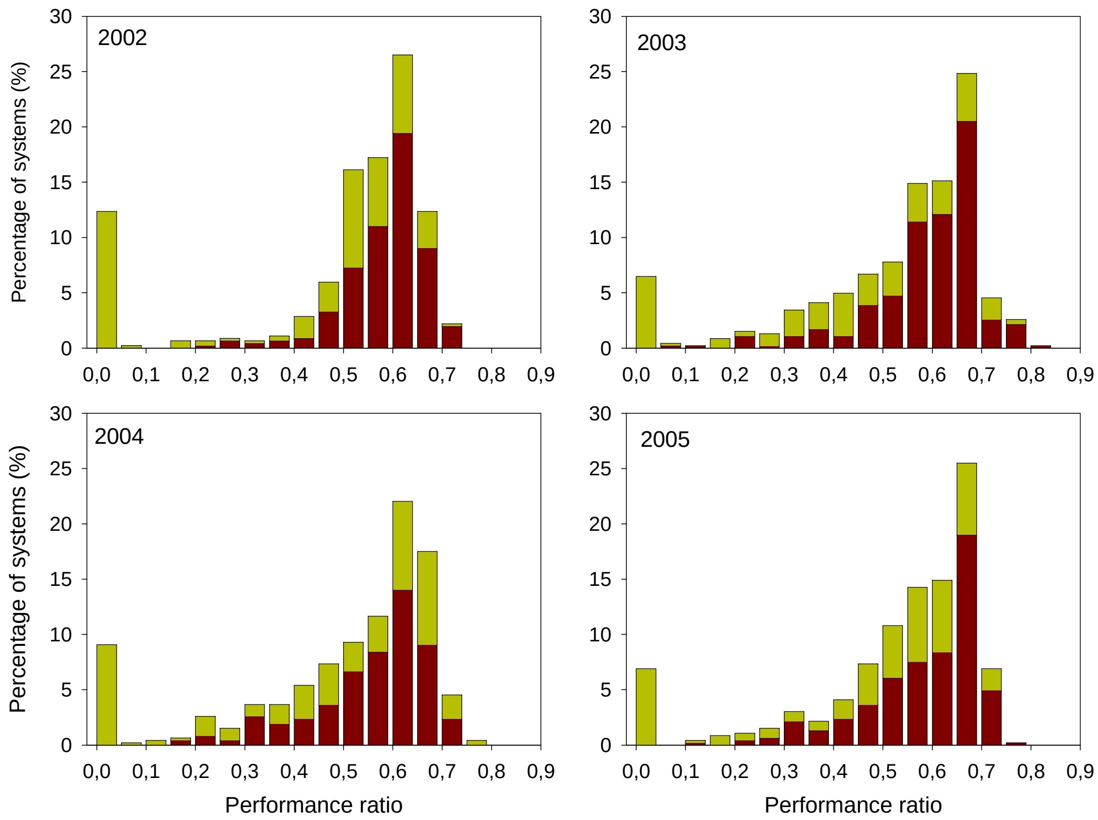


Figure: The systems which have been operating for the entire time frame are shown in red, those which have data that is either zero or missing for several months (monthly energy yield is less than 5 kWh) are shown in green. The performance ratio is only calculated over the time frame with monthly energy yield > 5 kWh. The considered time period runs from January 2001 to February 2006.

Our main conclusions on the performance from the PV systems in Nieuwland 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. 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.

1. Introduction

The development of the 1 MW building integrated photovoltaics (BIPV) project in Nieuwland, Amersfoort started about 10 years ago (Vlek, 1998). 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 (Molenbroek, 2000; Vlek, 2002; Kil 2004). This study will focus on the evaluation of the performance monitoring of the Nieuwland project between January 2001 and February 2006.

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 (Kil, 2004). The Nieuwland project consists of building integrated and grid connected PV installations, with different 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 (Kil, 2002). 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.

Table 1.1: PV systems installed on houses in Nieuwland; 486 systems totaling 1.321 MWp (Kil, 2002).

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

Our analysis consists of two parts. Firstly, the developments over time of systems that are performing well 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.

In Chapter 2 the methodology used in this report is presented. In Chapter 3 to 11 the performance details for every section in Nieuwland will be analysed. The conclusions and the discussion is presented in Chapter 12. Finally in the appendix, yearly performance maps of all PV systems are displayed for every year. These maps give a quick overview of the performance in a certain sector in a certain year.

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 (Kil, 2004). 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:

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

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 (1987) and Orgill and Holland (1977). 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 (Sjerps-Koomen, 1996).

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 % (Ramaekers, 1996) 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. Section K1

Section K1	Waterscheerling and Waterviolier
Number of systems (monitored)	97
Rated Power (per array)	3.495 kWp (46 systems) 3.932 kWp (33 systems) 4.369 kWp (18 systems)
Module manufacturer and type	Shell Solar IRS75LA
Number of modules (per array)	48 54 60
Area	33 m^2 37 m^2 41 m^2
Inverter type	ASP TCG4000/6
Nr of strings	8 9 10
Location	Sloping roofs
Integration system	BOAL
Orientation	187 °
Tilt angle	23 °
Total power (monitored)	369 kWp
Monitoring data for period	January 2001 to February 2006

Guaranteed performance of 617 kWh/kWp

In Section K1 only 1 system has functioned sufficiently well during the whole period. Between November 2001 and May 2002 the system was down. The average performance ratio for this system, excluding November 2001 to May 2002, is 0.68.

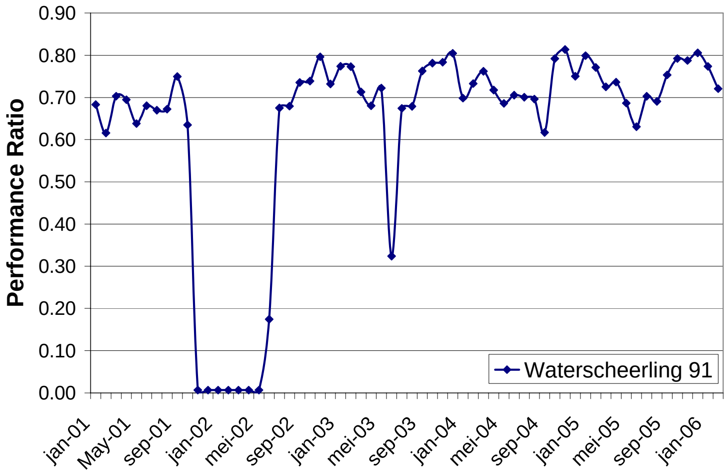


Figure 3.1 PR for Waterscheerling 91 in section K1

In Figure 3.3 the frequency distribution is shown for the annual PR on basis of the months the system produces energy. The green bar indicates that for one or more months energy yield data is missing or zero. The expected PR for this sector is 0.7. A quick overview of the average yearly performance ratio can be seen on the performance maps in the appendix.

It is clear that only very few systems have a performance ratio higher than 0.7; a large share of the systems is not functioning as expected. Firstly the share of systems with a PR larger than 0.6, declines from circa 50 % in 2001 to about 20 % in 2005. Secondly, the frequency distribution of PR's is very broad after 2003, there are a lot of systems with a PR lower than 0.45. In figure 3.4 the distribution of how many months of data are missing (red bars) or zero (green bars) is shown.

An example of the PR development over the five years for several PV-systems equally distributed over the performance scale is given in Figure 3.2. Note that data for most systems is missing from November 2004 for about three months, due to problems with the dataloggers. From the graph it can be seen that for many systems for certain periods one or more strings may not have been operating well.

Detailed measurements for 4 systems in section K1 and K2 in May 2005 showed that for all systems one or more strings did not deliver any power. After turning the inverter off on both DC and AC side and turning it on again, all strings worked. These problems do not seem to be caused by the inverter, since the strings are connected parallel to the inverter and since it happens for both ASP inverters in Section K1 as for Mastervolt inverters in Section K2 (Ecofys, 2005)

The cause of these problems is expected to be corrosion of the connectors (Welschen, 2007). Part of the connectors causing the string problems have been replaced, but it looks this has not been enough. This should be investigated, but this will be difficult and time-consuming, because it requires panels to be lifted from the roof.

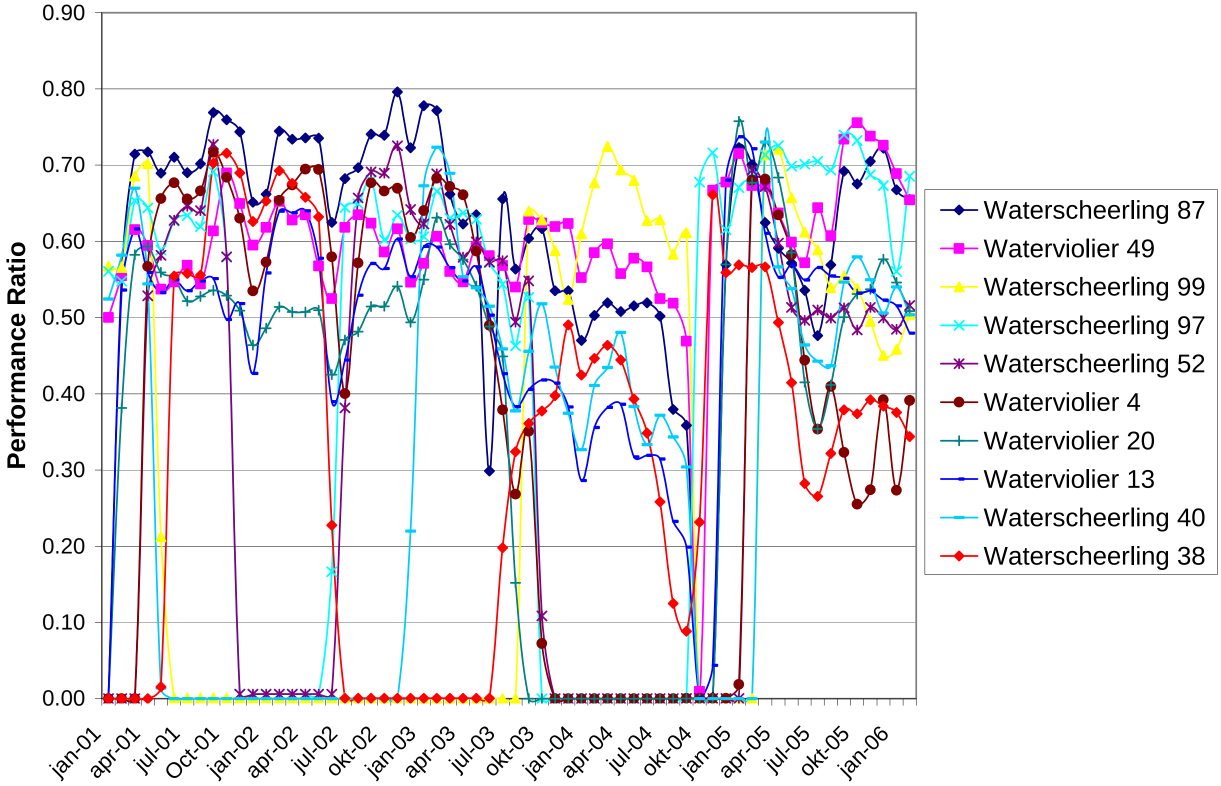


Figure 3.2 **PR's for several systems in Section K1 from January 2001 to February 2006**

Frequency plot of PR's in Section K1

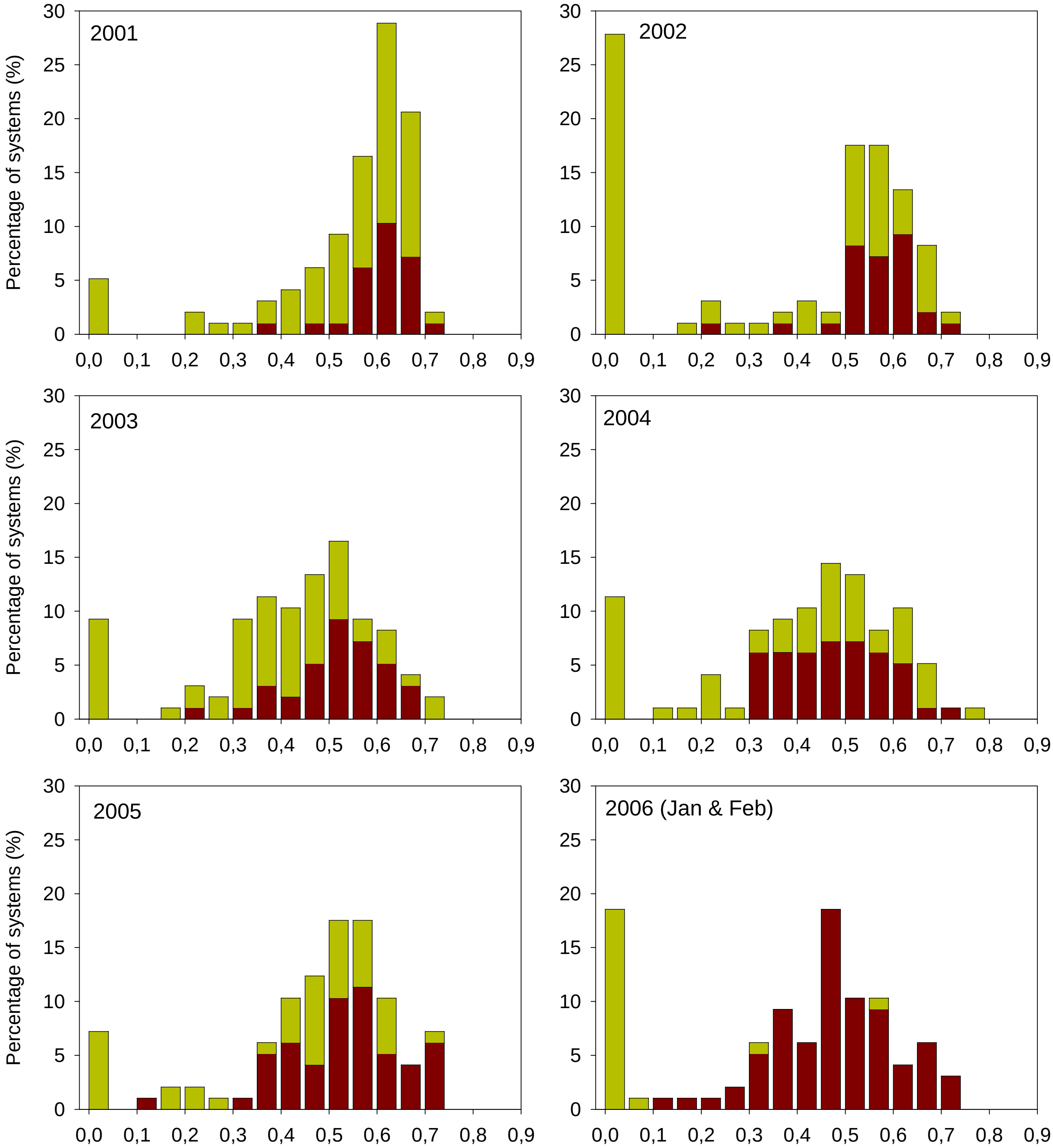


Figure 3.3 The 97 systems of section K1 are grouped into Performance Ratio ranges, which run from 0 to 0.05, 0.05 to 0.1 etc. The systems which have been operating for the entire time frame are shown in red, those which have data missing for several months (monthly energy yield is less than 5 kWh) are shown in green. The considered time period runs from January 2001 to February 2006.

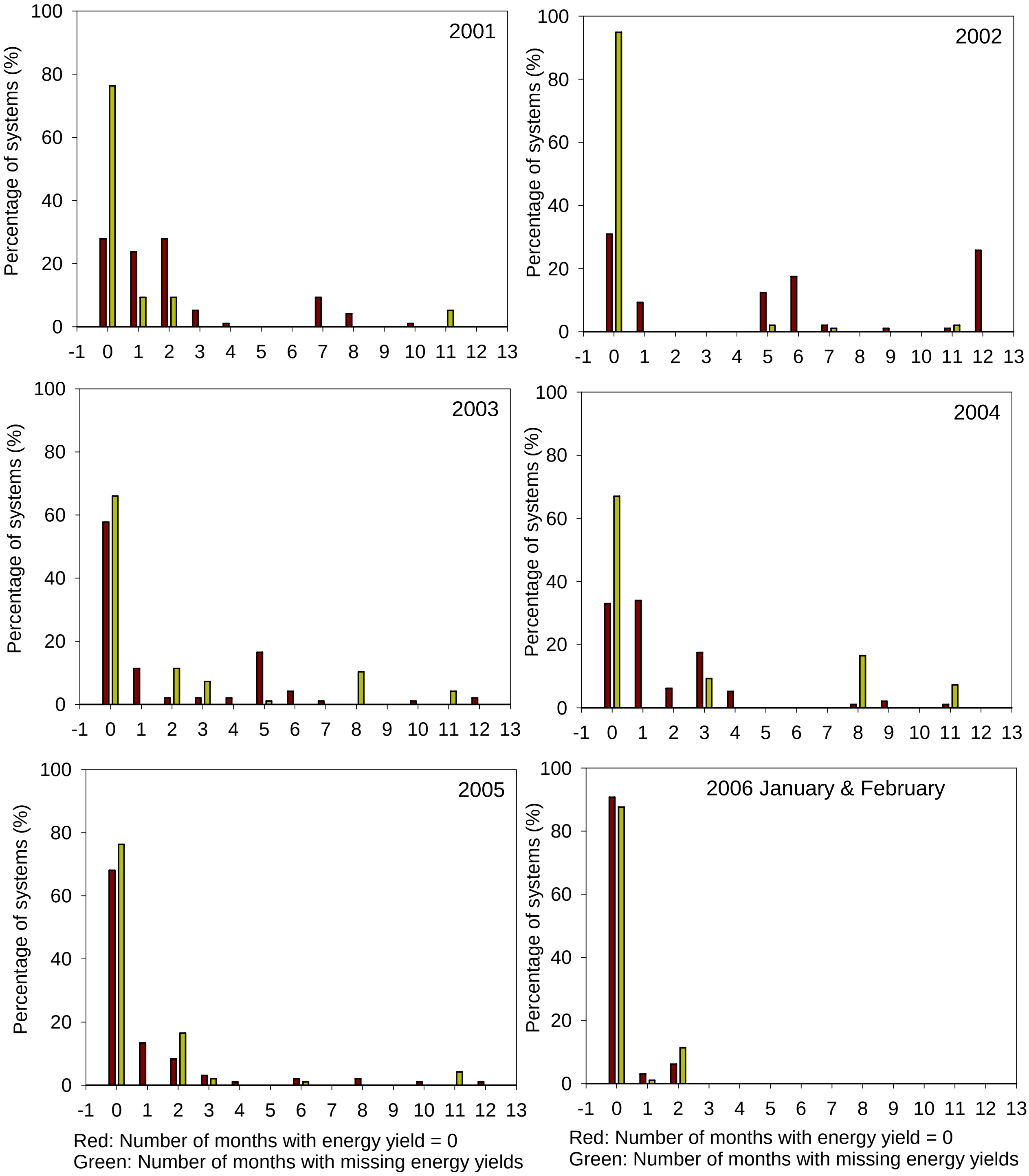


Figure 3.4 Frequency distribution for missing data and data that is zero for the period January 2001 to February 2006. On the horizontal axis the number of months data is zero (red bars) or missing (green bars) is shown, on the vertical axis the percentage of systems.

4. Section K2

Section K2	Waterlelie and Watermunt
Number of systems (monitored)	38
Rated Power (per array)	2.139 kWp
Module manufacturer and type	Shell Solar IRS75LA
Number of modules (per array)	30
Area	20 m²
Inverter type	Mastervolt Sunmaster 2500
Nr of strings	5
Location	Sloping roofs
Integration system	BOAL
Orientation	187 °
Tilt angle	20 °
Total power (monitored)	81 kWp
Monitoring data for period	January 2001 to February 2006

In Section K2 38 systems were monitored. The PR development from 2002 to 2006 for the 10 'best' systems in section K2 is shown in Figure 4.1. It is clear that, like in sector K1, the systems are not performing well. Several systems seem to have a string error of these ten best, seem to have a string error. Between October 2005 and February 2006 data is missing because of problems with the datalogger.

In Figure 4.2 the frequency distribution for the PR of all systems in section K2 is shown. The distribution is very broad; there are a lot of systems with a low PR. Like in Sector K1, the problems are supposed to be caused by corrosion of connectors (see Ch. 3.1) Detailed measurements for 4 systems in section K1 and K2 have been conducted in May 2005 by Ecofys. These showed that for all systems one or more strings did not deliver any power. After turning the inverter off on both DC and AC side and turning it on again, all strings worked (Ecofys, 2005).

