Rijksdienst voor Ondernemend Nederland

Evaluatie fotovoltaïsch-thermische zonnepanelen (PVT)

EOS-LT Waels

Datum Augustus 2008

ECN, H.A. Zondag

In opdracht van SenterNovem (nu Rijksdienst voor Ondernemend Nederland)

Publicatienr RVO-156-1501/RP-DUZA
www.rvo.nl
Dit rapport is tot stand gekomen in opdracht van het ministerie van Economische Zaken.

Realized PV/T installations - experiences and monitoring results

Report DD2/DD3 of IEA SHC Task 35 on PV/Thermal Solar Systems

August 2008

FINAL DRAFT

Report compiled by:

H.A. Zondag,
Energy research Centre of
The Netherlands (ECN)

SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

Final draft version, May 2007

Report DD2/DD3 of subtask D
Realized PV/T installations - experiences and monitoring results

By

Herbert Zondag
Energy research Centre of the Netherlands (ECN)

This report can be downloaded at the IEA SHC task 35 website: www.pv-t.org

IEA Solar Heating and Cooling Programme

The *International Energy Agency* (IEA) is an autonomous body within the framework of the Organization for Economic Co-operation and Development (OECD) based in Paris. Established in 1974 after the first "oil shock," the IEA is committed to carrying out a comprehensive program of energy cooperation among its members and the Commission of the European Communities.

The IEA provides a legal framework, through IEA Implementing Agreements such as the *Solar Heating and Cooling Agreement*, for international collaboration in energy technology research and development (R&D) and deployment. This IEA experience has proved that such collaboration contributes significantly to faster technological progress, while reducing costs; to eliminating technological risks and duplication of efforts; and to creating numerous other benefits, such as swifter expansion of the knowledge base and easier harmonization of standards.

The *Solar Heating and Cooling Programme* was one of the first IEA Implementing Agreements to be established. Since 1977, its members have been collaborating to advance active solar and passive solar and their application in buildings and other areas, such as agriculture and industry. Current members are:

Australia	Finland	Portugal
Austria	France	Spain
Belgium	Italy	Sweden
Canada	Mexico	Switzerland
Denmark	Netherlands	United States
European Commission	New Zealand	
Germany	Norway	

A total of 39 Tasks have been initiated, 30 of which have been completed. Each Task is managed by an Operating Agent from one of the participating countries. Overall control of the program rests with an Executive Committee comprised of one representative from each contracting party to the Implementing Agreement. In addition to the Task work, a number of special activities—Memorandum of Understanding with solar thermal trade organizations, statistics collection and analysis, conferences and workshops—have been undertaken.

The Tasks of the IEA Solar Heating and Cooling Programme, both underway and completed are as follows:

Current Tasks:
Task 32 *Advanced Storage Concepts for Solar and Low Energy Buildings*
Task 33 *Solar Heat for Industrial Processes*
Task 34 *Testing and Validation of Building Energy Simulation Tools*
Task 35 *PV/Thermal Solar Systems*
Task 36 *Solar Resource Knowledge Management*
Task 37 *Advanced Housing Renovation with Solar & Conservation*
Task 38 *Solar Assisted Cooling Systems*
Task 39 *Polymeric Materials for Solar Thermal Applications*

Completed Tasks:
Task 1 *Investigation of the Performance of Solar Heating and Cooling Systems*
Task 2 *Coordination of Solar Heating and Cooling R&D*
Task 3 *Performance Testing of Solar Collectors*
Task 4 *Development of an Insolation Handbook and Instrument Package*
Task 5 *Use of Existing Meteorological Information for Solar Energy Application*
Task 6 *Performance of Solar Systems Using Evacuated Collectors*
Task 7 *Central Solar Heating Plants with Seasonal Storage*
Task 8 *Passive and Hybrid Solar Low Energy Buildings*
Task 9 *Solar Radiation and Pyranometry Studies*
Task 10 *Solar Materials R&D*
Task 11 *Passive and Hybrid Solar Commercial Buildings*
Task 12 *Building Energy Analysis and Design Tools for Solar Applications*
Task 13 *Advance Solar Low Energy Buildings*
Task 14 *Advance Active Solar Energy Systems*
Task 16 *Photovoltaics in Buildings*
Task 17 *Measuring and Modeling Spectral Radiation*
Task 18 *Advanced Glazing and Associated Materials for Solar and Building Applications*
Task 19 *Solar Air Systems*
Task 20 *Solar Energy in Building Renovation*
Task 21 *Daylight in Buildings*
Task 23 *Optimization of Solar Energy Use in Large Buildings*
Task 22 *Building Energy Analysis Tools*
Task 24 *Solar Procurement*
Task 25 *Solar Assisted Air Conditioning of Buildings*
Task 26 *Solar Combisystems*
Task 28 *Solar Sustainable Housing*
Task 27 *Performance of Solar Facade Components*
Task 29 *Solar Crop Drying*
Task 31 *Daylighting Buildings in the 21st Century*

Completed Working Groups:
CSHPSS, ISOLDE, Materials in Solar Thermal Collectors, and the Evaluation of Task 13 Houses

To find Solar Heating and Cooling Programme publications and learn more about the Programme visit **www.iea-shc.org** or contact the SHC Executive Secretary, Pamela Murphy, e-mail: pmurphy@MorseAssociatesInc.com.

September 2007

Executive Summary

At this moment, worldwide only a very small number of commercial PV/T products exists and the amount of realized projects with these collectors is small. This is in marked contrast to the large potential that is seen for such systems as a standard solar component in both renovation and new housing projects, in particular if the available area is limited, such as for multifamily buildings. The International Energy Agency (IEA) Solar Heating and Cooling (SHC) Programme, Task 35 on PV/Thermal Solar Systems was set up to improve this situation by generating awareness for PV/Thermal Solar Systems and catalysing the further development and marketing of PV/T systems.
In order to show the potential of PV/T systems and to help disseminating the lessons learnt, the present overview report on realised PV/T installations was compiled. All together, the report presents information on 70 realised PV/T installations. Most of these systems are PV/T-air systems (39 systems), but also 15 PV/T-liquid systems are described, as well as 16 systems with PVT collectors heating both liquid and air. Most of the PV/T-air projects have been built by the German manufacturer Grammer Solar using their unglazed PV-air collector. Another large number of projects was realized in national Danish projects led by the Danish consultant Cenergia, applying ventilated PV facades with heat recovery, as well as Solarwall systems. The oldest residential PV/T air installation found in the project was realized in the USA by Sunwatt in 1987; it is still in operation.
With respect to liquid collectors, a number of systems was realised recently in Thailand, in which 5 large-scale PV/T systems were installed on various governmental buildings over a period of about 2 years (2003-2004). These systems have been developed by NSTDA and are mostly unglazed PV/T collectors using amorphous silicon, but in one project also glazed PV/T collectors were used. The largest of these systems is a 152 m^2 system on the Queen Sirikit hospital in Chonburi. Other projects to be mentioned are a 54 m^2 glazed PV/T liquid project that was realised by the Dutch companies ECN, Shell Solar and ZEN Solar in the UK in 2003. This PV/T work has been continued by the ECN spin off company PVTWINS, that in 2007 has realized a 27 m^2 glazed PV/T liquid system on a Dutch governmental building and five 2.8 m^2 systems in a residential renovation project, while more market introduction projects have been planned for 2008.
With respect to the PVT systems heating both liquid and air, a large number of systems was realized by the company Solor, that has realized projects with unglazed PV/T collectors from 1991 onwards, among which several PV/T systems installed at 6 off-grid residences in Klil village, 2 PV/T systems in a recreation village in the Negev desert and 2 PV/T systems on an alpaca farm. Since 1999, the PV/T activities of Solor have been taken over by Millennium Electric, that is now marketing these systems.
Concluding, it can be stated that PV/T is an interesting technique with a large potential and a large amount of experience on PV/T is available. After a long market preparation phase in PV/T development, we hope that the results obtained in this task will contribute to the final take-off of the PV/T market.

Finally, while some demonstration projects run smoothly, others may be plagued by various unforeseen problems. From the reports on the various demonstration projects, a number of lessons has been learnt:

- Realize beforehand that the PV/T project is in many cases additional to an existing building project or renovation project, that has its own dynamics;

substantial delays may occur during this process and it is wise to allow for these in the planning of the deadline of the PV/T project. