1,3 MWATT INTEGRATED PV-ROOFS PROJECT

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ABSTRACT

The application of Photovoltalic (PV) systems has been supported strongly by the Dutch Government during the recent years. Several big projects have been heavily subsidised. At first instance this seems surprising, because the costs for PV-systems are very high, specifically in The Netherlands, with low energy prices and a very efficient energy distribution network. The policy however, is based on the opinion that large-scale introduction of network coupled PV-systems is the best solution to the future shortage in fossil fuels. An important advantage of PV-systems is that they do not have any moving parts and therefore are practically maintenance free and also do not produce any noise. Specifically when they are integrated in the building envelope (as building materials) they do not require any extra space such as windmills.

Two major projects that recently have been realised are Nieuw-Sloten near Amsterdam and Nieuwland at Amersfoort with 250 kWp and 1,3 MWp installed capacity respectively. The paper describes the research that has been done to develop the first generation of roof-integrated PV-systems (Nieuw-Sloten and partly Nieuwland) and the second generation, based on

performance evaluation of the Nieuw-Sloten project and applied in a part of Nieuwland.

ZUSAMMENFASSUNG

Die Anwendung von Photovoltalic (PV) Systeme sind stark von der holländischen Regierung während der letzten Jahre unterstützt worden. Mehrere große Projekte wurden schwer subventioniert. Zum Erstem scheint dies zu überraschen, da die Preise für PV-Anlagen sehr hoch sind, besonders da in Den Niederlanden niedrige Energie-Preise und ein sehr tüchtiges Energie-Verteilungs-Netzwerk vorhanden sind. Die Politik wird aber auf der Meinung gegründet, daß eine großangelegte Einführung von Netzwerk PV-Anlagen die beste Lösung zum zukünftigen Mangel in Fossil-Brennstoffen sei. Ein wichtiger Vorteil von PV-Anlagen ist, daß sie keine beweglichen Teile haben und deshalb praktisch Unterhaltsfrei sind, und lautlos arbeiten. Besonders wenn sie im Gebäude-Umschlag integriert werden (mit Konstruktions Materialien), da sie keinen extra Raum erfordern, wie zum Beispiel Windmühlen.

Zwei größere und wichtige Projekte wurden kürzlich in Nieuw-Sloten, in der Nähe von Amsterdam, und Nieuwland bei Amersfoort mit 250 k Wp und 1,3 MWp installierte Kapazität beziehungsweise fertiggestellt. Das Papier beschreibt die Forschung, die gemacht wurde, um die erste Generation dafür zu entwickeln - Dach-integreated PV-Anlagen (Nieuw-Sloten und teilweise Nieuwland), - und die zweite Generation - basierend auf Leistungs-Einschätzung des Nieuw-Sloten Projektes und angewandt in einem Teil von Nieuwland.

RÉSUMÉ

Au cours de ces dernières années, l’utilisation des systèmes photovoltaïques (PV) a été vivement soutenue par le gouvernement hollandais. Plusieurs grands projets ont, en effet, été fortement subventionnés. Cela semble à première vue surprenant étant donné le coût élevé de ces systèmes ; surtout aux Pays-Bas, où le coût de l’énergie est faible et le réseau de distribution performant. Cependant, la politique consistant à introduire à grande échelle les systèmes PV en couplage avec le réseau existant, est la meilleure solution à la future crise de l’énergie fossile. Ces systèmes présentent un avantage

important : ils ne possèdent aucune partie mobile. Ils ne nécessitent donc pratiquement pas d'entretien et fonctionnent sans aucun bruit. De plus, quand ils sont intégrés aux bâtiments en tant que matériau de construction, ils ne demandent aucun espace supplémentaire contrairement aux moulins à vent, par exemple. Les deux projets majeurs qui ont été récemment réalisés sont Nieuw-Sloten à côté d'Amsterdam et Nieuwland près d'Amersfoort, avec des capacités respectives de 250 kWp et 1,3 MWp.

Cet article présente les recherches qui ont été menées pour développer, d'une part, la première génération de systèmes PV, intégrés aux toits des bâtiments (à Nieuw-Sloten et en partie à Nieuwland) ; et d'autre part, la seconde génération, fondée sur les performances évaluées lors du projet Nieuw-Sloten et appliquée en partie à Nieuwland.

INTRODUCTION

PV-systems (Photovoltaic or Solar panels) on roofs of residential buildings, have been applied in the Netherlands for about 10 years now. PV-panels convert solar energy into electricity. The first house with a PV-system roof in the Netherlands was built in Castricum and is a so-called stand-alone system, where the generated electricity is stored in batteries. More recently, the residential PV-systems in the Netherlands are hooked up to the electricity network utilities because of its extensive storage capacity. Excess output can be fed back in the network and shortages can be supplemented from it.

In the past few years, significant experience was gained on PV panel integration in roofing systems. Problems have appeared in the area of the building's structural functioning due to insufficient preparation and research on the system to be applied. A number of problems with PV roofs, specifically water leakage, has occurred in so called learning-projects. Extensive testing of the integrated PV roof system prior to application in the field will lead to improved performance and functioning in the application. Such testing typically includes the evaluation of the system's watertightness, thermal performance, wind up-lift resistance and reaction-to-fire aspects.

BDA Dakadvies B.V. has been active in the field of integration of PV in roofs since 1994. In the past recent years many systems have been tested and a variety of building projects were inspected, contributing to an extensive overview of the methods of integrating PV panels in roofing systems and the way these systems should be tested. One of the most important things we have learned from this work is that by prototype testing of PV-systems a lot of trouble with leaking roofs can be avoided. Another important measure is to install always a vapour-open water-retaining membrane underneath a waterproof PV-system. In certain areas however the collected knowledge remains insufficient. This paper will address the achievements of the past years with respect to an important project, the 1,3 MWp integrated PV-roof project in Nieuwland, Amersfoort, The Netherlands.

Figure 1. Overview of the Nieuwland project.

Test procedures

During system testing at BDA it occurred that the current Dutch standards, as referred to in the Dutch 'Bouwbesluit' (Building Decree: public legislation regarding building requirements for new constructions), section watertightness, insufficiently warrants a waterproof PV roof in actual applications. Watertightness testing of building envelope structures is performed in compliance with NEN 2778 'Moisture prevention in buildings, testing methods'. This standard describes a test model set up and procedure to expose the model to a water quantity of $2 \cdot 10^{-3}\ m^3 \cdot m^{-2} \cdot min^{-1}$.

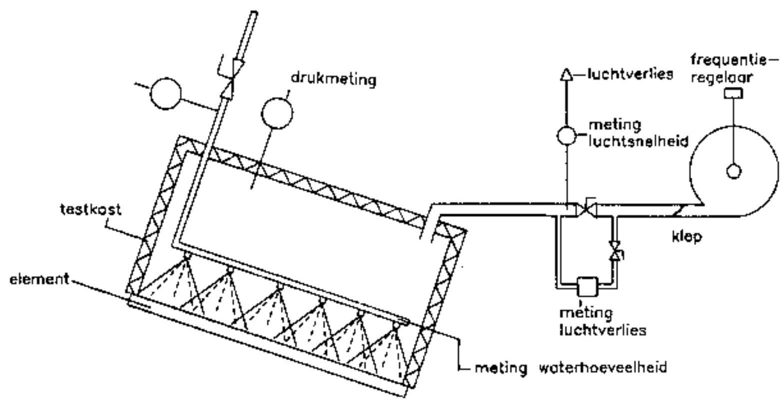
During the test, the pressure differential across the dividing structure is increased from 0 Pa to a prescribed test pressure. This test pressure varies, depending on the actual height in the application. PV-systems however, are mostly applied on roofing elements (roof boxes, sandwich elements, hinged frames, etc.), where ventilation between the PV-system and the lower roofing elements exists. During testing of a PV-system using a static pressure differential according NEN 2778, the pressure differential will apply to the roofing elements instead of the PV-system. Small chinks and openings in the PV-system will not result in leakage during this test, whereas the wind loads and rapidly changing pressures ('driving rain') in the application will cause leakage due to the pressure differentials across small openings in the PV-system. Due to the imperfections in the test methods, PV-systems with insufficient quality, however tested with good results, can reach the market. Consequently, this does not mean that the PV-system is in compliance with all legal requirements. The BDA-INTRON directive for PV integrated roofing systems on sloping roofs therefore includes an additional requirement to determine the watertightness of the system. This will be explained hereafter.

Determination of watertightness

Test set up requirements

To determine the watertightness of a PV-system, a representative section of the construction has to be reproduced. The testing- or certification institute will define what will qualify as representative. The roof system test model has to include at least the details that will be listed in the KOMO agrément certificate. Multiple tests may have to be executed when it is impossible to include all these details in one test model.

Figure 2. Watertightness test



Static test without pressure differential

A sprinkler grid which provides an amount of water of $2{\cdot}10^{-3}$ $m^3{\cdot}m^{-2}{\cdot}min^{-1}$ is mounted over the test model. When testing the watertightness of a PV-system, section 1 of the test procedure is mandatory: The model has to be soaked for 15 minutes without pressure differential applied. After the soaking of the PV-system according method 1 no water shall be found on the lower roof. A visual inspection within 5 minutes after completion of the test will indicate if the system is capable of meeting this requirement.

Alternative static test with pressure differential.

Three testing methods are available, where the selection of one depends on whether ventilation in the area under the PV-system is provided or not:

1. With a non ventilated airtight PV-system the pressure differential across the entire PV-system shall be increased in steps of 50 Pa up to the test pressure as described in the NEN 2778. Each step shall have a 5-minute duration, during which water spraying is applied.

2. When the area below the airtight PV-system is in open connection with the outside air and the PV-system itself is airtight, the pressure differential across the PV-system will be increased in 5 Pa increments up to an 80 Pa maximum

(see figure 3). Each step shall have a 5-minute duration, during which water spraying is applied.

3. No static pressure differential will have to be applied over the PV-system if this system is not airtight in the plane. Only the static test method and the dynamic test will have to be conducted.

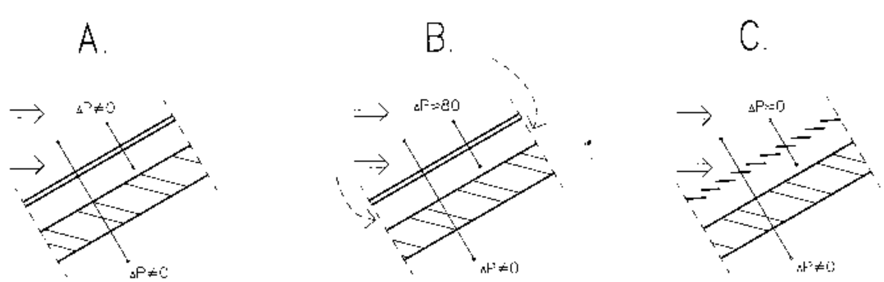
Dynamic test

In addition to the watertightness test of the entire roof surface, all details need to be tested dynamically. The details are exposed to a fan generated wind load equivalent to 12 $m \cdot s^{-1}$. A water quantity of $2 \cdot 10^{-3}$ $m^3 \cdot m^{-2} \cdot min^{-1}$, in accordance with the static test, shall be applied simultaneously. All details present in the PV-system shall be sprayed: parallel to the roof plane, perpendicular to the detail; at a 45° angle with the roof plane and a 45° angle with the detail's perpendicular.

For the investigation, three different systems are considered:

A. Non ventilated PV-systems, which are subjected to currently known tests.
B. PV-systems mounted on an airtight substructure, where ventilation between the PV panels and the substructure is provided through ventilation openings on ridge and gutter sides.
C. PV-systems that are open in the PV plane, mounted on a roof waterproofing structure which in turn is installed on an airtight substructure.

Figure 3. Three different systems to be considered.



To determine the developing wind pressures to which the systems are exposed, measurement in the application is the only available method. This requires the construction of test roofs for each of the three mentioned systems. Research during the testing is required to determine the effects of resizing the cavity below the panels, enlarging or reducing the size of the ventilation openings, etc.

Effect of ventilation on the annual output of PV-systems

The question whether cavity ventilation below PV-systems exists and its effects on the system's output performance, has been discussed for a number of years now. To obtain more clarity regarding this subject matter, testing and test model validation will have to reveal the effects of cavity ventilation and the degrees in which cavity ventilation develops with the currently applied systems. This can be accomplished through measurement and CFD simulation programs. For the investigation three different systems shall be considered as described.

Manufacturers of multi crystalline PV panels emphasise the importance of cavity ventilation. The reason for this is that the output performance of most commonly used panels is reduced with 4% for each increase of 10 °C in temperature, related to the reference temperature of 25 °C. Based on experience (test data), the temperature can reach levels of about 75 °C in the summer season, which causes a 20% reduction in the output performance.

However, the question remains to which degree cavity ventilation takes place in current systems. Because of several dimensional changes in the cavity an increased air flow resistance is caused. The actual levels of ventilation will be lower than what could have been expected. Further research is required in order to make the right selections in this regard. Collecting test data in the field as well as on a test model with optimised cavity geometry can provide further insight. Additional CFD computer simulations are meaningful because a reduction in the number of tests is possible.

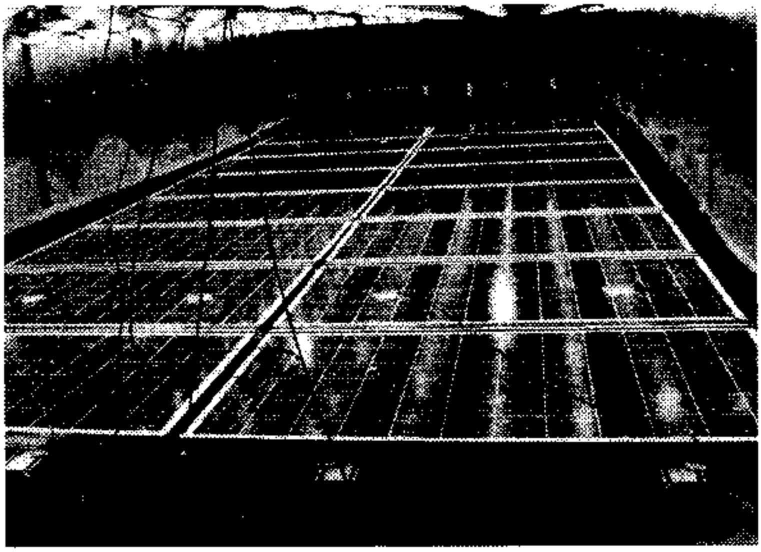
Furthermore, simulation calculations by Van de Pol (1997) show that the positive effect of ventilation on the yield of a solar system during a year is very limited. For example, the difference with this effect in the situations 'no ventilation' and 'forced ventilation' (0,5 $m.s^{-1}$) is only 1,3%. The same simulations also show that a decrease in cavity-resistance by a factor 10 results in an increase of the efficiency of the panels of only 0,33%. It is therefore very questionable wether the attention for the efficiency, when considered for a whole year, is worth the effort.

Experiences with the Nieuwland project

During the Nieuwland project a lot of things went wrong with the integrated PV-roofs. Most of the time this was due to the time pressure on one hand and the communication structure on the other. Despite agreements which were made between different firms regarding prototype testing beforehand and inspections on the site, prototype testing took place after the integrated PV-roofs were installed. The planning of inspections was very difficult because the firm which had to carry out the inspections had to be triggered by an consultancy firm which did not have a direct sight on the construction site. During the prototype testing afterwards BDA found out that some systems did not meet the requirements on the aspect of watertightness. This meant that the systems, which were already mounted, had to be modified while the dwellings were already inhabited. These modifications lead to questions of the inhabitants of the dwellings and therefor did not contribute to the acceptance of solar energy. Inhabitants expect their roofs to be 100% watertight. Therefore, in the future prototype testing has to be executed beforehand. This means that in the time schedule prototype testing shall be enclosed.

Beside the problems with prototype testing and inspections on site, it also became clear that not all, vapour-open water-retaining membranes are resistant to the high temperatures onto which they are exposed when used underneath an integrated PV-roof. Also it became clear that the membranes have to be of a superior quality. Micro perforated membranes are not recommended.

Figure 4. Prototype testing of a PV-roof. Thermal shock test during which the prototype is heated up until 75 °C and afterwards cooled down with tap water until 15 °C.



Despite the problems mentioned before and the modifications which needed to be done, the inhabitants of the district Nieuwland are positive about the use of solar power integrated in roofs.

Conclusions

1. During the last years the knowledge regarding the use of PV in buildings has increased and the method for testing the watertightness has been refined.

2. By testing PV-systems by the new method for watertightness there is more security that a system which meets the requirements will also be watertight in real building projects.

3. The experiences with the Nieuwland project show that prototype testing and well communicated inspections on the building site are very useful and result into much less performance problems.