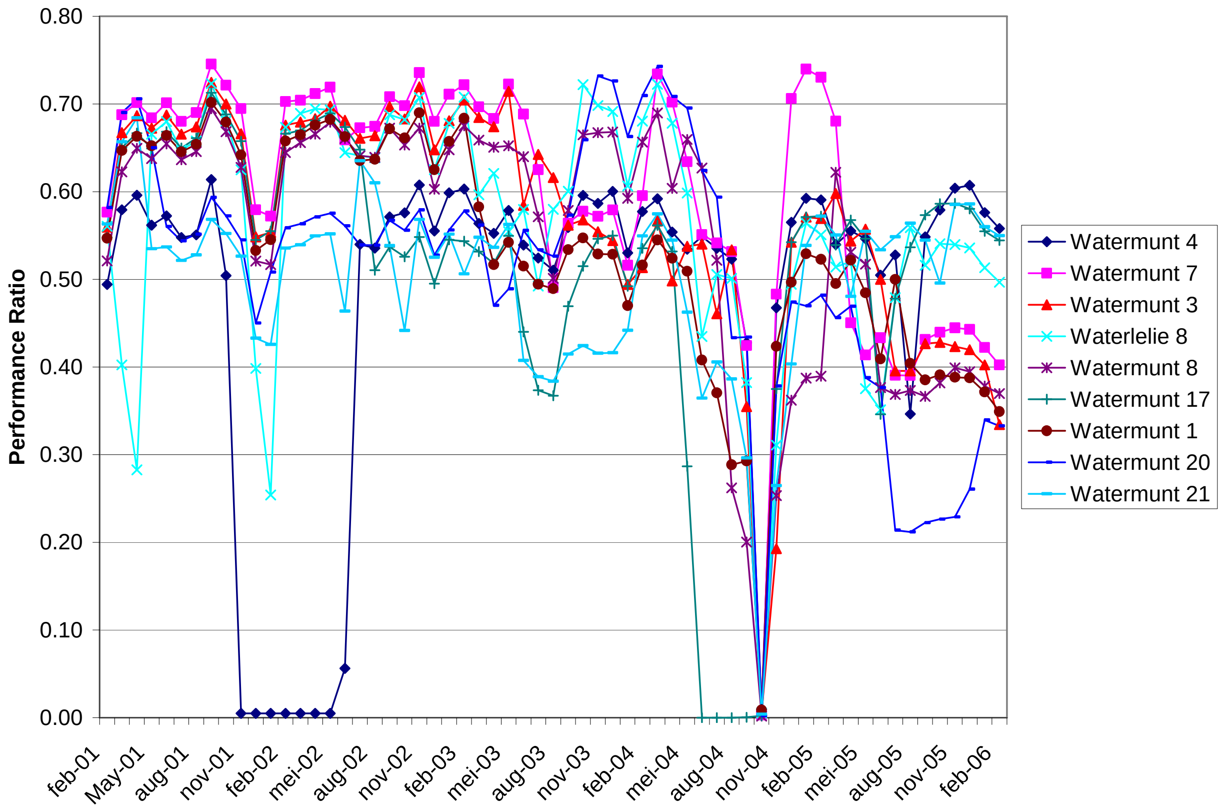


Figure 4.1 PR's of 10 systems with best performance ratio's in K2

Frequency plot of PR's in Section K2

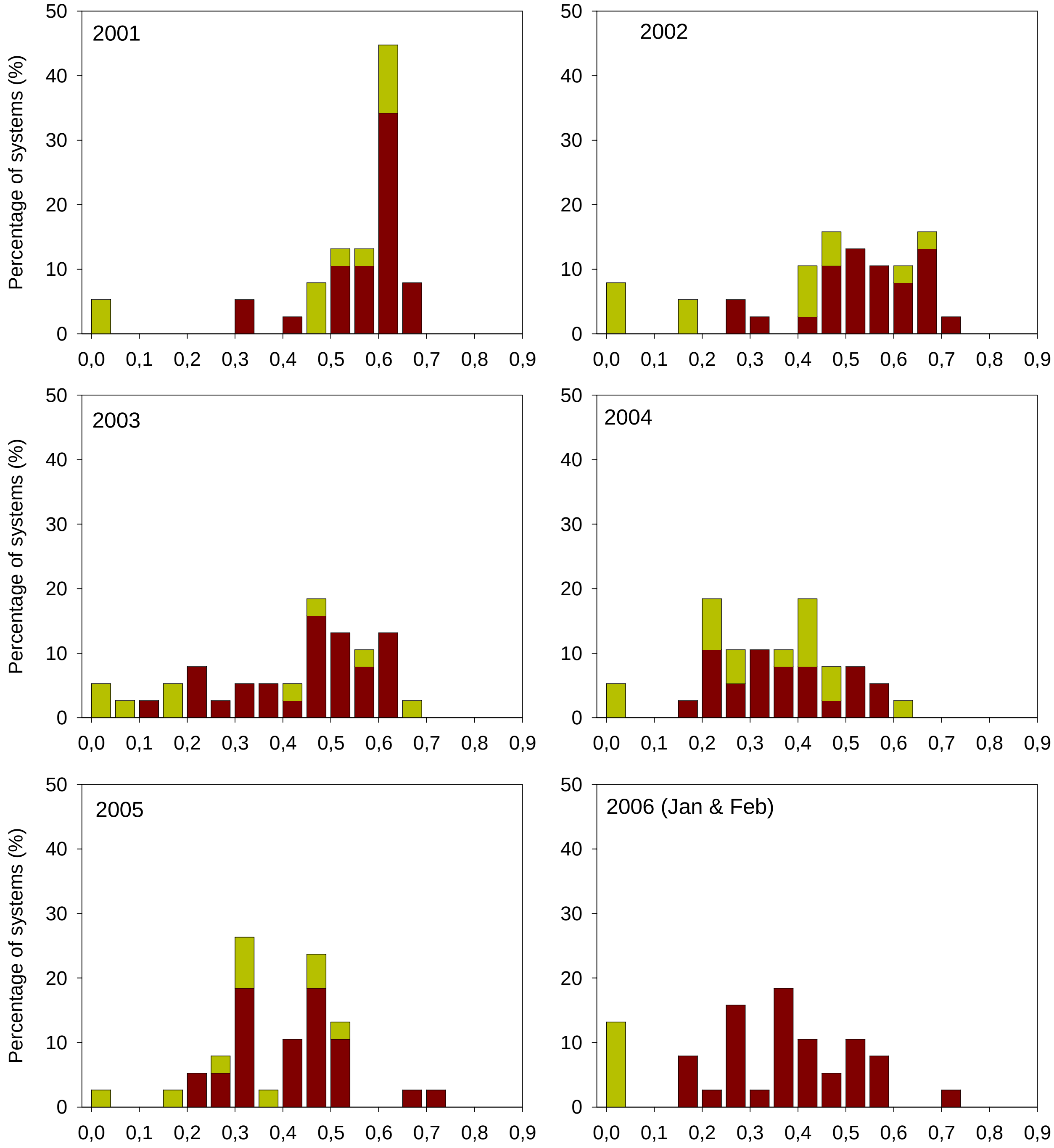
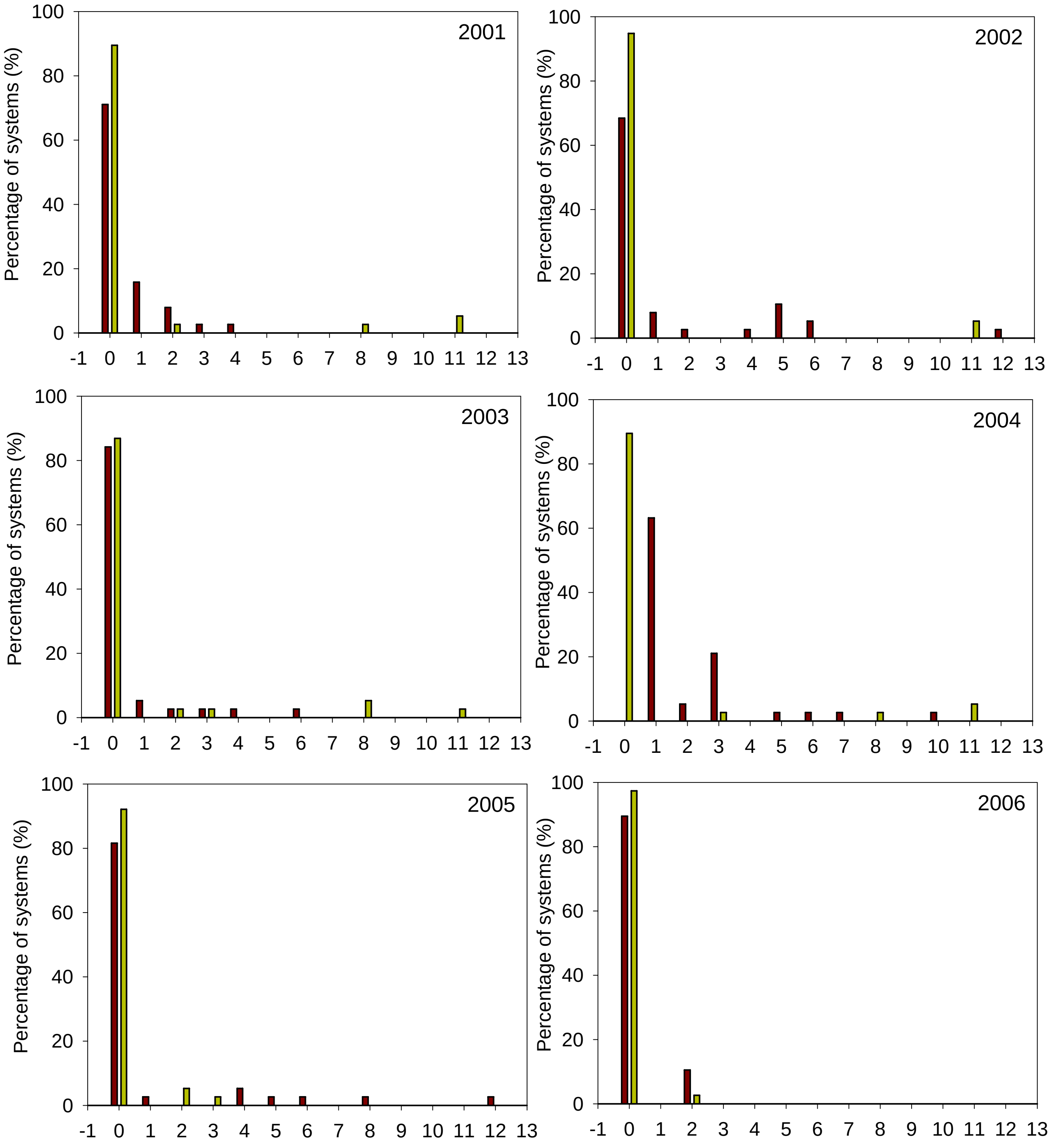


Figure 4.2 The 38 systems of section K2 are grouped into Performance Ratio ranges, which run from 0 to 0.05, 0.05 to 0.1 etc. The systems which have been operating for the entire time frame are shown in red, those which have data missing for several months (monthly energy yield is less than 5 kWh) are shown in green. The considered time period runs from January 2001 to February 2006.



Red: Number of months with energy yield = 0
Green: Number of months with missing energy yields

Red: Number of months with energy yield = 0
Green: Number of months with missing energy yields

Figure 4.3 Frequency distribution for missing data and data that is zero for the period January 2001 to February 2006. On the horizontal axis the number of months data is zero (red bars) or missing (green bars) is shown, on the vertical axis the percentage of systems.

5. Section K3

Section K3	Waterdrieblad, Watergentiaan
Number of systems (monitored)	30
Rated Power (per array)	3.037 kWp
Module manufacturer and type	BP Solarex BP585F
Number of modules (per array)	36
Area	23 m^2
Inverter type	Mastervolt Sunmaster 2500
Nr of strings	6
Location	Flat roofs
Integration system	ConSole
Orientation	192 °
Tilt angle	25 °
Total power (monitored)	91 kWp
Monitoring data for period	January 2001 to February 2006

Figure 5.1 Pictures from Section K3 (Kil, 2001)

Thirty systems in Section K3 are monitored. The frequency distribution of the performance of the systems is shown in Figure 5.4. The expected performance ratio for Section K3 is 0.7. A large share (> 60 %) of the systems perform well and have a PR that is larger than 0.65. This can be seen well from the performance maps in the appendix.

The performance of the 10 best performing systems is shown in Figure 6.2. Energy yield data for two systems (red and orange line) is missing for several months. For all systems part of the data from September to December 2004 is missing due to problems with the datalogger. 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.

The results for well-working systems can be summarized as follows:

- The average performance ratio for a calendar year of a well-working system is 0.68 with a standard deviation of 0.02. Only systems with data for all 12 months have been considered. 2004 was not taken into account.
- The performance ratio in winter is lower than the PR of the rest of the year. One major reason for this is shading. The systems in K3 are installed in rows as can be seen in the photographs. In winter the sun is low and causes shading. Another reason could be snow for several days in winter.
- The performance ratio in September and October is larger than 0.7.

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.

In Figure 5.3 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 Figure 5.4 systems with a high PR, but a low operating time are shown.

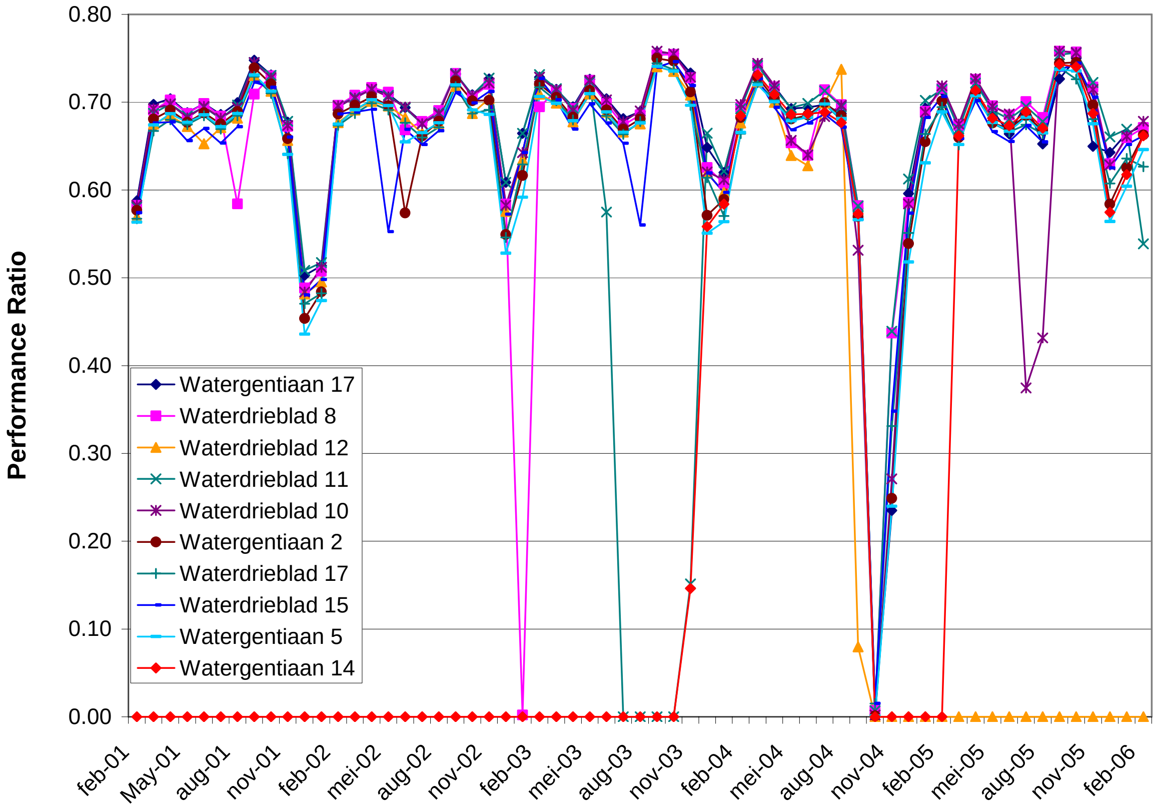


Figure 5.2 **PR of the 10 best performing systems in Section K3**

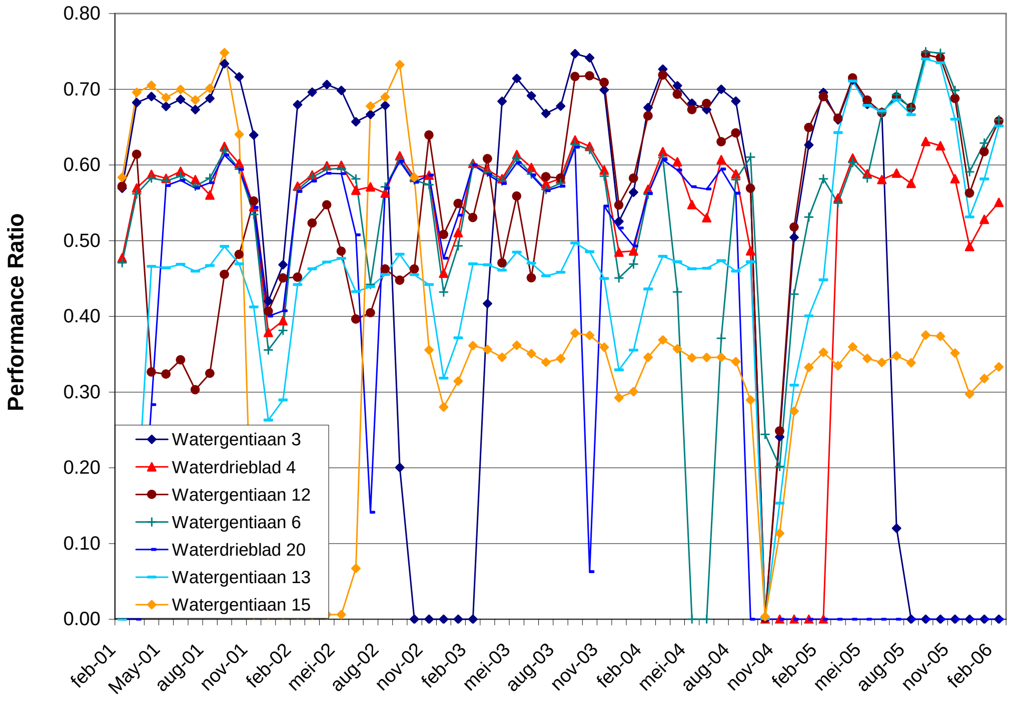


Figure 5.3 PR for systems in K3 with lower PR's

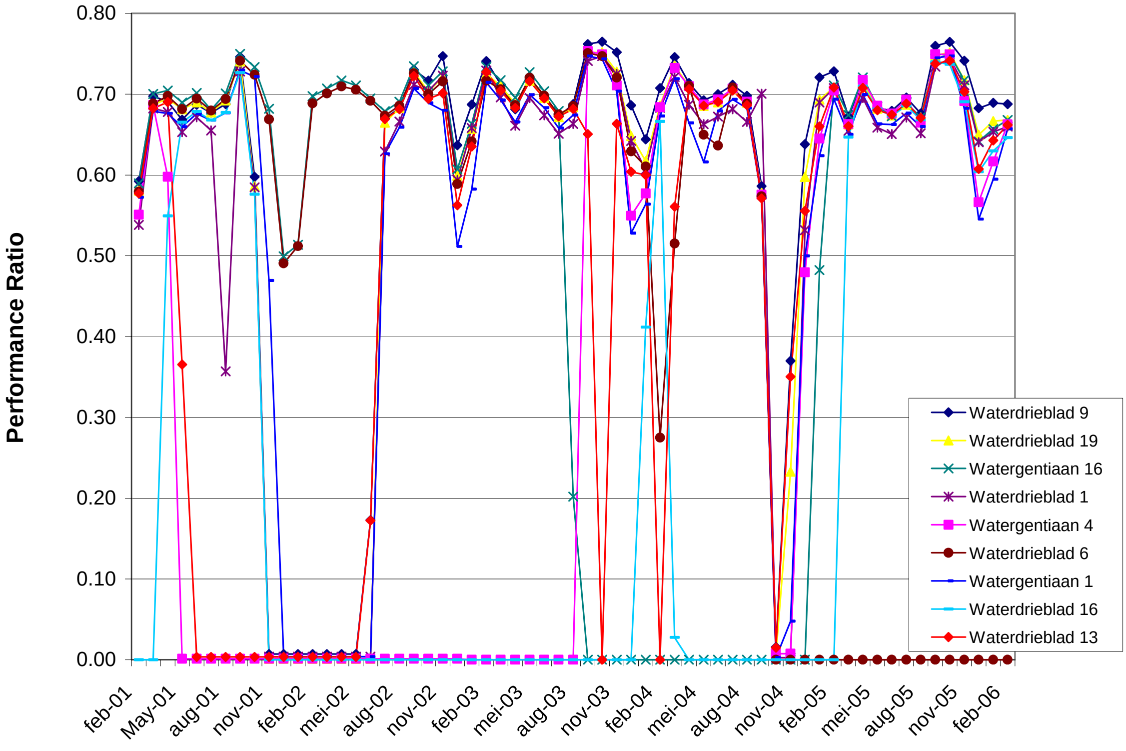


Figure 5.4 PR for systems in K3 with high PR's but low operating time

Frequency plot of PR's in Section K3

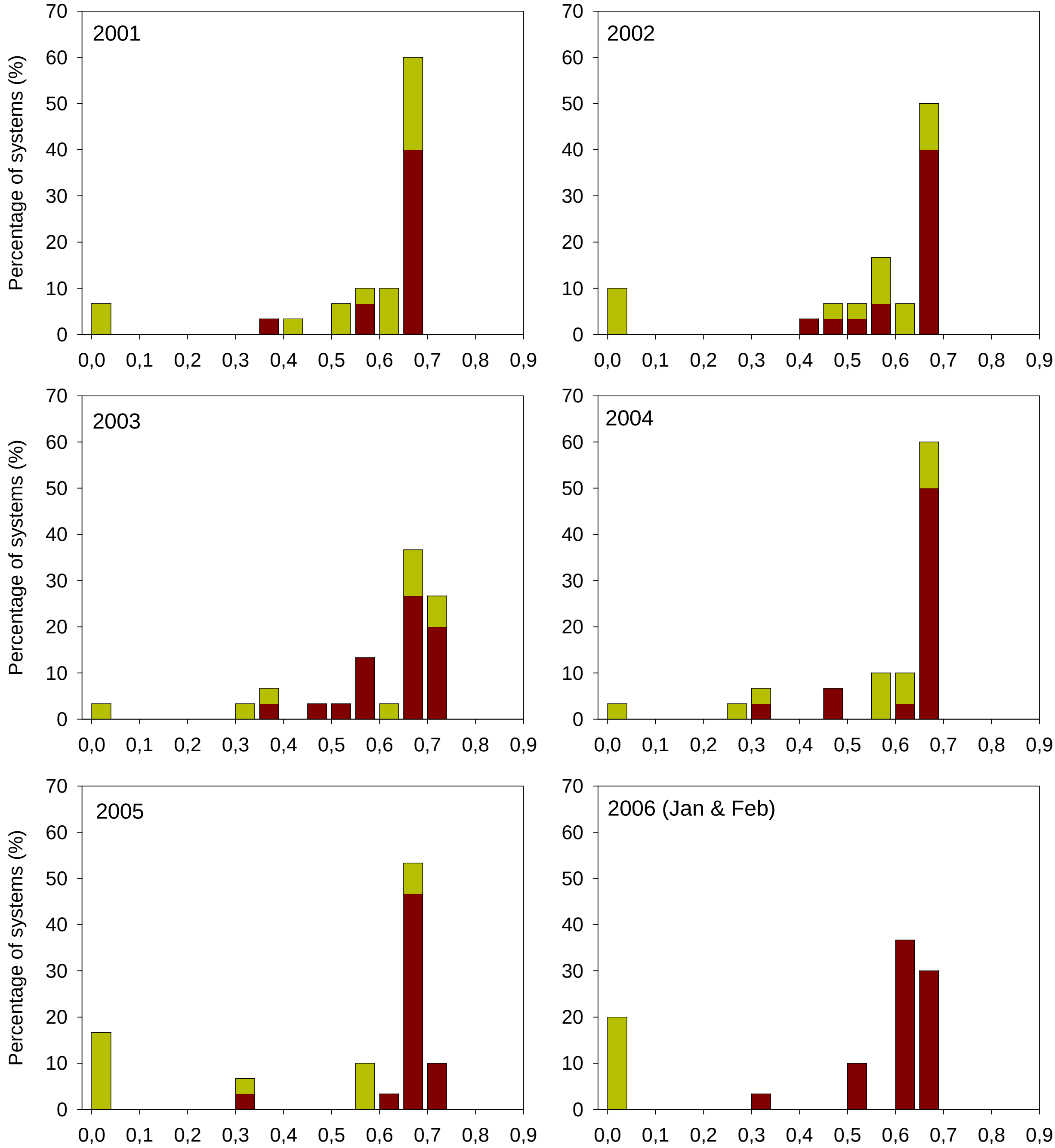


Figure 5.5 The 30 systems of section K3 are grouped into Performance Ratio ranges, which run from 0 to 0.05, 0.05 to 0.1 etc. The systems which have been operating for the entire time frame are shown in red, those which have data missing for several months (monthly energy yield is less than 5 kWh) are shown in green. The considered time period runs from January 2001 to February 2006.

