PLUG-AND-PLAY LIQUID PV THERMAL PANELS –

INTEGRATED DESIGN FOR EASY MANUFACTURING AND INSTALLATION

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ABSTRACT

A photovoltaic-thermal panel or PVT panel simultaneously generates heat and electricity. This paper reports about the design of a new PVT panel by paying specific attention to user requirements, costs, manufacturing, building integration and installation. The panel's technical aspects and energy performance where also optimized. The result is a plug-and-play liquid PVT panel which consists of a PV laminate glued on top of a plastic channel absorber. The panel is covered by a plastic layer to reduce heat losses. It is equipped with four connection points which enhance the flexibility of the positioning of PVT panels on a tilted roof. Because of this feature the installation process will be simplified and installation costs will be decreased. Since part of the production process can be automated, production costs can be decreased as well. In Western Europe at an irradiation of 1000 kWh/m2.year, the PVT panel is expected to yield about 100 kWh/m2 of electricity and 1.0 GJ/m2 of heat.

INTRODUCTION

A photovoltaic-thermal panel or PVT panel generates both heat and electricity at the same time. The main advantages of PVT panels, compared to sole thermal collectors and sole PV systems, are a higher energy yield, lower material and installation costs and architectonical uniformity on the roof.

Until now, prototypes of several PVT concepts have been developed and tested. A large field test with 45 m^2 of PVT collectors was carried out in the UK. In the EU project PV-Catapult a PVT Roadmap [1] and a guideline for PVT performance testing [2] have been developed. Though expectations are high, until now PVT panels have appeared on the market only to a limited extent. Apart from this fact, nowadays they perform well given an up-to-date evaluation of seventy realized demonstration projects worldwide [3].

In product development of current liquid PVT panels (see Figure 1) the improvement of the energy performance has been the first priority. Since technology is only one out of many topics to be considered for successful industrial product design, in our project we designed a PVT panel while paying attention to user requirements, costs, manufacturability, building integration and ease of roof installation without losing touch with the technical and energy aspects. The result is a plug-and-play liquid PVT panel. The panel has been designed for usage in the Netherlands and other West-European countries in the year 2020. In the Dutch climate with an annual irradiation of 1000 kWh/m2, a PVT panel would annually yield about 100 kWh/m2 of electricity and 300 kWh/m2 of heat.

Fig. 1. A conventional PVT panel heats water in tubes and generates electricity by PV cells. The photo shows the electrical and thermal parts.

The project has been collaboratively executed by the unit Energy in the Built Environment of the Energy Research Centre of the Netherlands (ECN), which conducts research on the performance of PVT panels, and the department of Design, Production and Management of the University of Twente, which has a focus on research in design processes for sustainable energy systems. The Dutch company PVTwins, which is manufacturing PVT modules for commercial use, took part in the project as a future user of the results of our project.

The design process applied in this project consists of five phases, i.e. (I) analysis, (II) set-up of requirements, (III) concept development, (IV) selection of an appropriate concept and (V) final design. In the following sections we will explain and illustrate each phase with results. The paper will be completed by conclusions.

ANALYSIS

The analysis focused on technical aspects of PVT panels, costs, market developments, the built environment and installation aspects. By a stakeholder analysis of the PVT field, actors were categorized.

Main actors that will profit from a new design of a PVT panel are installation companies, architects, and occupants of houses with solar panels. Therefore, an inventory is made of their whishes and demands by personal communications and interviews.

Looking at the installation process, it appears that the current PVT panels' weight is too heavy for a proper installation. Since it is about 70 kg, four men are required to precisely place the 2.5 m2 panel at its position. Moreover, flashing sets are required to properly drain rain water between the PVT panels and the roof tiles. Adding to this, since roof tiles are produced in different dimensions, they often have to be cut to connect to the dimensions of a PVT panel. This is undesirable.

Architects' most important aspect requirement is that PVT panels fit in the environment of use and to the style of the building on which they are installed This requirement might conflict with the –current- high-tech appearance of PVT panels According to architects, inconspicuous charcoal-grey panels are more favorable. Furthermore attention should be paid to an aesthetic finishing of the sides of the panels; especially the changeover from one panel to another or to the roof tiles should be smooth. Finally, for building integration flexibility in the dimensions of the PVT panels is desirable.

Recently, it was found by interviews with occupants of dwellings that the presence of PVT panels hardly influences the appreciation of the building by its occupants. Generally, full roof systems with dark solar cells are appreciated best by occupants, because of the full integration in the building design, less outstanding PV cells, and a nice and calm appearance of the roof.

Table 1. Dutch standards regarding PVT systems

Code or name	Topic
NEN-EN 12976-1	Thermal solar systems and components – Factory made systems – Part 1: General requirements
NEN-EN 12976-2	Thermal solar systems and components – Factory made systems – Part 2: Test methods
NVN 7250	Solar energy systems – Integration in roofs and facades – Building aspects
Bouwbesluit	Legal Dutch building code
Arbowet	Legal Dutch regulations for employers and employees concerning labor conditions.

REQUIREMENTS

Requirements for the design of a new PVT panel followed from the analysis phase. Here we list a few of them. The PVT panel's electrical output should be in the order of 100 kWh/m2.year with a thermal output of 300 kWh/m^2.year. The costs price target is less than 750 euros/m^2. The minimum life time of the panel is 25 years. The product must be suitable for integration in roofs with a minimal tilting angle of 20 degrees from the horizontal plane. Also it must be suitable within new housing development projects and (roof) renovation projects and comply with the Dutch regulations for the construction buildings with regard to safety, health, usability, energy efficiency, and environment. The system must meet with the norms for solar energy systems (see Table 1) and withstand various weather conditions, fire and damage by animals.

The system is preferably produced locally, automated, and in mass-production. The installation of the system must be easy, clear, and fast. The system must be able to connect to the regular heating unit and the public electricity grid. The panel must fit in its environment and be consistent with the style of building that is used.

CONCEPT DEVELOPMENT

Using different brainstorm techniques a variety of ideas is generated. The ideas can be categorized into the categories shape of the panel, thermal connections, joining between the panels, joining between the panels and the roof, physical working principle, and attachment of the panels to the roof, see Figure 3. The main challenge of this project was to combine the good ideas of each category into one design.

Three concepts for a new PVT panel have been designed based on the ideas within the different categories. Each concept has a different focus, being efficiency, costs and building integration. They are called Traditional, Plastic and Skylight.

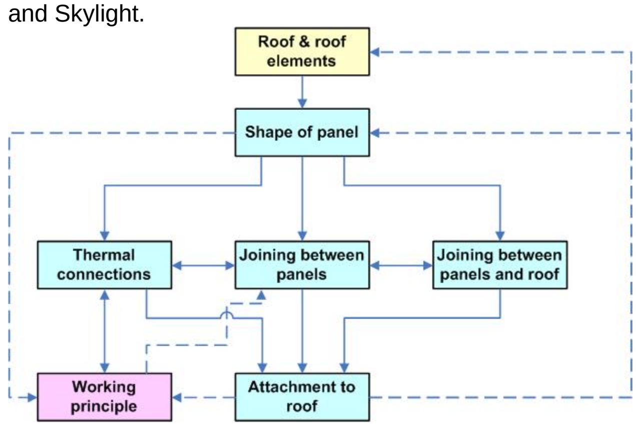

Fig. 3. Schematic overview of relations between technical topics during concept development.

Concept 1: Traditional

The first concept is called Traditional, since it looks the most like the PVT panel we already know (see Figure 1 and Figure 4). The focus of this concept is on efficiency.

The panel consists of a PV laminate glued on a copper sheet-and-tube absorber and is covered with a layer of glass to reduce thermal losses. The PVT panel has two connection points, positioned at two opponent sides. To attach the panels to the roof, they can be slid between special joining rails, which are attached to the roof. This is depicted in figure 5. Advantages of this concept are the well-known technology and the high efficiencies. Disadvantages are the high weight and costs due to the copper and glass.

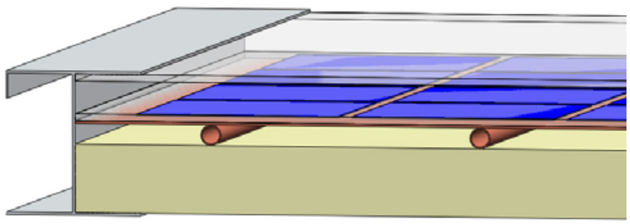

Fig. 4. Cross-section of concept Traditional.

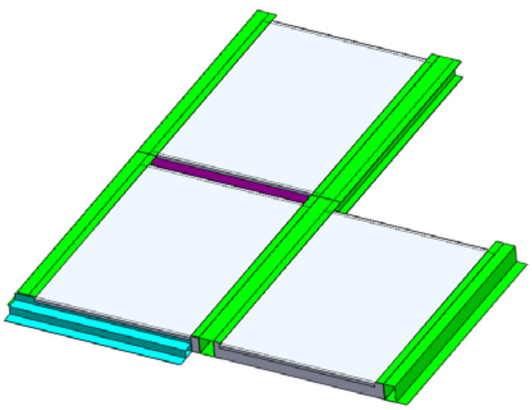

Fig. 5. Joining system for concept Traditional.

Concept 2: Plastic

The second concept is called Plastic. The focus on this concept is on lowering the costs, which can be realized by reducing both the weight, the product costs and installation costs of the panel. For this reason plastics are used in this PVT concept where PV laminate is glued on top of a plastic channel absorber (see Figure 6). Preferably, the PV cells are laminated in a plastic instead of glass to reduce the weight. Thin film roll-to-roll may be a good option for this concept. The panel is covered by a layer of plastic to reduce thermal losses. Advantages of using plastics are the complex shapes that can be realized and the good opportunities for automated mass-production. However, plastics are less resistant to UV and high temperatures than conventional solar panel materials. The panel has four thermal connection points at two opponent sides. During the installation the installer determines which connection points are being used. To attach the panels to the roof, they are slid onto special rails which are attached to the roof beforehand, as shown in figure 7. The rails also take care of the drainage of rain water.

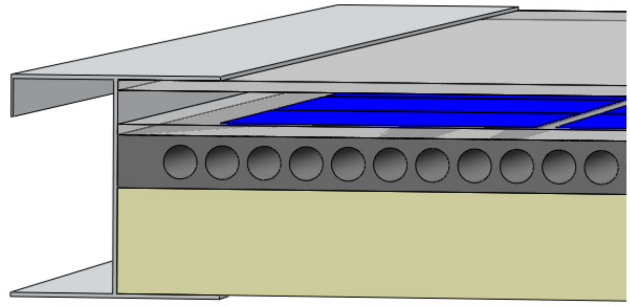

Fig. 6 Cross-section of concept Plastic.

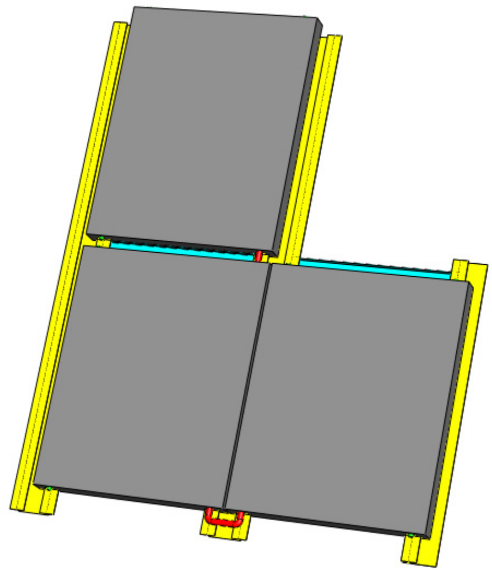

Fig. 7. Joining system for concept Plastic.

Concept 2: Skylight

The third concept is called Skylight and focuses on building integration by combining a PVT panel with a skylight as depicted in figure 8. Part of the panel is transparent like a normal skylight, while another part is covered with a plastic channel absorber and a PV laminate (see Figure 9). The panel does not have an extra covering layer to reduce thermal losses. The PVT panel can be positioned on the roof like a normal skylight, after which the thermal and electrical connections are made. Often this means the installer can do part of this work from inside the building, using well-known flashing sets for skylights.