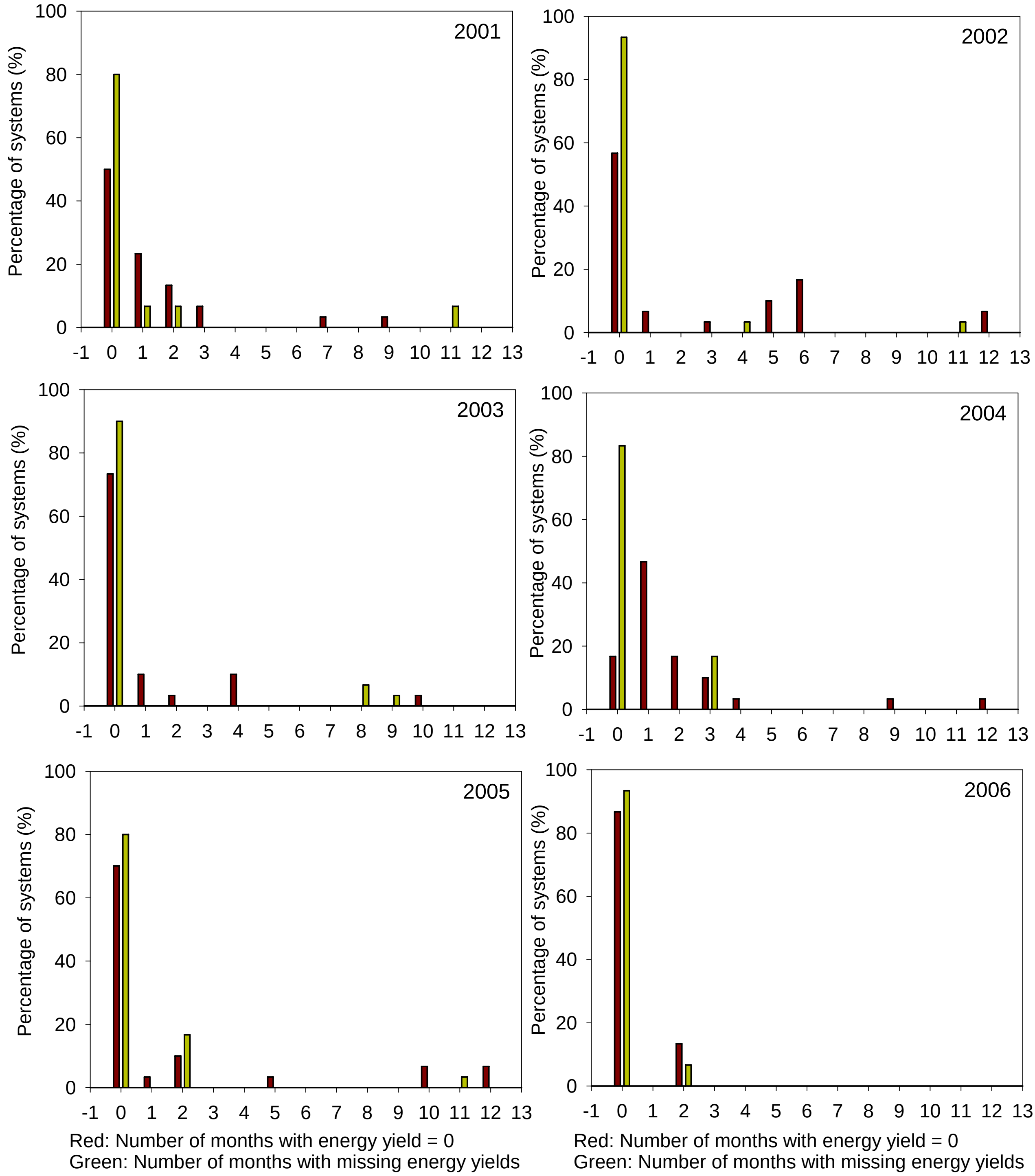


Figure 5.6 Frequency distribution for missing data and data that is zero for the period January 2001 to February 2006. On the horizontal axis the number of months data is zero (red bars) or missing (green bars) is shown, on the vertical axis the percentage of systems.

6.

1. Section K4

Section K4	Waterdreef
Number of systems (monitored)	31
Rated Power (per array)	2.73 kWp
Module manufacturer and type	BP Solarex BP585L
Number of modules (per array)	32
Area	20 m²
Inverter type	Mastervolt Sunmaster 2500
Nr of strings	4
Location	Sloping roofs
Integration system	WPL
Orientation	191 - 198 °
Tilt angle	20 °
Total power (monitored)	84 kWp
Monitoring data for period	January 2001 to February 2006

In Section K4 31 systems have been monitored. The expected PR for these systems was 0.7, circa 60 % of the systems have a PR larger than 0.65, thus they perform well. In Figure 6.1 the performance of 9 systems with a good performance and a high operating time are shown. The performance ratio is consistent between the systems.

The results for these systems can be summarized as follows:

- The average performance ratio for a calendar year of a well-working system is 0.67.
- The performance ratio for several winter months is slightly lower than average, this may be caused by shading or an inaccurate irradiation value.

In Figure 6.2 systems with a high performance ratio while operating, but also with a lower operation time are shown. In Figure 6.3 systems with a lower PR, but a high operation time are shown. The systems in K4 have 4 strings, string errors for several months can be clearly distinguished for the different systems.

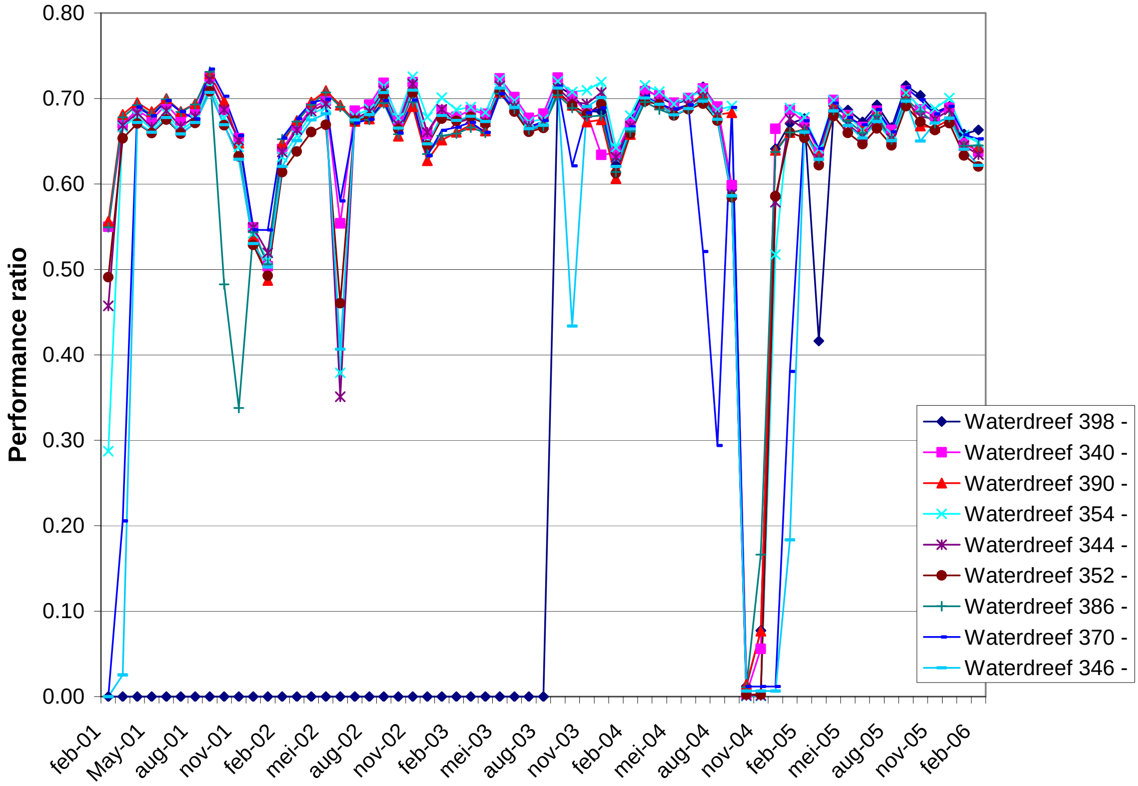


Figure 1.1 **9 well-working systems in Section K4**

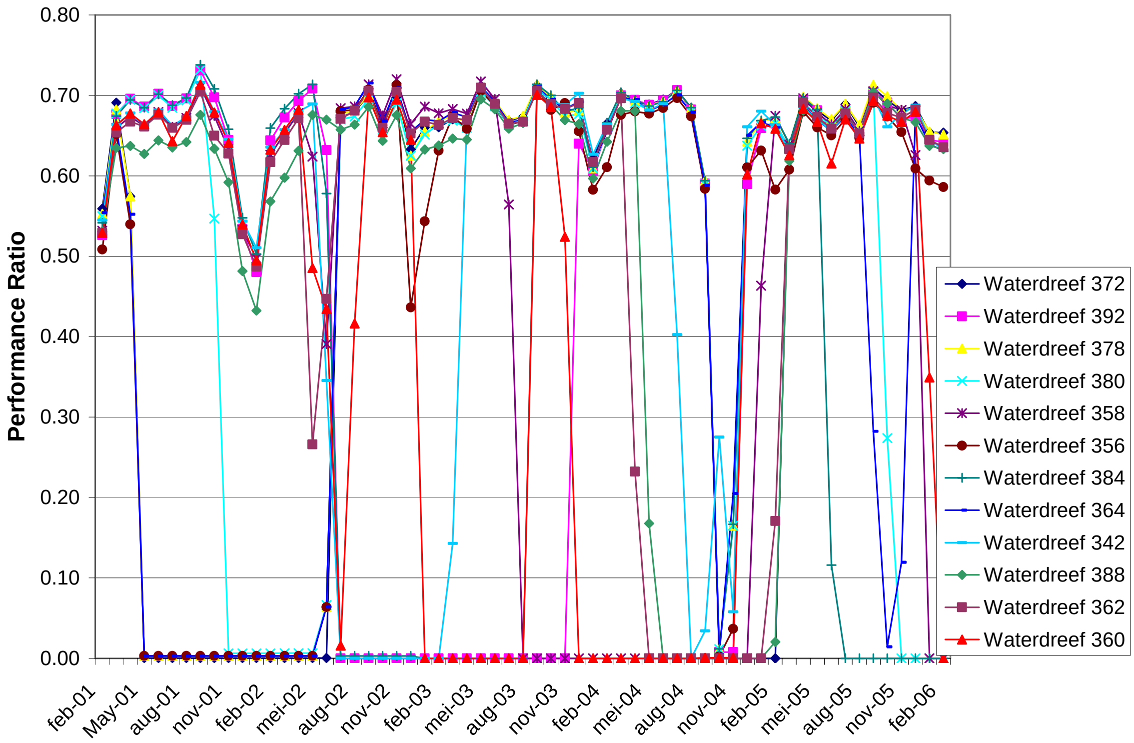


Figure 1.2 **systems in Section K4 with a good PR, but a low operation time**

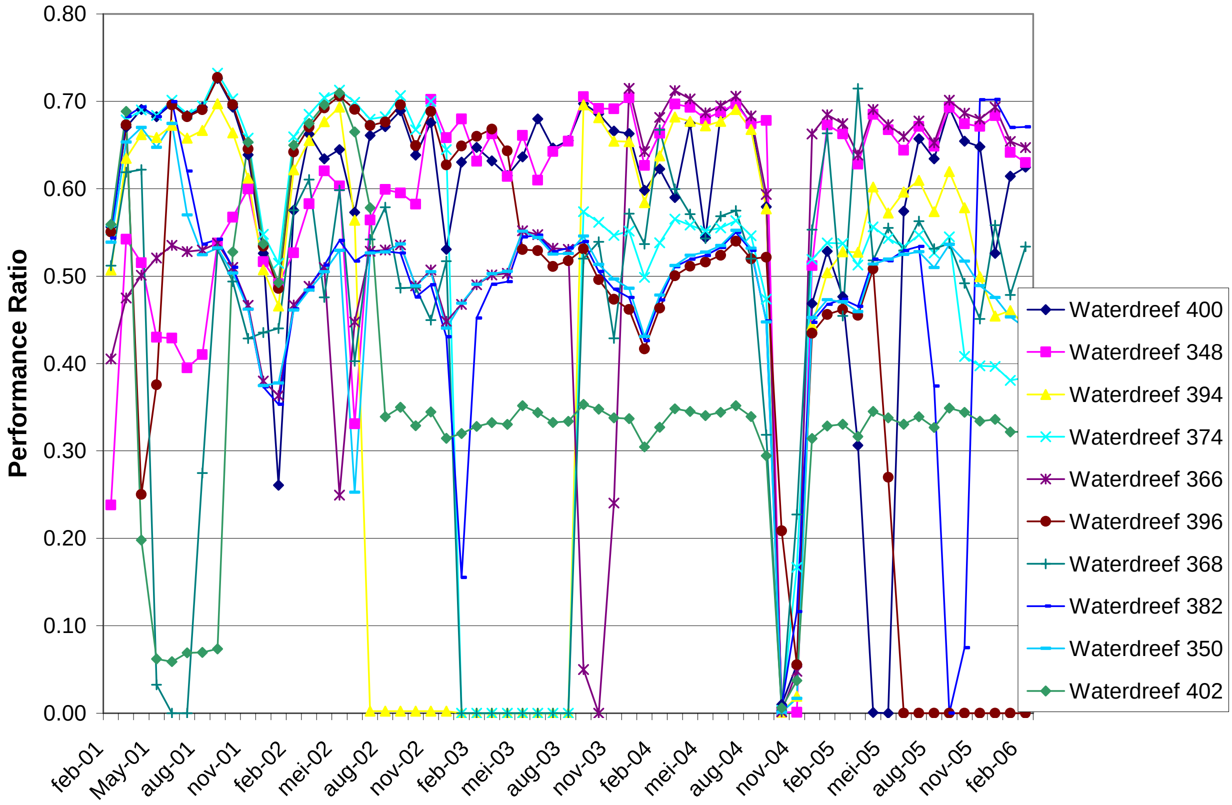


Figure 1.3 Systems with a low PR

Frequency plot of PR's in Section K4

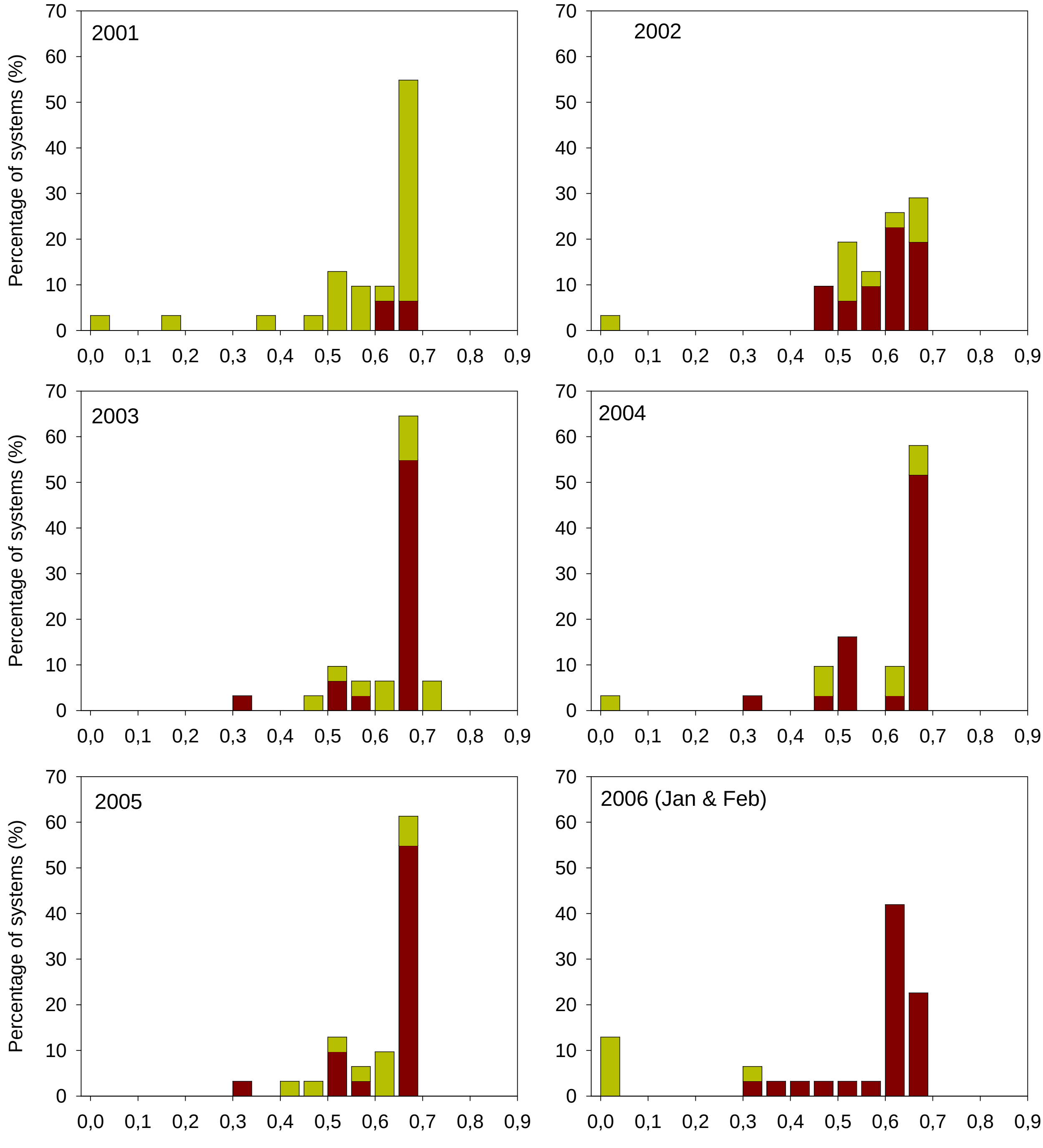


Figure 1.4 The 31 systems of section K4 are grouped into Performance Ratio ranges, which run from 0 to 0.05, 0.05 to 0.1 etc. The systems which have been operating for the entire time frame are shown in red, those which have data missing for several months (monthly energy yield is less than 5 kWh) are shown in green. The considered time period runs from January 2001 to February 2006.

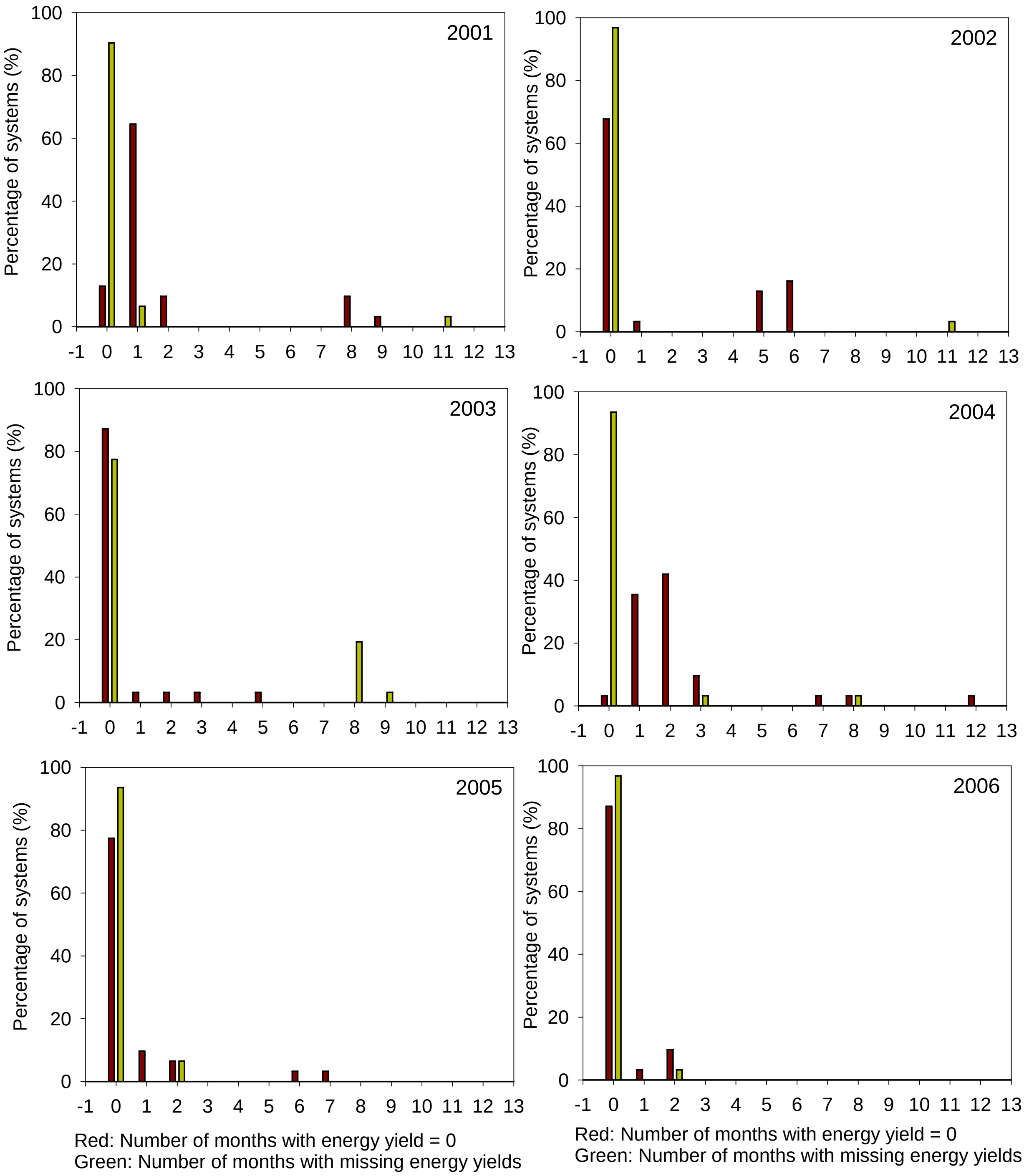
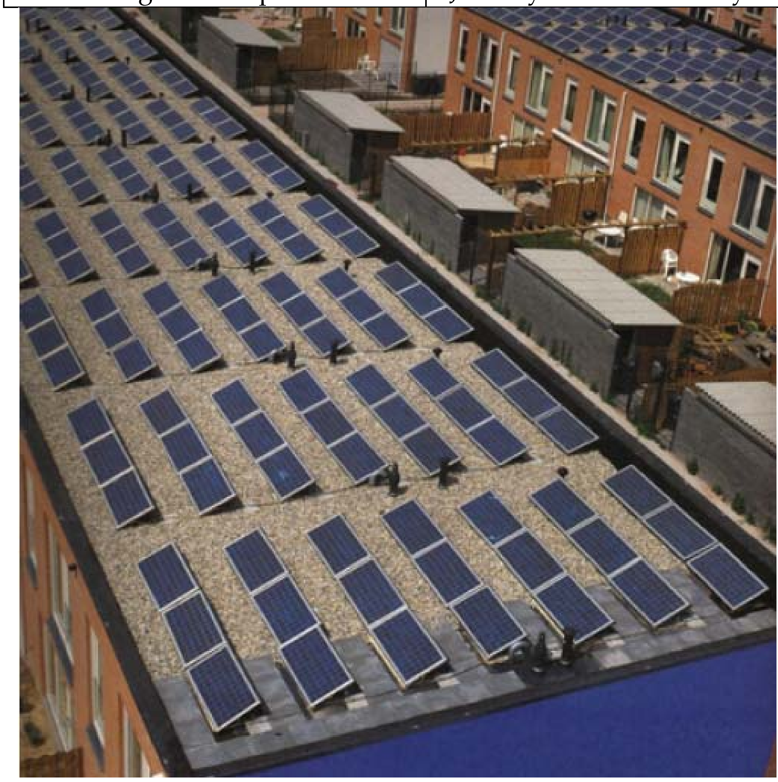


Figure 1.5 Frequency distribution for missing data and data that is zero for the period January 2001 to February 2006. On the horizontal axis the number of months data is zero (red bars) or missing (green bars) is shown, on the vertical axis the percentage of systems.

2. Section N2

Section N2	Eendenkroos, Gele Plomp, Kikkerbeet, Klein Kroos and Sterrenkroos
Number of systems (monitored)	121
Rated Power (per array)	1.995 kWp (93 systems) 2.280 kWp (28 systems)
Module manufacturer and type	Shell Solar RSM95
Number of modules (per array)	21 24
Area	20 m^2 23 m^2
Inverter type	Mastervolt Sunmaster 2500
Nr of strings	7 8
Location	Flat roofs
Integration system	ConSole
Orientation	179 - 188 °
Tilt angle	25 °
Total power (monitored)	249 kWp
Monitoring data for period	January 2001 to February 2006



In Section N2 121 PV-systems have been monitored. In the documentation on Nieuwland 28 systems should have 8 strings and an installed peak power of 2280 Wp. After being alarmed by lower PR’s for these systems, we had a look at the installation schemes and Google Earth. The systems had only 7 strings and an installed peak power of 1995 Wp. We assumed this to be true in our further analysis. It shows it is important to document changes in plans.

Circa 70 % of these systems have a yearly PR higher than 0.6. See also the performance maps in the appendix. For about 10 % of the systems data is missing or zero.
The 10 systems with high operating time and high PR are shown in Figure 7.1.

- The average PR for the 10 best working systems is 0.67
- The systems are shaded in winter, because of the rows of modules.
- Also for these systems a clearly repetitive PR pattern can be seen, the trend does not show a deteriorating PR.

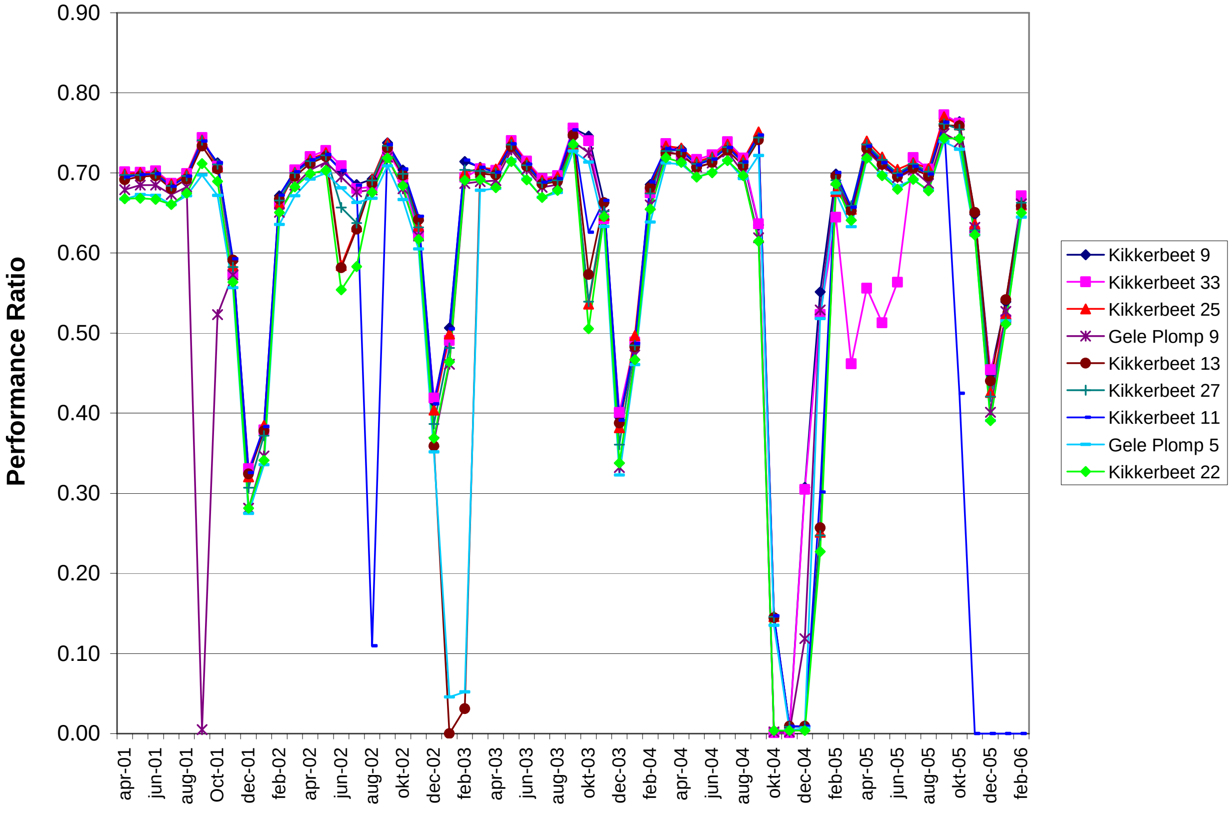


Figure 2.1 Performance Ratio for well-working systems in Section N2

Extra floors (Google Earth)

On a total of 16 houses in Section N2 an extra floor was built, this can be seen in Figure 7.2 for Klein Kroos 21, 23, 31, 33 and 35. For these houses one would expect more shading in winter, because the rows are closer to each other. Also the neighbours get more shading in the morning for neighbours to the west (see Nr 25 in the picture) or in the afternoon for systems to the east.

The PR's for these systems are shown in Figure 7.3. Please note that a lot of data is missing from October 2004 to February 2005 due to problems with dataloggers. It can be seen that there is more shading in winter 2006 for systems with an extra floor (21, 23 and 33). Furthermore the summer performance in 2005 of Klein Kroos 19 and 29 is much lower; this may be due to shading of the neighbouring houses. Since the analysis was done on a monthly and not an hourly basis, this is not completely certain.

Figure 2.2 Klein Kroos 35 (left) to Klein Kroos 19 (right)   (Google Earth)

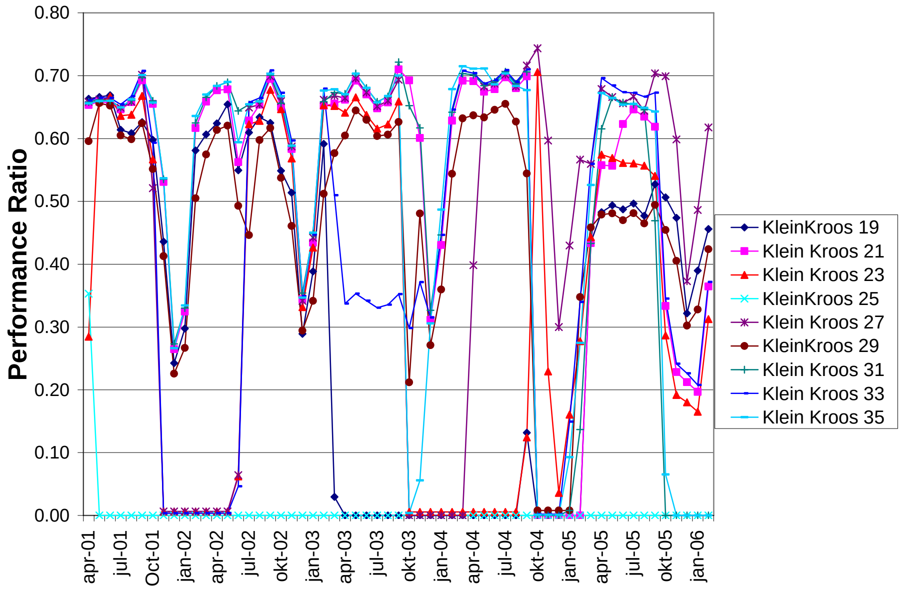


Figure 2.3 PR's for Klein Kroos 19 to 35

Frequency plot of PR's in Section N2

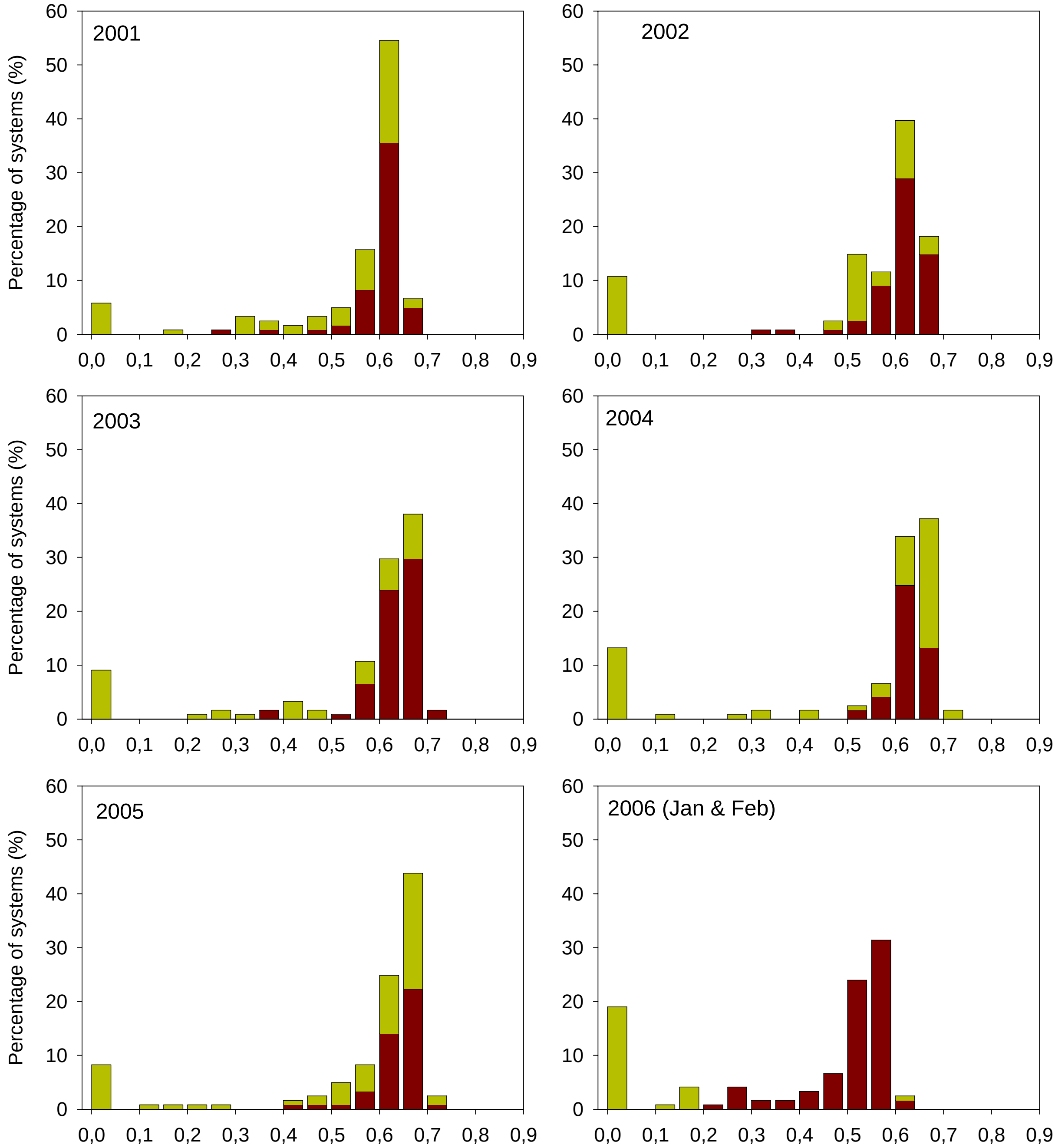


Figure 2.4 The 121 systems of section N2 are grouped into Performance Ratio ranges, which run from 0 to 0.05, 0.05 to 0.1 etc. The systems which have been operating for the entire time frame are shown in red, those which have data missing for several months (monthly energy yield is less than 5 kWh) are shown in green. The considered time period runs from January 2001 to February 2006.

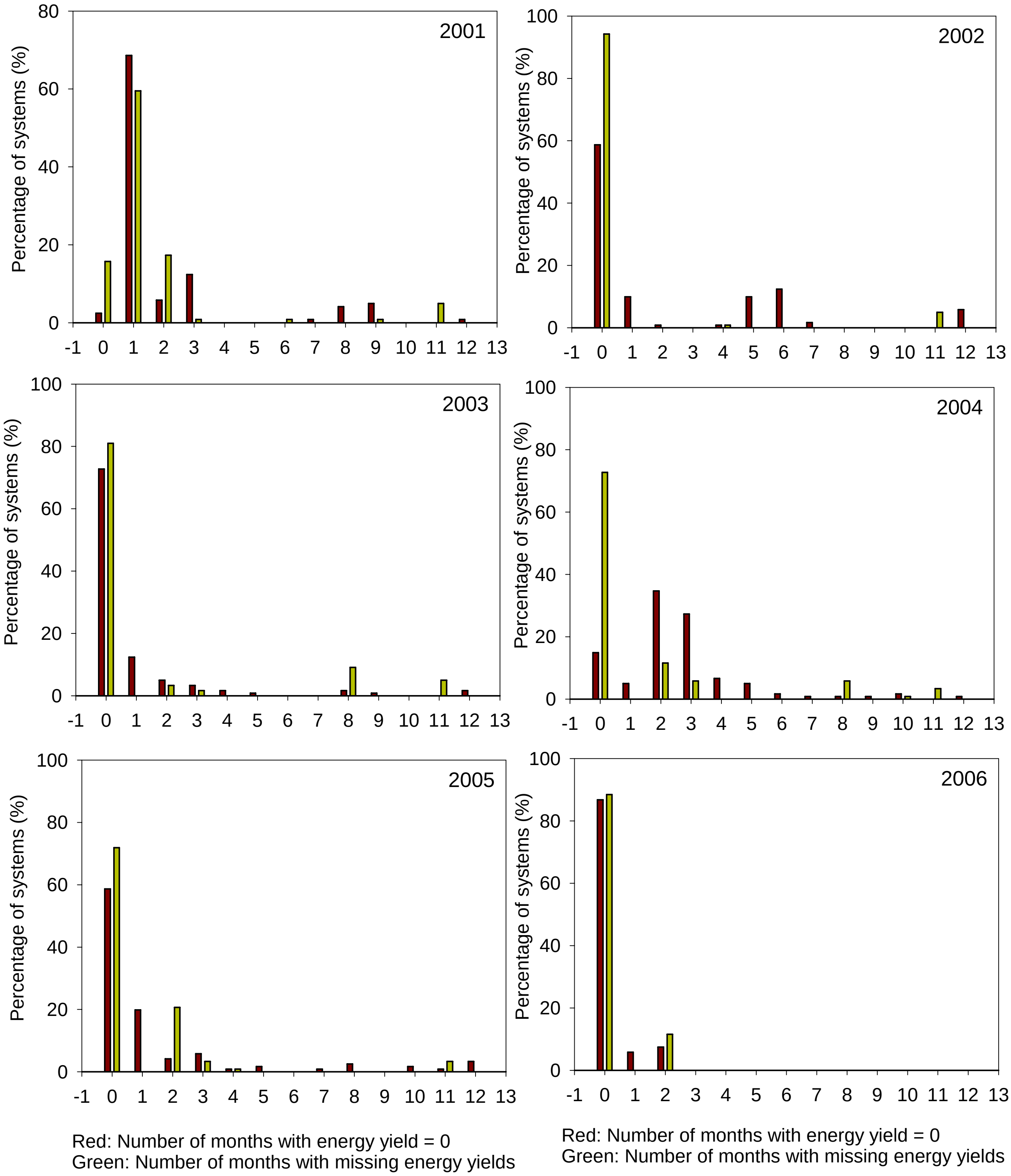


Figure 2.5 Frequency distribution for missing data and data that is zero for the period January 2001 to February 2006. On the horizontal axis the number of months data is zero (red bars) or missing (green bars) is shown, on the vertical axis the percentage of systems.

3. Section N3 (façade)

Section N3	Gele Plomp and Pitrus
Number of systems (monitored)	23
Rated Power (per array)	0.796 kWp
Module manufacturer and type	Shell Solar IRS75LA
Number of modules (per array)	11
Area	7 m²
Inverter type	SMA Sunnyboy SWR 700
Nr of strings	1
Location	Façades
Integration system	wooden window-frames
Orientation	175 - 199 °
Tilt angle	90 °
Total power (monitored)	18 kWp
Monitoring data for period	January 2001 to February 2006

In Section N3 23 systems have been monitored. In Figure 8.1 the PR of well working systems are shown. The average PR for these type of systems is 0.56, which is higher than the expected PR of 0.5. The performance ratio is quite low, because of shading and reflection issues.

In Figure 8.1 can be seen that the PR has a year pattern with two periods with a lower PR, one in winter and one in summer. When the incoming irradiation is more perpendicular to the PV plane of array, there is less reflection,. For façades this means that there is less reflection in winter, but more in summer. Because the sun in summer is high in the sky, reflection is high and the PR is low. In winter there is some shading by the rows of houses. Gele Plomp 30 is at the start of a row of houses and has therefore no shading in winter (see Figure 8.1 and the performance maps in the appendix). Note that there are often high uncertainties in irradiation calculations for facades.

Some systems may have shading from objects, like fences, plants and e.g. drying laundry, on the terrace in front of the PV systems.

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

In Figure 8.2 the frequency distribution of PR’s for systems in section N3 is shown. Circa 50 % of the systems have a performance ratio higher than 0.5.

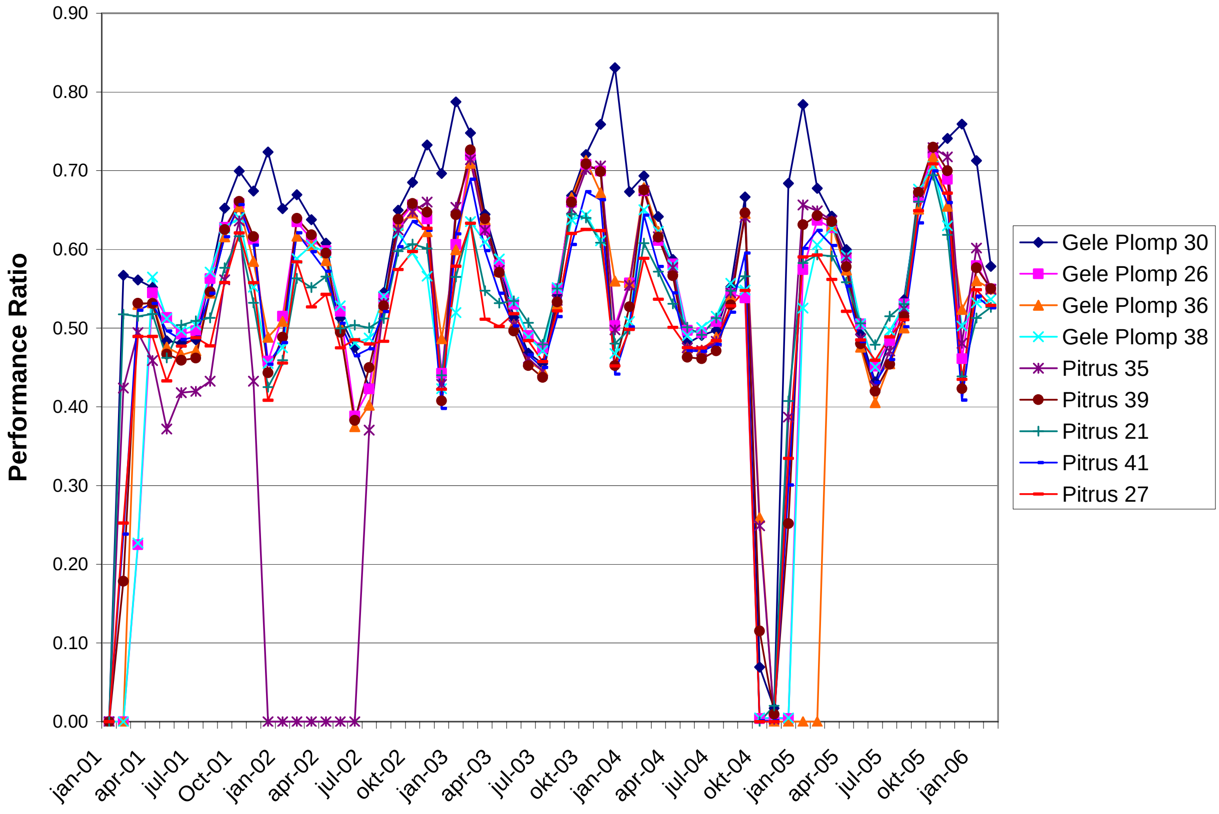


Figure 3.1 **PR of well working systems in Section N3**

Frequency plot of PR's in Section N3

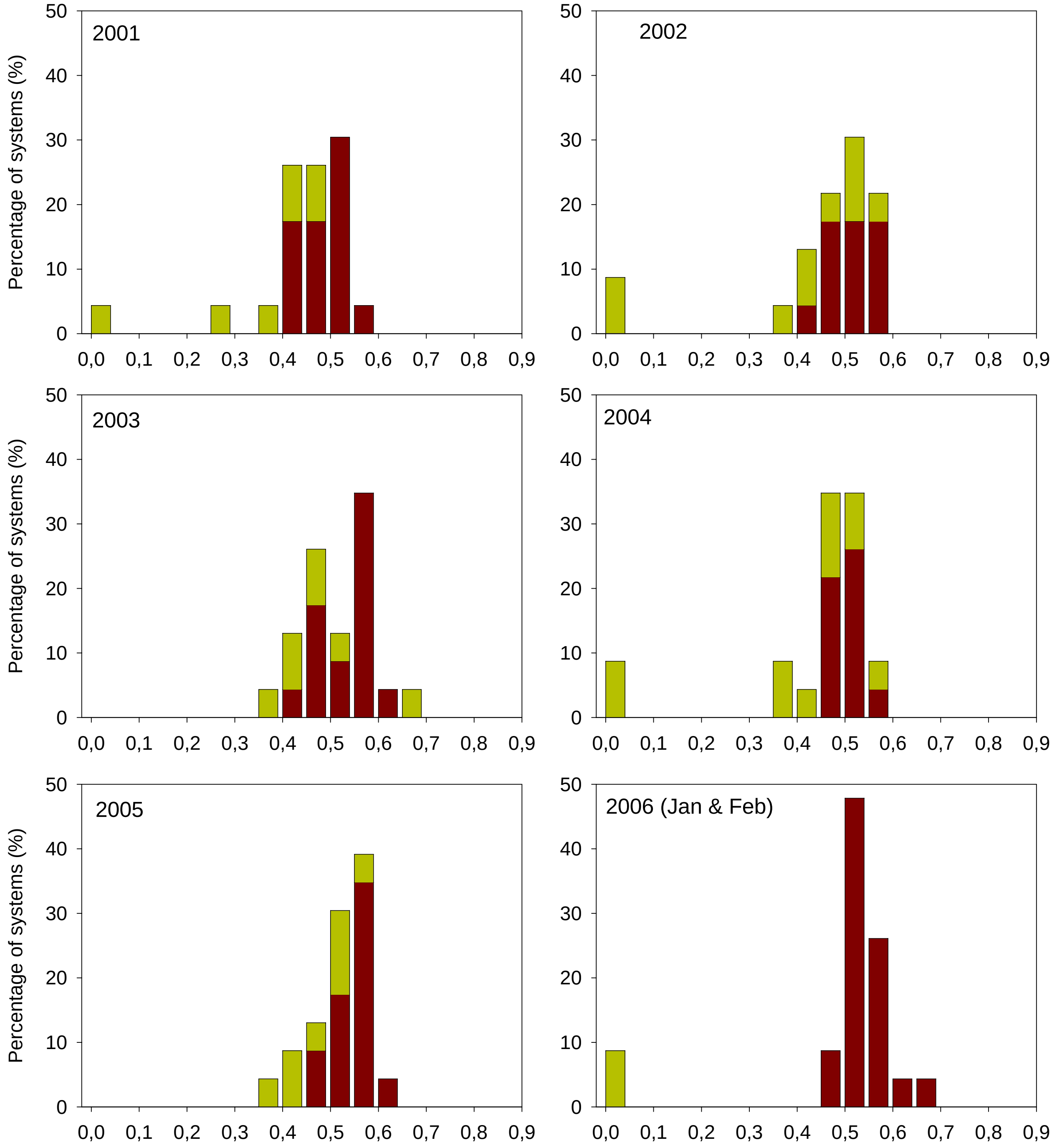


Figure 3.2 The 23 systems of section N3 are grouped into Performance Ratio ranges, which run from 0 to 0.05, 0.05 to 0.1 etc. The systems which have been operating for the entire time frame are shown in red, those which have data missing for several months (monthly energy yield is less than 5 kWh) are shown in green. The considered time period runs from January 2001 to February 2006.

4. Section N4/RBB

Section N4/RBB	Mattenbies and Pitrus
Number of systems (monitored)	22
Rated Power (per array)	2.053 kWp
Module manufacturer and type	Shell Solar SRT35
Number of modules (per array)	60
Area	23 $m^{2=}$
Inverter type	Mastervolt Sunmaster 2500
Nr of strings	4
Location	Sloping roofs
Integration system	RBB PV700
Orientation	194 °
Tilt angle	20 °
Total power (monitored)	48 kWp
Monitoring data for period	January 2001 to February 2006

In Section N4/RBB 22 systems are monitored. In general the performance of the systems in this section is good as can be seen in Figure 9.3. The average PR for well-working systems with a high operating time is 0.72. About 60 % of the systems have a PR above 0.7, which is the expected PR. There are a few systems with a lower performance ratio; this is partly caused by string errors (see Figure 9.2).

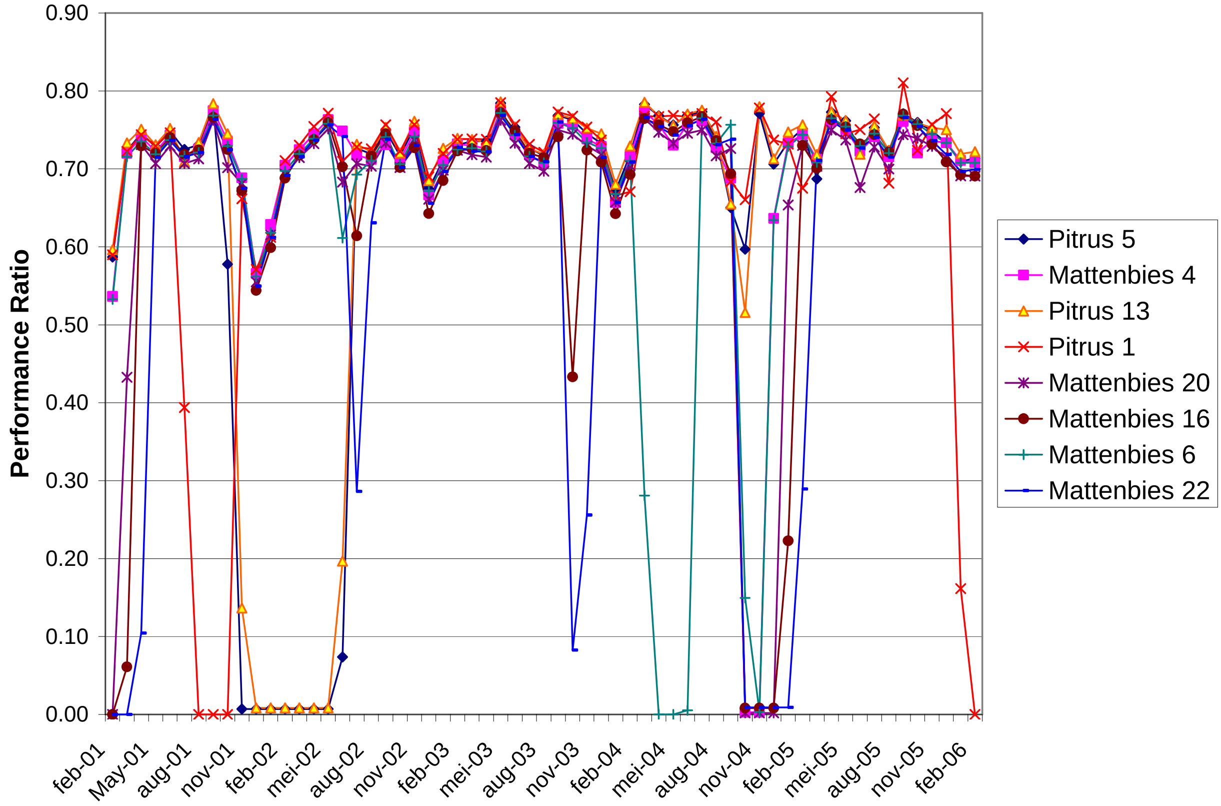


Figure 4.1 PR's of 8 systems with good performance ratio's

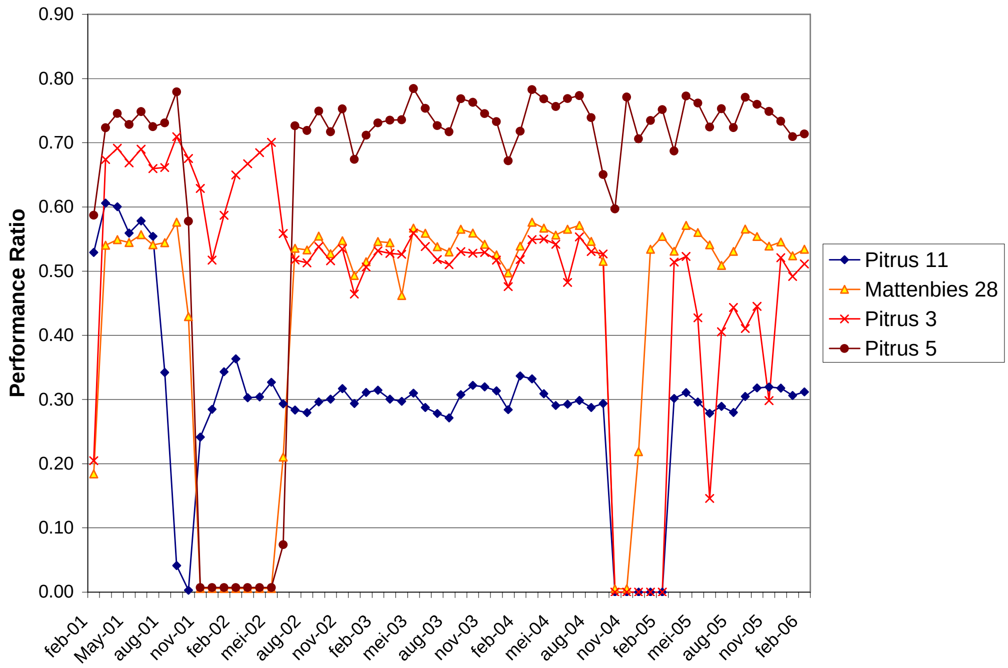


Figure 4.2 Some systems in section N4/RBB with string errors (Pitrus 5 for reference)

Frequency plot of PR’s in Section N4/RBB

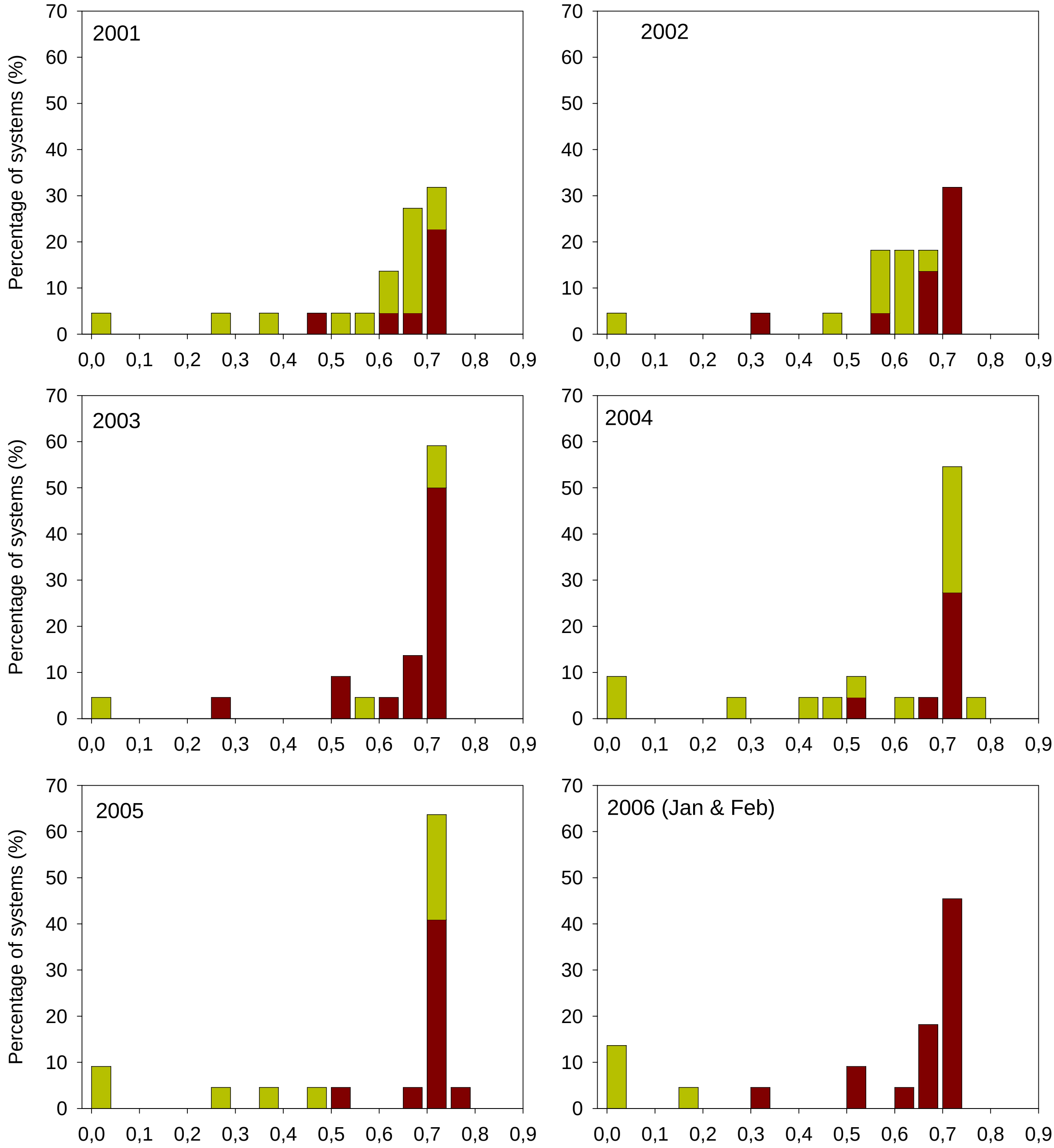


Figure 4.3 The 22 systems of section N4/RBB are grouped into Performance Ratio ranges, which run from 0 to 0.05, 0.05 to 0.1 etc. The systems which have been operating for the entire time frame are shown in red, those which have data missing for several months (monthly energy yield is less than 5 kWh) are shown in green. The considered time period runs from January 2001 to February 2006.

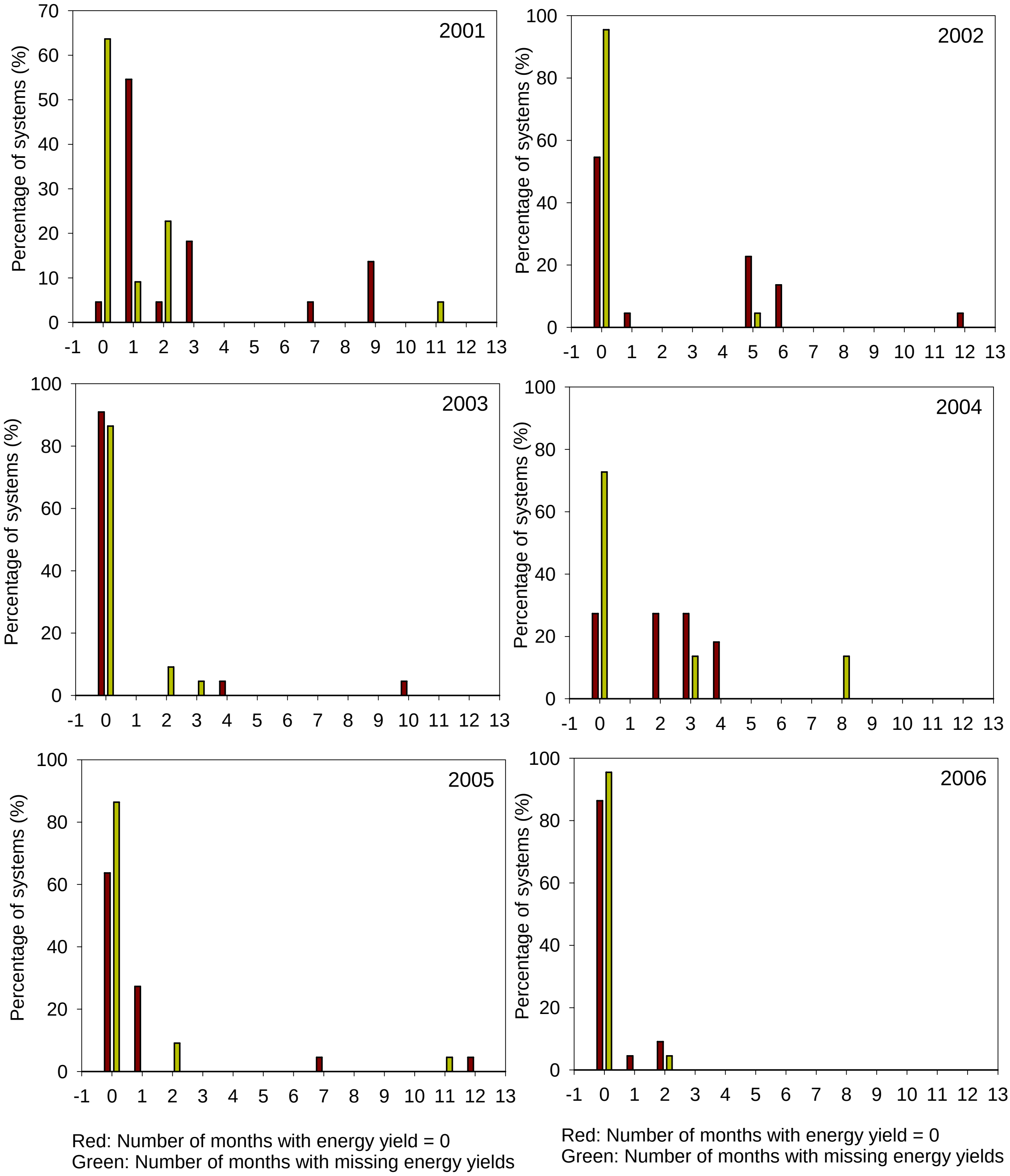


Figure 4.4 Frequency distribution for missing data and data that is zero for the period January 2001 to February 2006. On the horizontal axis the number of months data is zero (red bars) or missing (green bars) is shown, on the vertical axis the percentage of systems.

10. Section N4/Shell

Section N4/Shell	**Kalmoes, Lisdodde, Mattenbies and Pitrus**
Number of systems (monitored)	91
Rated Power (per array)	2.66 kWp
Module manufacturer and type	Shell Solar IRS95LA
Number of modules (per array)	27
Area	25 $m^{2=}$
Inverter type	Mastervolt Sunmaster 2500
Nr of strings	9
Location	Sloping roofs
Integration system	BOAL
Orientation	194 °
Tilt angle	70 °
Total power (monitored)	242 kWp
Monitoring data for period	January 2001 to February 2006

In Section N4/Shell 91 systems have been monitored. The systems perform quite well; about 60 % of the systems have a PR higher than 0.6, while the expected PR is 0.65. In Figure 10.1 the PR of several well-working systems with a high operating time are shown. It can be seen that the PR in winter is higher than in other seasons. This is probably caused by the tilt angle of 70 degrees, which results in more irradiance in the tilted plane in winter. In Figure 10.2 the frequency distribution for the PR's in this sector are shown. In the appendix the performance maps are shown.

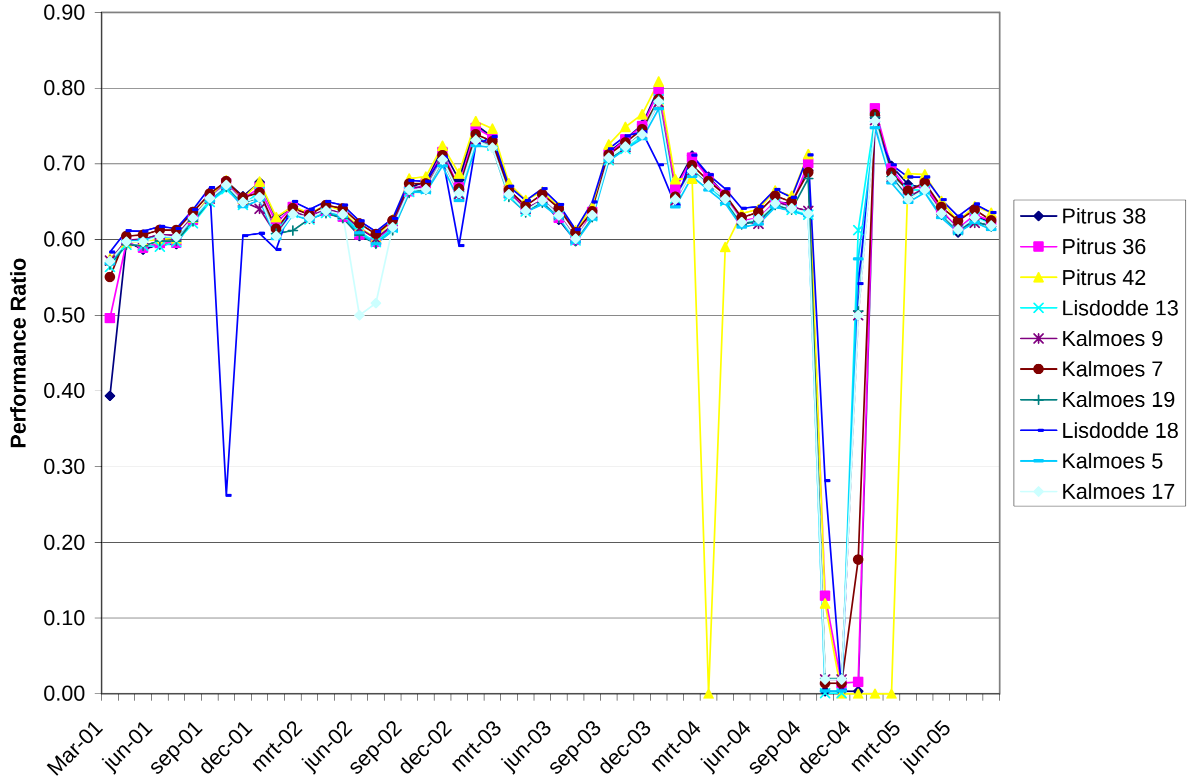


Figure 10.1 Performance of 10 well-working systems in Section N4/Shell

Frequency plot of PR's in Section N4/Shell

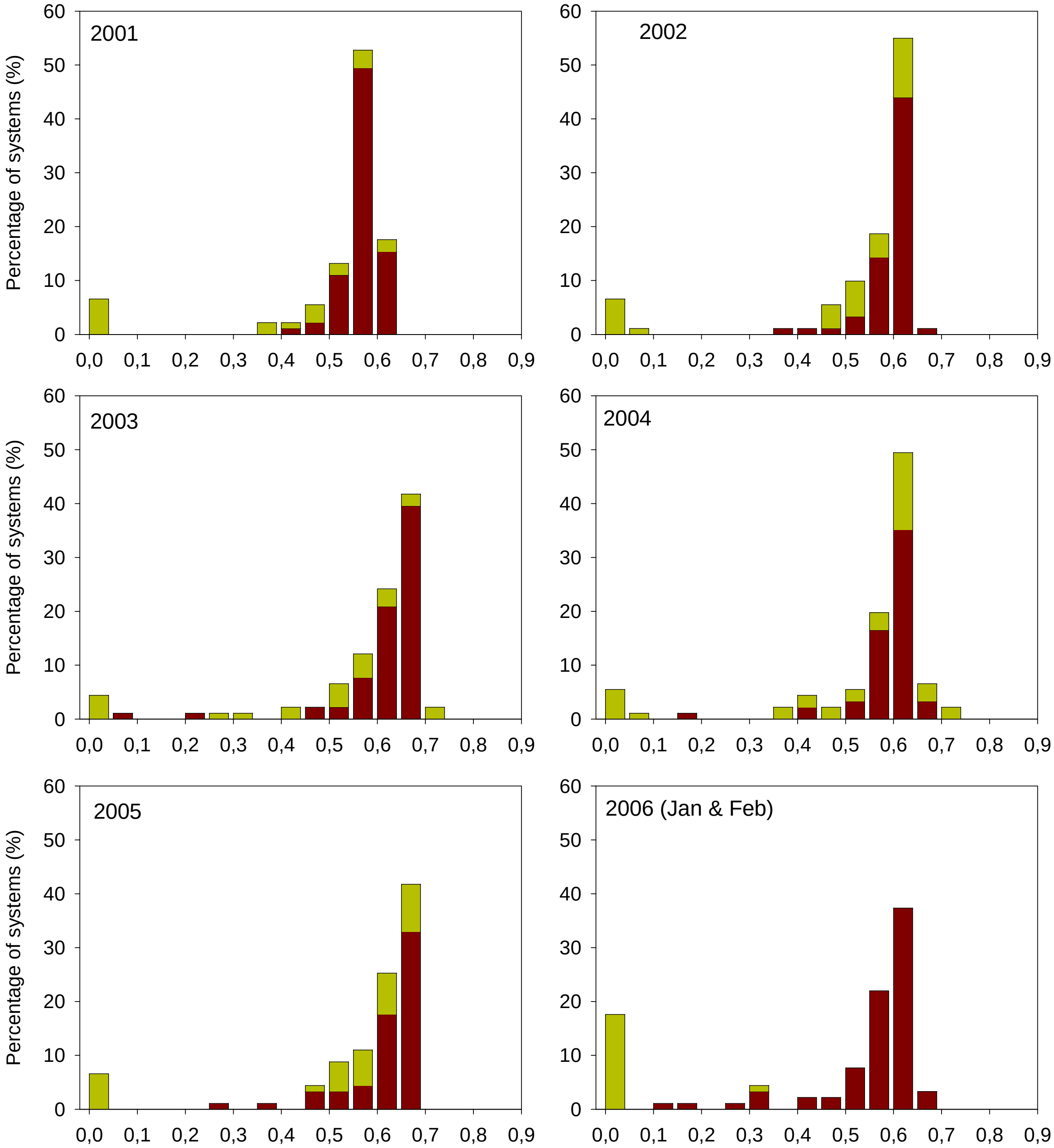


Figure 10.2 The 91 systems of section N4/Shell are grouped into Performance Ratio ranges, which run from 0 to 0.05, 0.05 to 0.1 etc. The systems which have been operating for the entire time frame are shown in red, those which have data missing for several months (monthly energy yield is less than 5 kWh) are shown in green. The considered time period runs from January 2001 to February 2006.

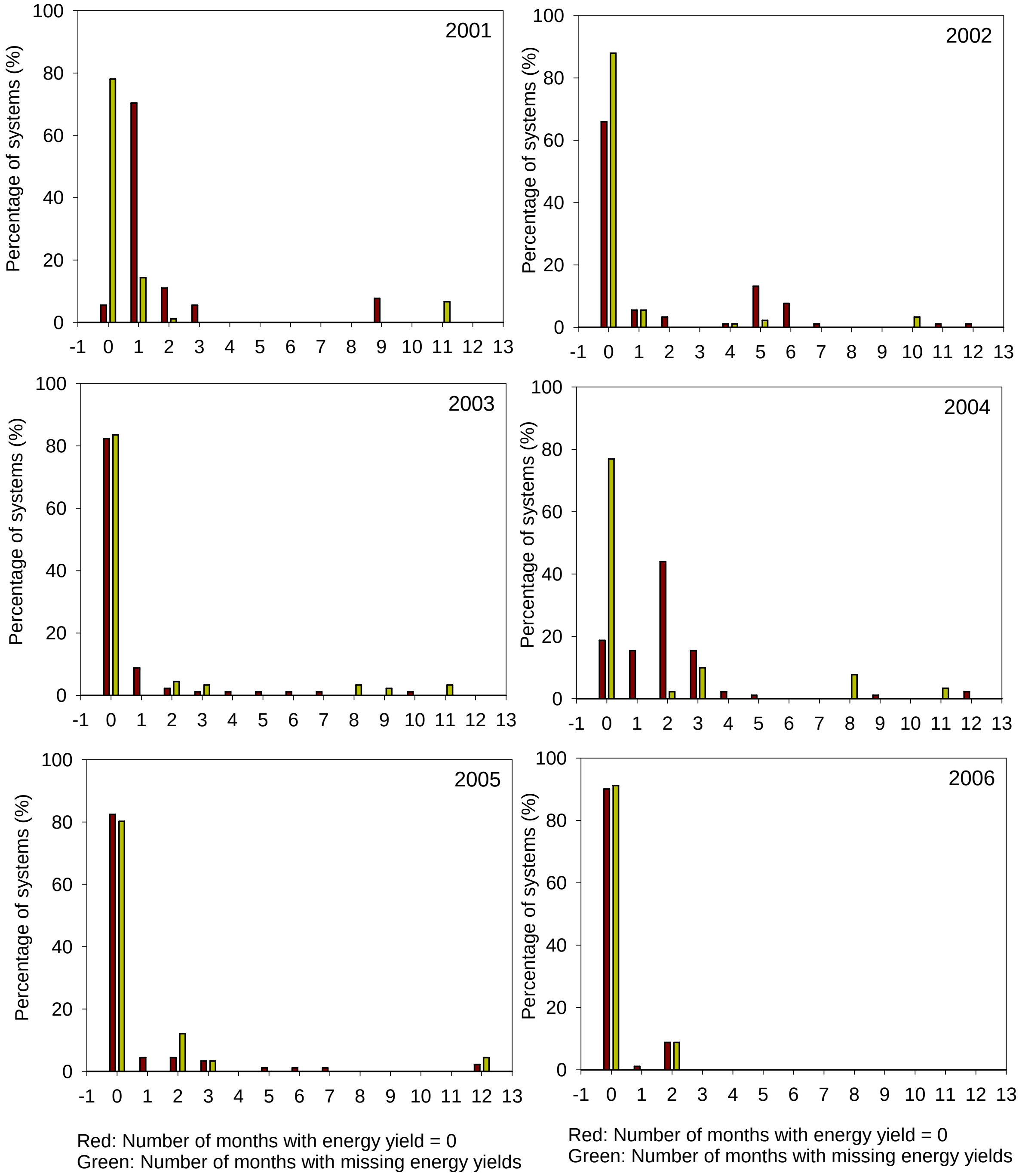


Figure 10.3 Frequency distribution for missing data and data that is zero for the period January 2001 to February 2006. On the horizontal axis the number of months data is zero (red bars) or missing (green bars) is shown, on the vertical axis the percentage of systems.

11. Section O; ten school houses

System description

Section O	Zeldertsedreef
Number of systems	10
Rated Power (per array)	2.57 kWp
Module manufacturer and type	Shell Solar SRT35
Number of modules (per array)	75
Area	29 m²
Inverter type	Mastervolt Sunmaster 2500
Nr of strings	5
Location	Sloping roofs
Integration system	RBB PV700
Orientation	157 (2 syst), 182 (6), 207 (2)
Tilt angle	23 °
Total power (monitored)	25.7 kWp
Monitoring data for period	July 2003 to February 2006

Figure 11.1 Sector O (Google Earth)

In section O 10 school houses have been built with integrated PV systems. These systems have been monitored from July 2003 to February 2006.

Performance of the systems

The monthly performance ratio's for the 10 systems are shown in Figure 11.2. It can be seen that 9 of the systems have been working well, while operating, with a performance ratio around 0.7. Several systems have missing data for several months. These systems have either not been working, data was not successfully extracted from the Eclipse, or there were problems with the datalogger.

Five systems have missing data for several months, these are: Zeldertsedreef 12, 20, 22 and 28. Zeldertsedreef 12 and 20 are respectively missing data for 21 and 18 months, the cause is unknown. Zeldertsedreef 22 and 28 are missing data for respectively 18 and 9 months, at least half of this is due to the lack of data. 5 months of data at Zeldertsedreef 18 are missing.

The system on Zeldertsedreef 14 has a performance ratio around 0.6. The energy yield of this system is 18 % lower than the average 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.

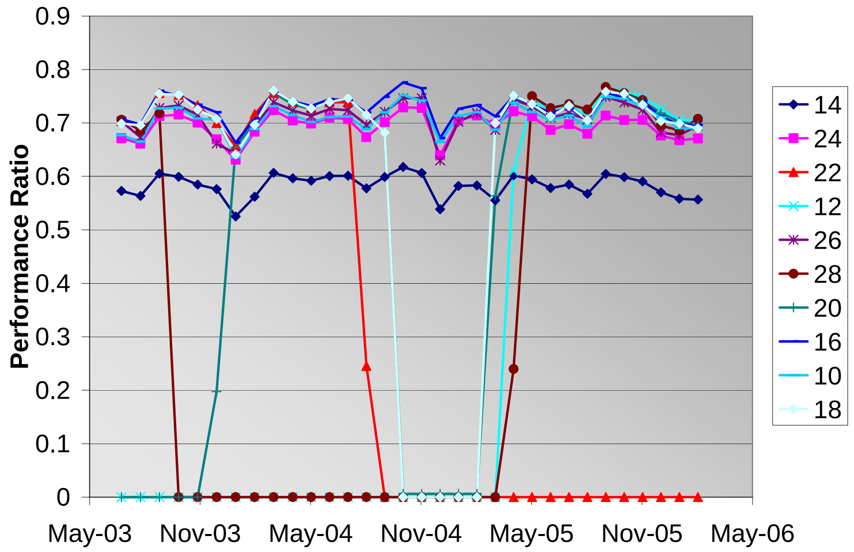


Figure 11.2 Performance ratio for systems in Section O

Frequency plot of PR’s in Section O

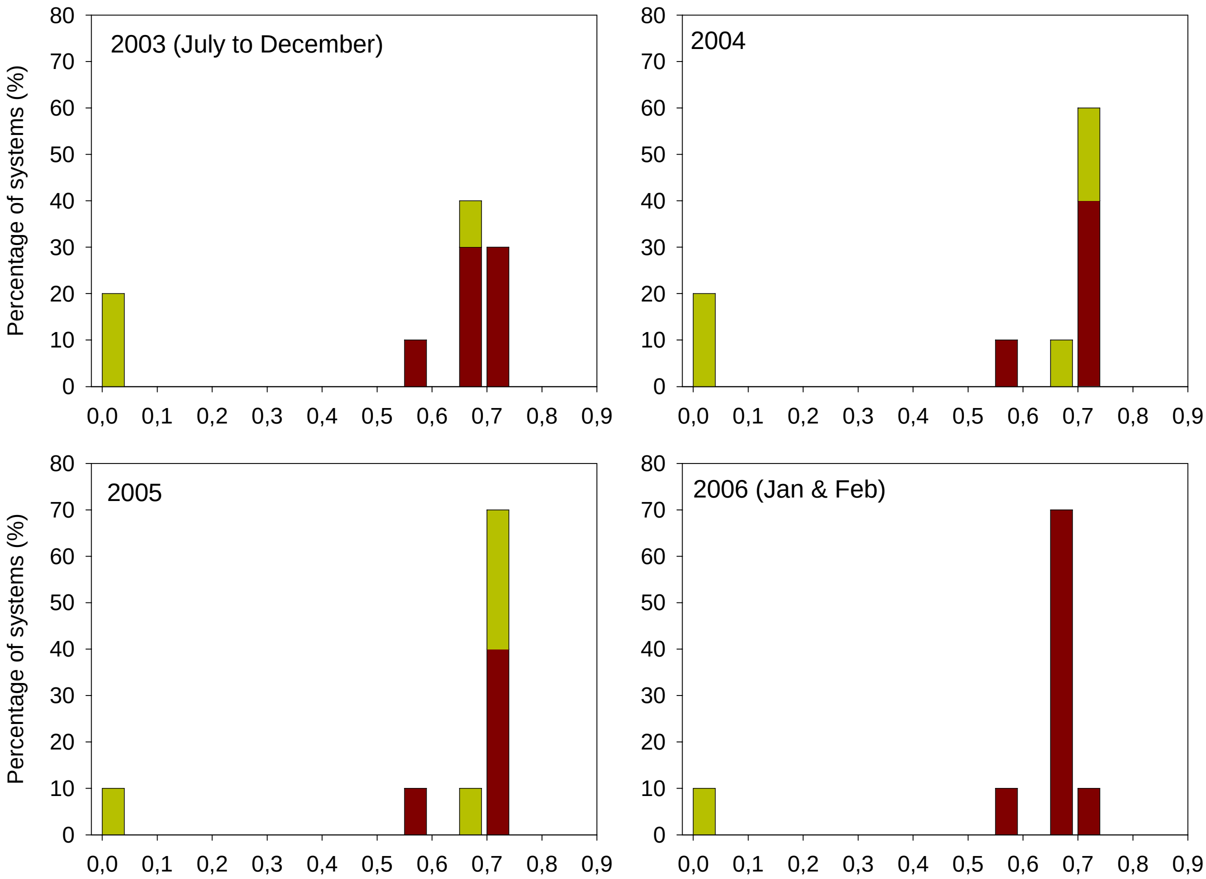


Figure 11.3 The 10 systems of section O are grouped into Performance Ratio ranges, which run from 0 to 0.05, 0.05 to 0.1 etc. The systems which have been operating for the entire time frame are shown in red, those which have data missing for several months (monthly energy yield is less than 5 kWh) are shown in green. The considered time period runs from July 2003 to February 2006.

12. Conclusion and discussion

Discussion

Uncertainties

The calculation of the performance ratios depends on the measured energy yields and the calculated irradiation data in the plane-of-array, assuming the installed peak power is correct. The modules passed the acceptance tests. Therefore we will discuss here the reliability of the measurement data and the irradiation data.

Reliability measurement data

The accuracy of the kWh counters is 2 % (Kil, 2002). The quality of the measured energy yield is thus quite good. For this study only monthly energy yield information was available. Therefore if a monthly energy yield was about half of what was expected, it is not entirely certain if the system was not operating for half a month or that the yield was continuously too low. Also when the energy yield is zero, it may be so for different reasons, e.g. defective logging or the system is off.

Reliability irradiation data

The monthly in-plane irradiation data was calculated by Ecofys with the program PVSyst and based on horizontal irradiation data from the KNMI for De Bilt (about 25 km from Amersfoort). The accuracy for the monthly data was checked by comparing the calculated in plane irradiation values with measured in-plane irradiation for 2001. The measured irradiance values were measured by a reference cell for the analytical monitoring (Kil, 2001). The comparison is shown in Figure 12.1.

Measured irradiation data is circa 10 % lower than the modeled irradiation data for four systems with a tilt angle between 20 and 25 degrees. This difference has a potentially large influence on the performance ratio. The accuracy is higher in summer than in winter. The difference between Shell (3) systems and the BP system is large (~10 %).

There are a number of possible causes:

- The horizontal irradiation at De Bilt differs too much from the horizontal irradiation in Amersfoort
  - Horizontal irradiation should differ at most 5 % on a monthly basis for a 50 kilometer distance and only 1 to 2 % on a yearly basis (reference)
- The calculation method used to convert horizontal to in-plane irradiation is inaccurate
- The measurements of the reference cells are twisted by e.g. shading, temperature?

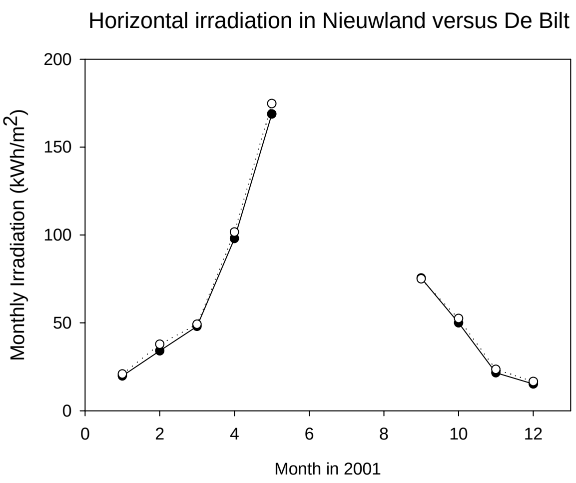


Figure 12.1 Horizontal irradiation in De Bilt versus in Nieuwland as measured with a pyranometer

Flawed irradiation data could cause PR's to be wrong, but it does not explain the large differences between systems. The majority of our analysis would still be valid. This is certainly a topic for further investigation.

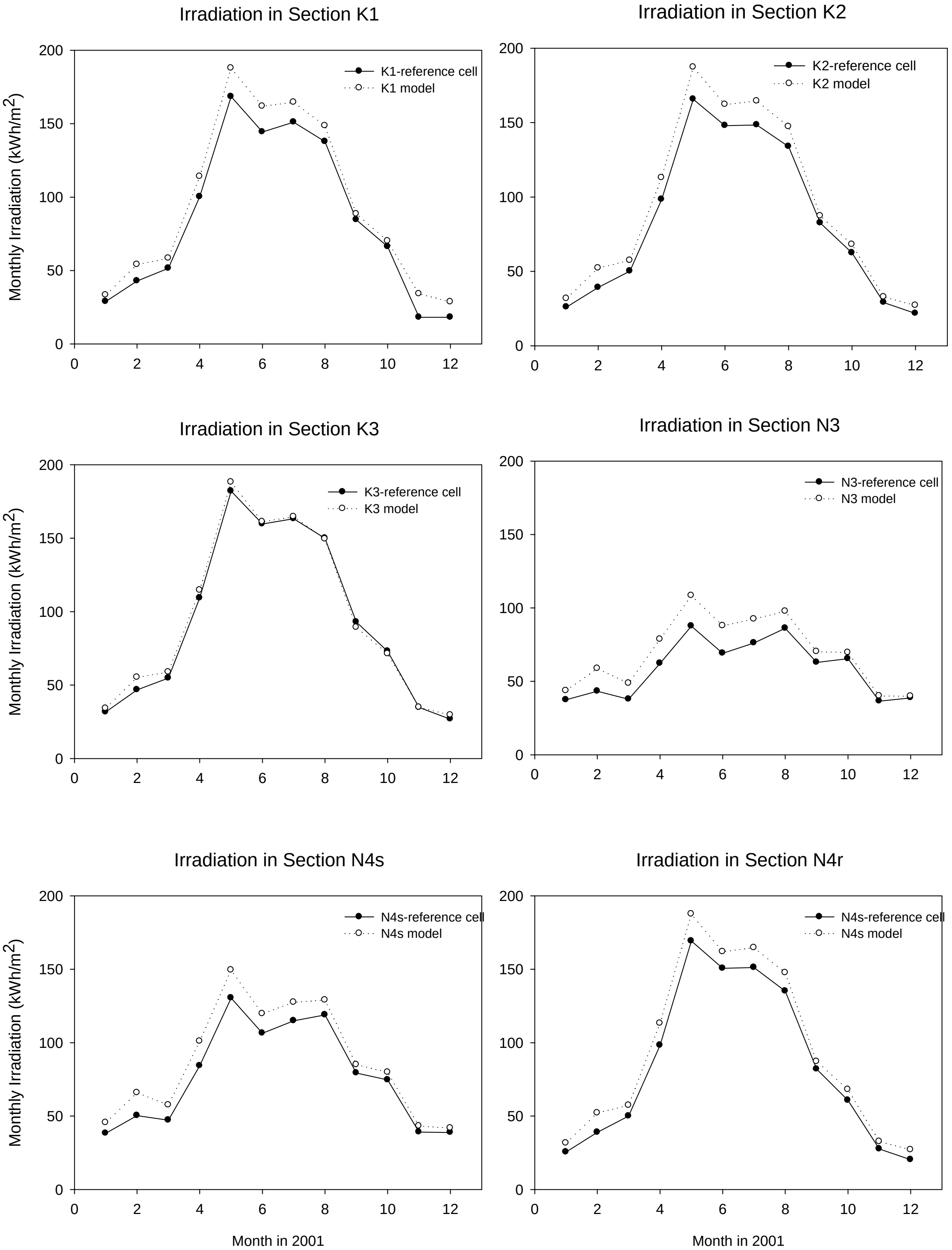


Figure 12.2 Comparison of monthly irradiation in the tilted plane of the reference cell and the model

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 (Welschen, 2007). Part of the connectors causing 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 (Molenbroek, 2000) or through the ‘Sundial’ internet service to keep track of the performance of their system (Molenbroek, 2002). 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.

Conclusion

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.

Recommendations

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.

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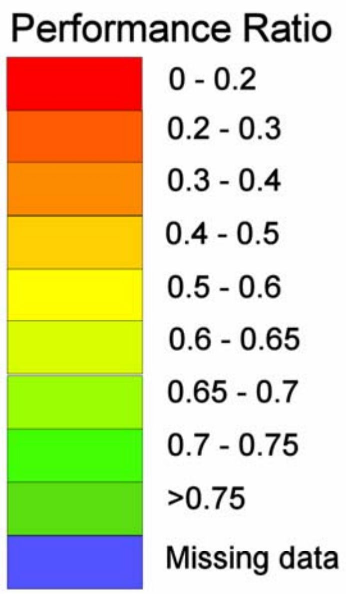
Appendix

On the next pages the performance maps for Nieuwland in the several years are plotted. The legend is shown below. The sectors are as follows:

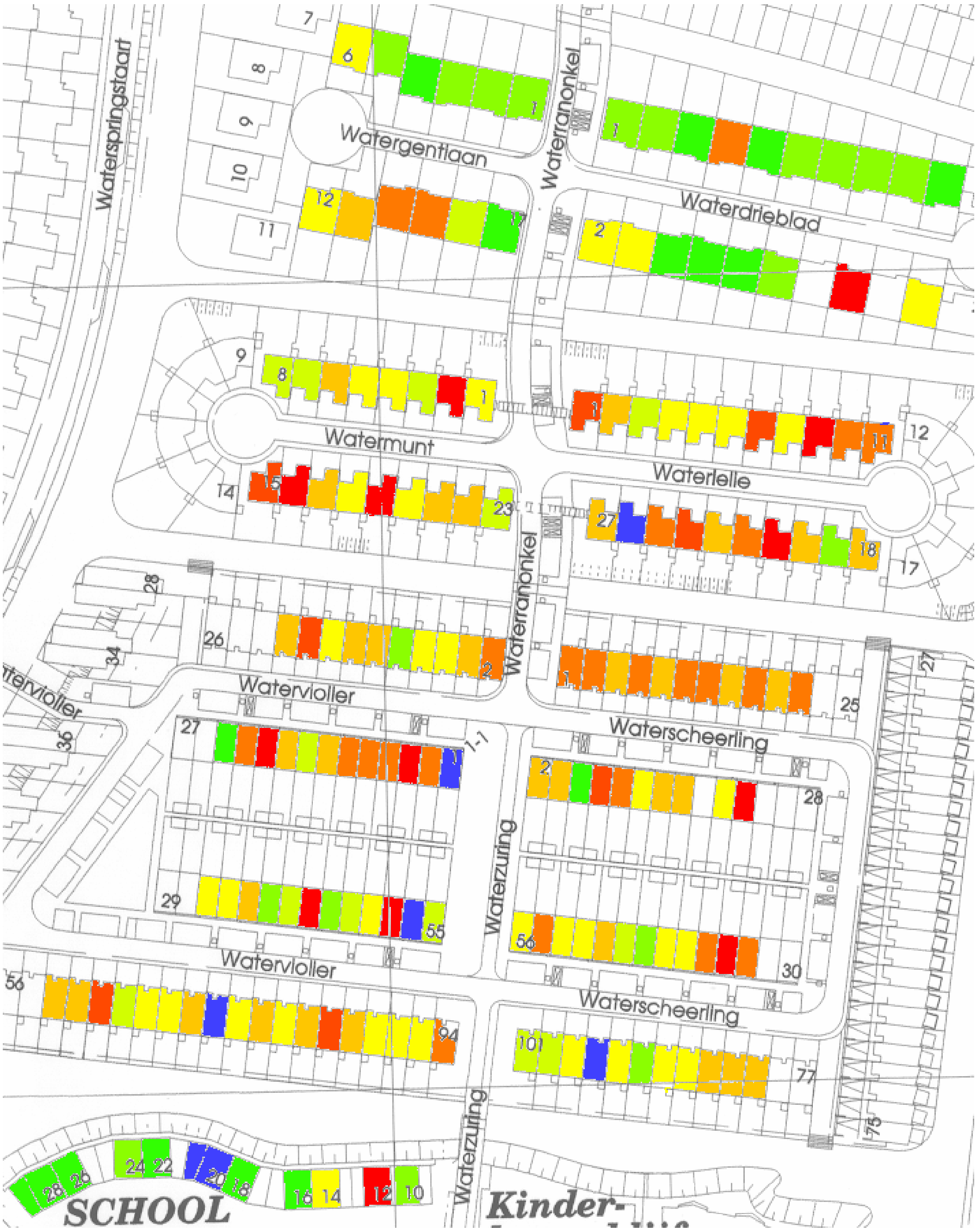
K1: Waterviolier and Waterscheerling
K2: Watermunt and Waterlelie
K3: Watergentiaan and Waterdrieblad
K4: Waterdreef (southside)
N4: Rest of the K4, N4 map
N2: Systems to the west (left) of Gele Plomp
N3: Systems to the east (right) of Gele Plomp



K1, K2, K3 2002

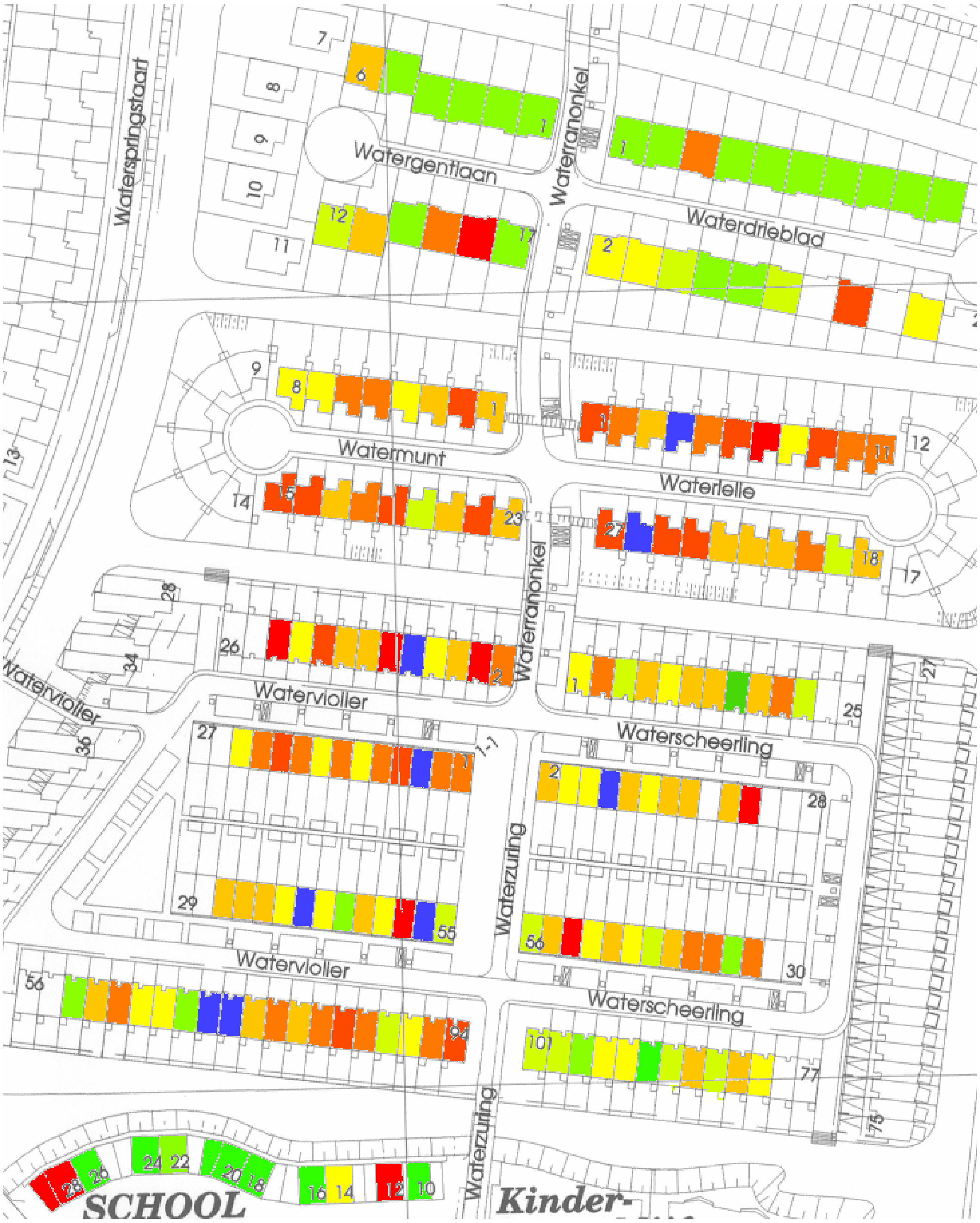
Waterspringstaart
Watergentiaan
Waterranonkel
Waterdrieblad
Watermunt
Waterlelie
Watervioller
Waterscheerling
Waterzuring

K1, K2, K3 2003



Waterspringstaart
Watergentiaan
Waterranonkel
Waterdrieblad
Watermunt
Waterlelie
Watervioller
Waterscheerling
Waterzuring
SCHOOL
Kinder-

K1, K2, K3 2004



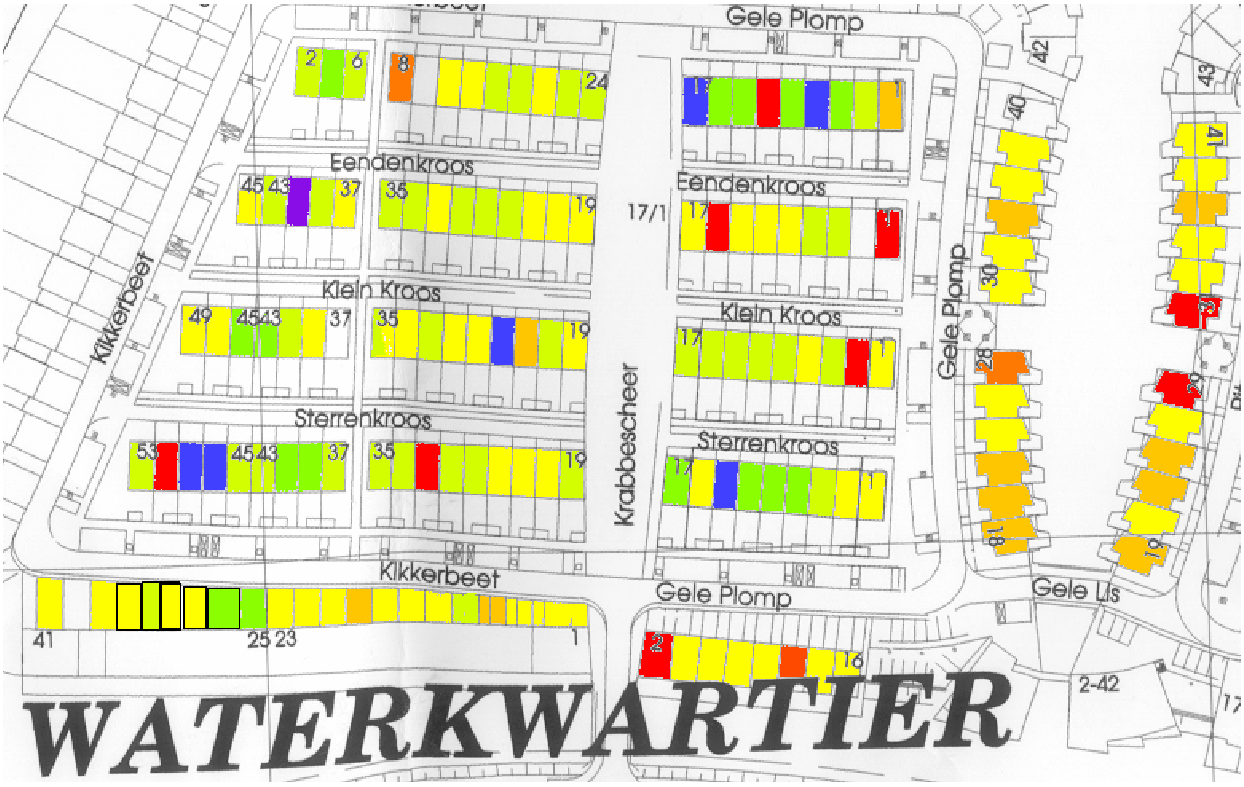
Waterspringstaart
Watergentiaan
Waterranonkel
Waterdrieblad
Watermunt
Waterlelie
Waterviolier
Waterscheerling
Waterzuring
SCHOOL
Kinder-

K1, K2, K3 2005

Waterspringstaart
Watergentlaan
Waterranonkel
Waterdrieblad
Watermunt
Waterlelie
Watervioller
Waterscheerling
Waterzuring
SCHOOL
peuterspeelzaal
't dubbeltje
Kinder-
dagverblijf
Openb. SCHOOL
BORDER

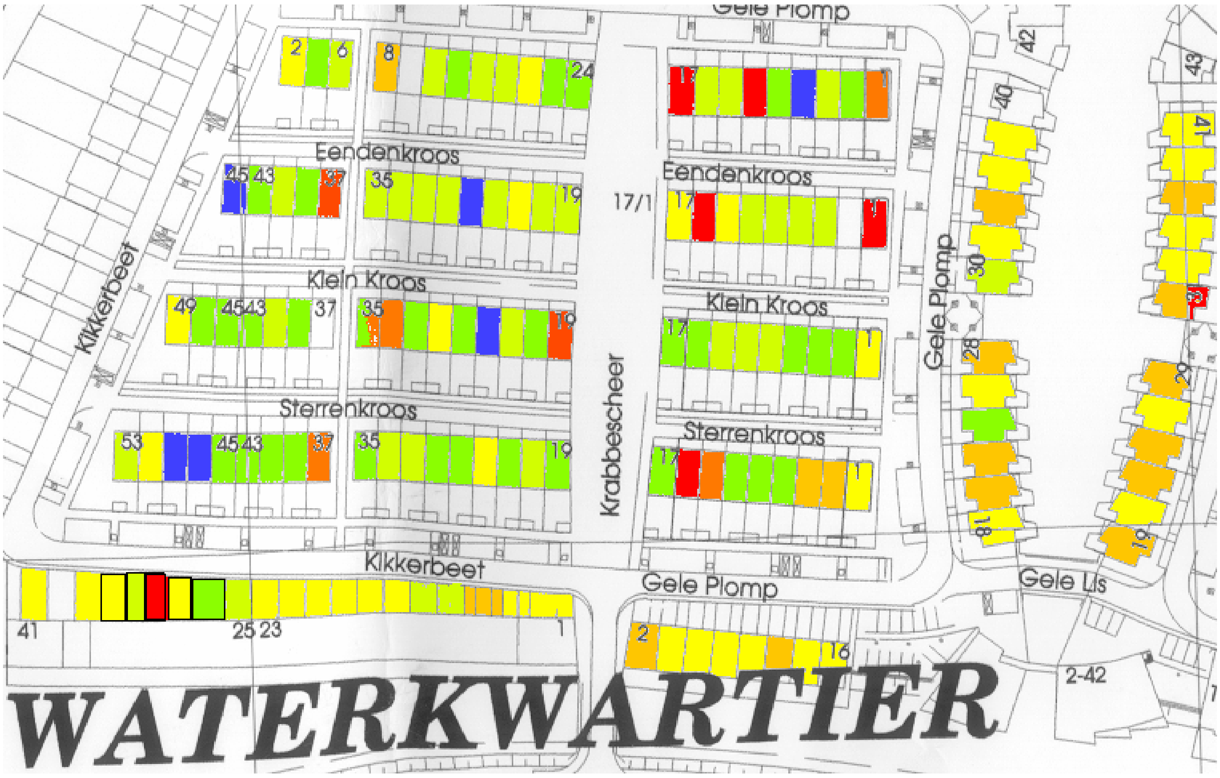
N2, N3 2002

Note: lowest row has 7 instead of 8 strings, this is not taken into account



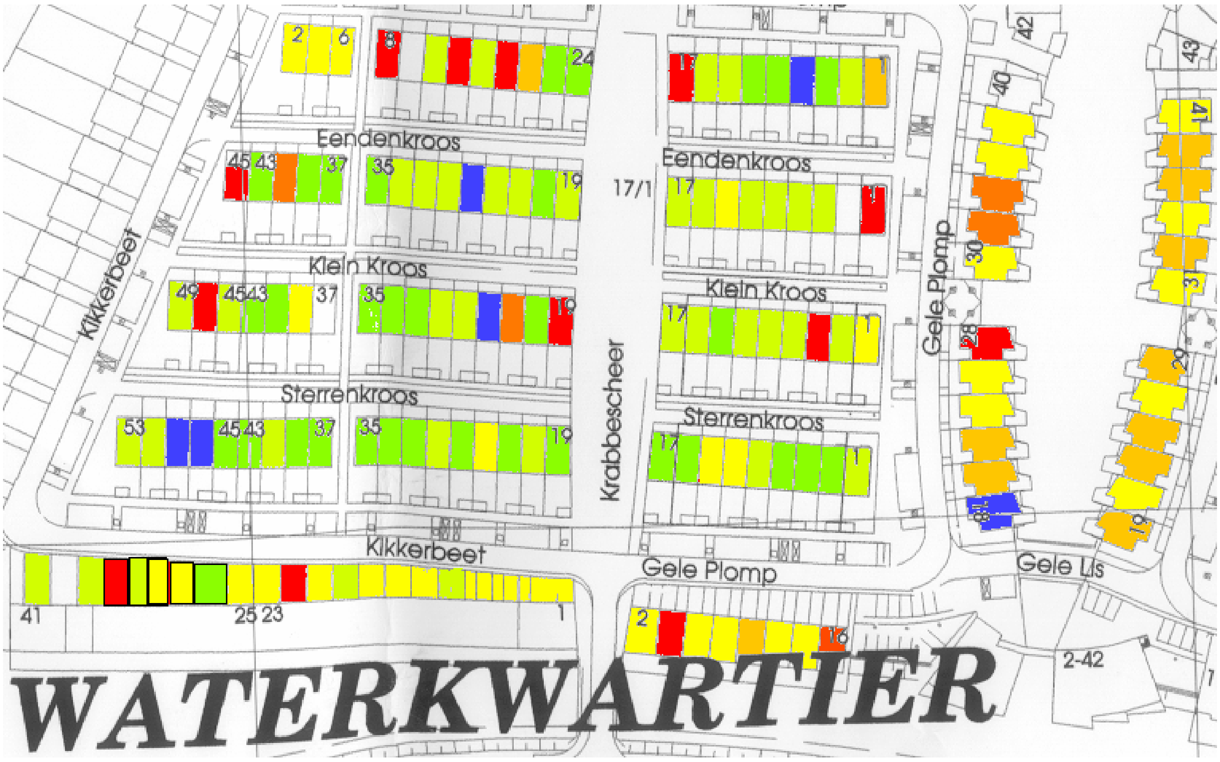
N2, N3 2003

Note: lowest row has 7 instead of 8 strings, this is not taken into account



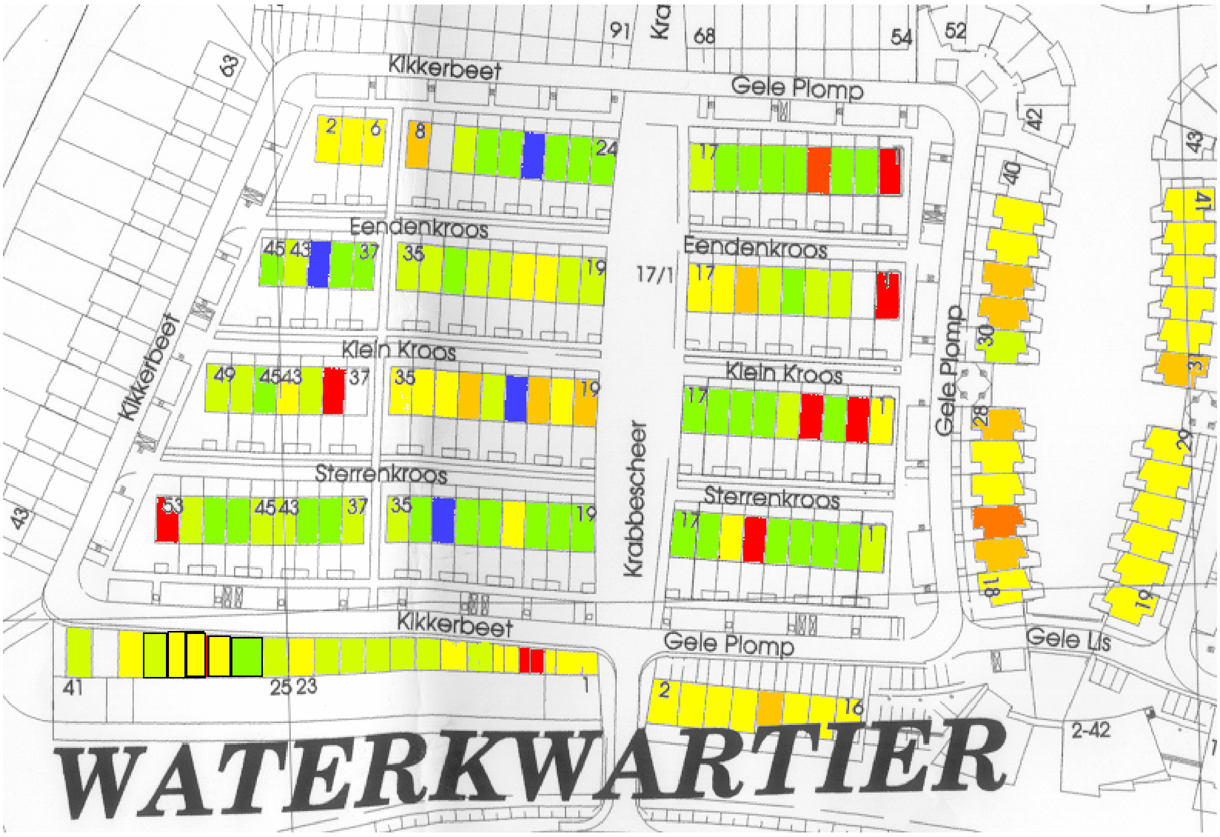
N2, N3 2004

Note: lowest row has 7 instead of 8 strings, this is not taken into account

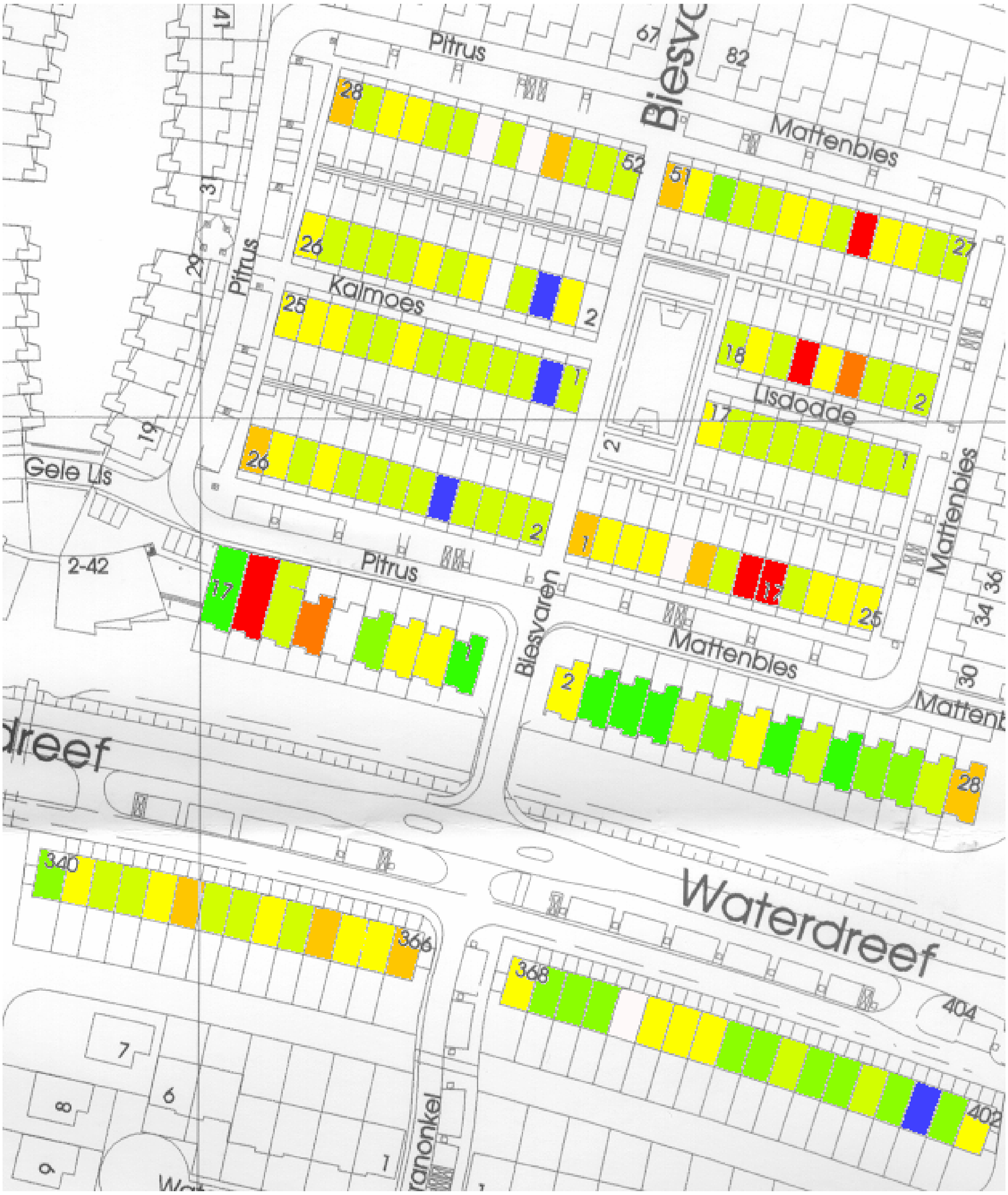


N2, N3 2005

Note: lowest row has 7 instead of 8 strings, this is not taken into account

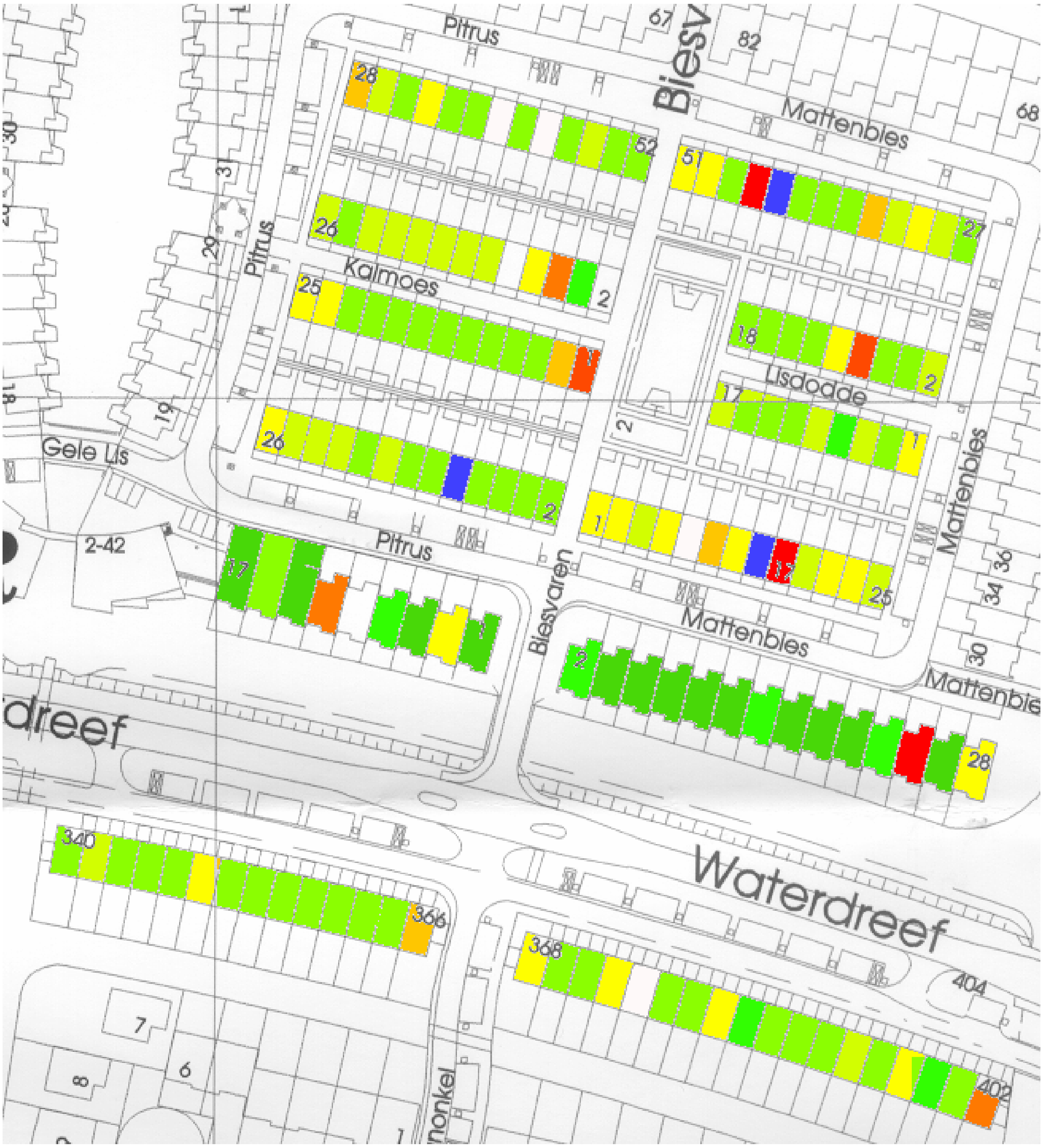


K4, N4 2002

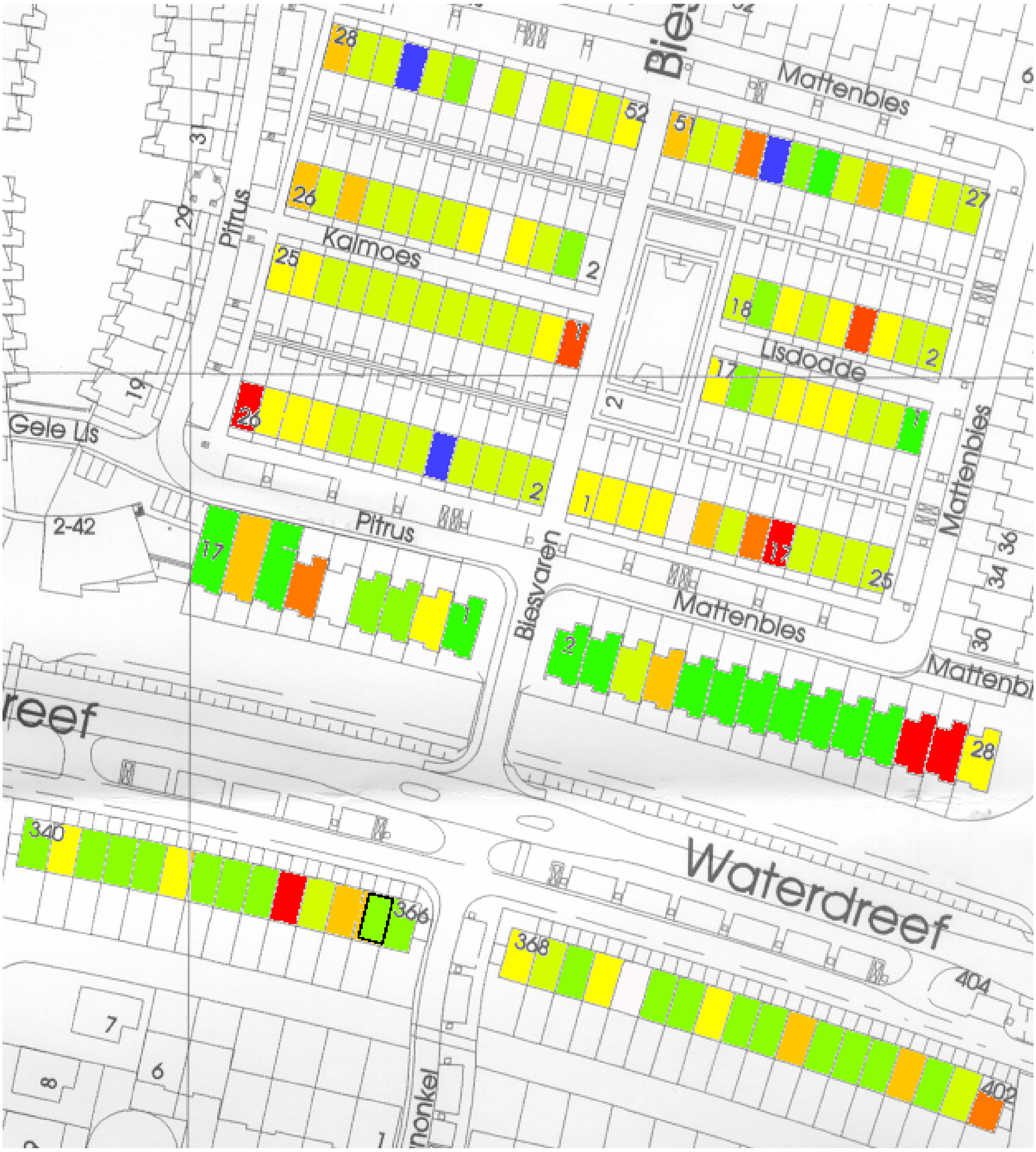


Pitrus
Mattenbles
Kalmoes
Lisdodde
Gele Lis
Biesvaren
Waterdreef

K4, N4 2003

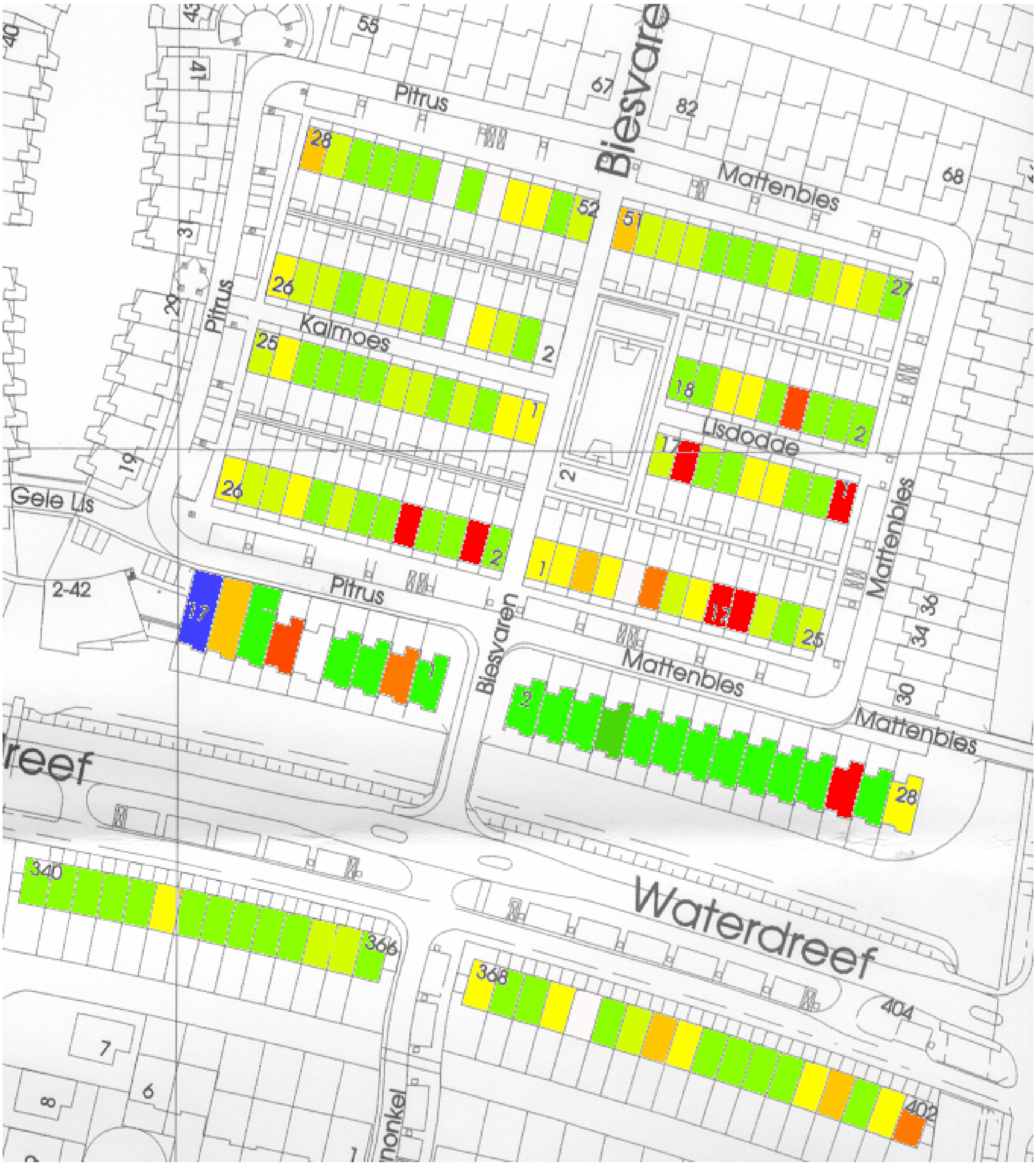

Pitrus
67
82
Biesv
Mattenbies
68
28
52
51
26
27
Kalmoes
25
2
18
Lisdodde
17
1
Gele Lis
2-42
Pitrus
17
Biesvaren
Mattenbies
12
25
Mattenbie
dreef
28
340
366
Waterdreef
368
404
402
7
6
8
30
31
29
19
18
34
36
Mattenbies

K4, N4 2004



Mattenbies
Pitrus
Kalmoes
Lisdodde
Gele Lis
2-42
Pitrus
Biesvaren
Mattenbies
Waterdreef
reef

K4, N4 2005


Pitrus
Biesvaren
Mattenbies
Kalmoes
Lisdodde
Gele Lis
Waterdreef