The panel has two thermal connection points integrated in the hinges of the window. Due to construction reasons it is not possible to create full roof systems with the PVT skylights.

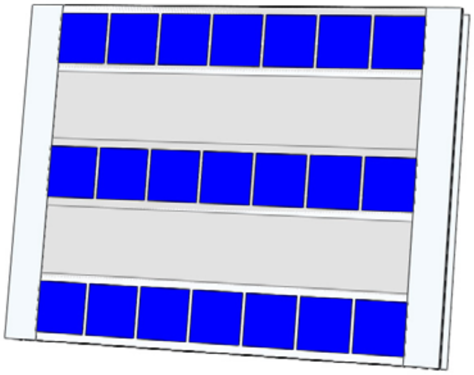

Fig. 8. Concept Skylight is a combination of a PVT panel and a skylight.

Fig. 9. Cross-section of concept Skylight

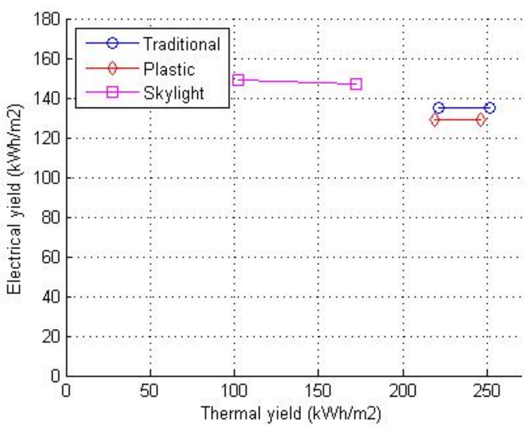

Fig. 10. Electrical and thermal yield of the three different PVT concepts.

Table 2. Main advantages and disadvantages of the different concepts.

Concept	Advantages	Disadvantages
Traditional	Known technology, high efficiencies	High weight, high costs, difficult to connect multiple panels
Plastic	Low weight, low costs	Low resistance to UV and high temperatures
Skylight	Very good building integration	Low efficiency per m^2

SELECTION OF CONCEPT

The final concept has been selected on the basis of the requirements and simulation calculations of the energy performance of three different concepts called Traditional, Plastic and Skylights and by using multi-criteria analysis, see figure 11.

To compare the electrical and thermal performances of the different concepts, as well as the weight and costs, simulation calculations are done. The simulation model of Zondag et. all [4] is used for these calculations.

The concepts Traditional and Plastic have a comparable yearly performance of 130 kWh/m^2.year. Concept Skylight has a slightly higher electrical yield, but also a considerable lower thermal yield, see Figure 10.

With 22 kg concept Traditional is the heaviest, while concept Skylight is the lightest (14 kg), see Figure 12.

The costs of the concepts are comparable and in the range of 400 €/m^2) since they are mainly (> 90%) determined by the costs for PV cells, see Figure 13. Installation costs are not taken into account here.

The main advantages and disadvantages of the concepts are listed in table 2. Considering all aspects, including performance, building integration, installation, manufacturing and developments in the solar energy industry, concept Plastic shows the best opportunities for the future. Therefore, this concept is further developed up to the prototype stage.

Concept choice						Concept Traditional	
				Weighting			
				factor		Score	Weighted
Performance		2					
	Thermal efficiency		2	0.3		4	1.3
	Electrical efficiency		3	0.5		4	2.0
	Total yield / m2		4	0.7		5	3.3
	Costs		1	0.2		3	0.5
	Manufacturing	+	2	0.3		4	1.3
			12				

Fig. 11. Part of the table used for the multi-criteria analysis.

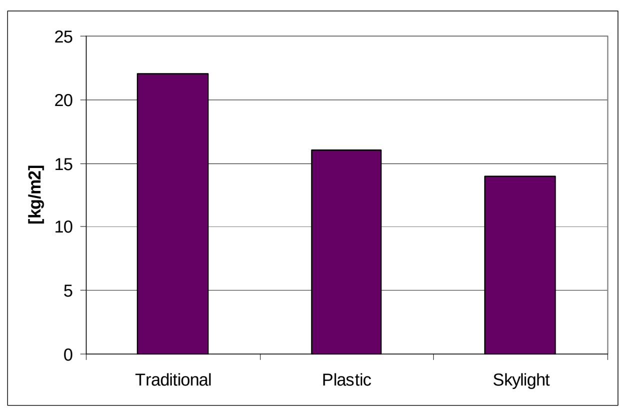

Fig. 12. Weight of the different concepts

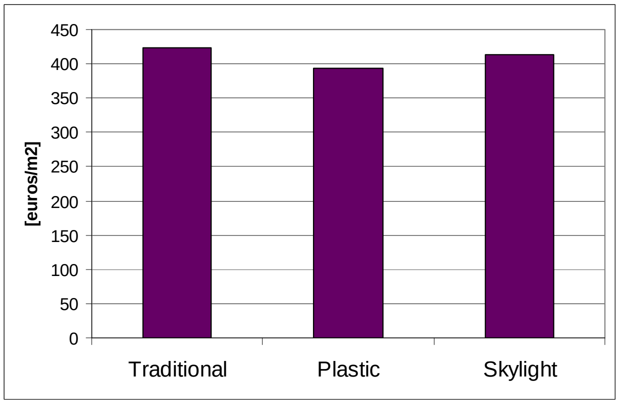

Fig. 13. Costs of the different concepts, excluding installation costs.

FINAL DESIGN

The focus of concept Plastic is to lower the costs. An easier installation – caused by among others a lower weight – should contribute to reach this goal. Also manufacturing costs can be decreased, since parts of the production process can be automated. The cross-section of the PVT panel is depicted in Figure 6, the exploded view of the final design is shown in Ffigure 14.
This PVT panel will yield 96 kWh/m^2.year electrically and 265 kWh/m^2.year thermally under Dutch circumstances of 1000 kWh/m^2.year of irradiation.

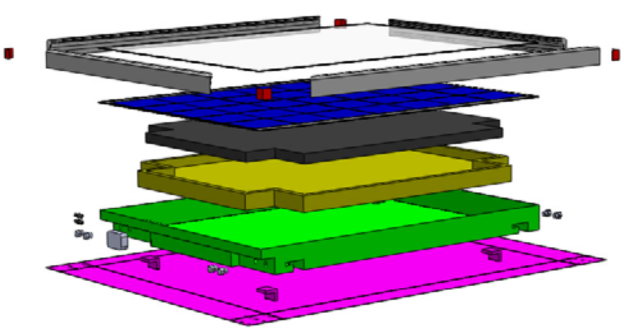

Fig. 14. Exploded view of the final design.

To attach the panel to the roof, it can be slid onto a special plastic plate, as can be seen in figure 15. The waterproof plates overlap, so a waterproof layer is created to guarantee that the roof is watertight. Within new housing development projects, the roof can be made watertight using only the plates. The PVT panels can be placed just before the delivery of the project, thereby preventing theft from the building site. In this concept each panel has four connection points positioned at two opponent sides. During the installation the installer determines at which points the water flows in and out the panel. Although this may seem to contradict with easy installation, it allows the use of standard components to connect the panels to the thermal installations inside a dwelling. To prevent wrong connections, male connectors are used to connect to thermal inlets, while female connectors are used for the thermal outlets. Furthermore, all connection points are labeled IN or OUT. The installer opens the connection points he needs for the specific situation and connects the panels with flexible plastic tube connectors.

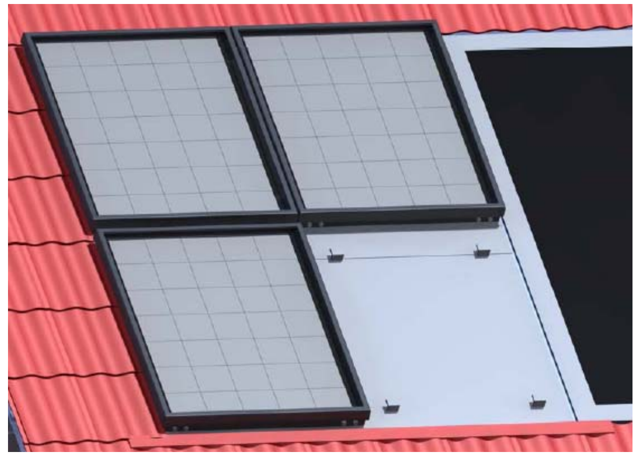

Fig. 15. The PVT panels are placed on waterproof plates attached to the roof.

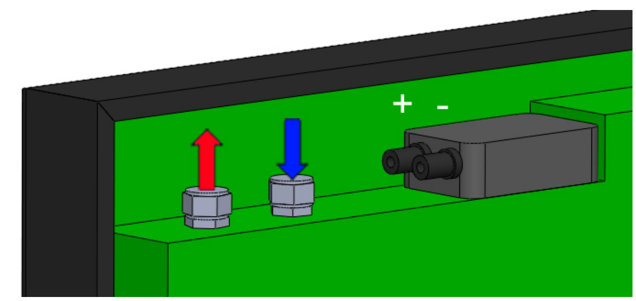

Fig. 16. Positioning of thermal and electrical connection points at the upper right corner of the panel.

The installation process has become less intense. The lower weight and smaller dimensions make the new panels easier to handle. Furthermore, precise positioning of the panels is not needed anymore. There is only one way to place the PVT panels on the waterproof plates. Therefore, if the plates are positioned correctly, so will be the panels. Due to the light weight of the plates, their positioning will be very simple. By changing the amount of overlapping between the plates, the dimensions of the PVT system can be changed by a few cm. This is enough to prevent gaps between the PVT panels and the roof tiles, without cutting roof tiles to fit the panels.

CONCLUSIONS

We hope that we have persuade the reader that we have developed an interesting concept for a liquid PVT panel that can be easily manufactured and installed, by paying attention to user requirements, costs, building integration and ease of installation, see Table 3. What makes this design special is the opportunity to use panels in many different situations. The panels can be placed horizontal and vertical, and are flexible in dimensions caused by the overlapping of the plates. This causes a good joining and smooth changeovers with different dimensions on the roof. Furthermore, the system can easily be extended with more PVT panels or with PV panels, to meet future whishes.

Table 3. Characteristics of the new PVT panel

Dimensions	
Panel	1150 x 895 x 80 mm (1.0 m2)
Working dimensions	1200 x 900 mm
Waterproof plate	1460 x 1115 x 2 mm
Channel absorber	1036 x 831 x 30 mm
Weight panel	16 kg (unfilled)
Weight plate	1.6 kg
Electrical properties	
Solar cells	Poly-crystalline 156 x 156 mm (6 inch)
No. of cells	35 (5x7)
Cell efficiency	15%
Operating cell efficiency	12.9 %
Maximum power (STC)	120 Wp
Operating voltage	17 V
Operating current	7 A
Thermal properties	
Working fluid	Glycol
Flow rate	50 l/h/m2
Tube diameter	15 mm
System pressure	Atmospheric
Performance (expected)	
Electrical yield per panel	96 kWh/yr
Thermal yield per panel	0.95 GJ/yr = 265 kWh/yr
Panel cost	€400,- to €500,- (excl. installation and VAT)
Of which costs for PV cells	€350,-
Pay back time	~ 15 years

Most of the requirements set are fulfilled. The electrical output is above the minimum, but the thermal output is lower than requested. Since the thermal yield is only slightly lower, optimizing the absorber used may increase the thermal yield to an acceptable value. Installation costs are expected to decrease with about 50%, due to the lower weight and the easier installation process. Because of their inconspicuous charisma the PVT panels fit in many different environments and building styles.

It is too early to tell if the panels comply with all regulations. Therefore, testing will be necessary. Special attention has to be paid to the UV resistance of the materials and the expansions due to high temperatures. Additives or special UV resistant layers may increase the life time of the plastic panel.

In order to evaluate its performance the PVT panel will be prototyped and tested in a follow-up project.

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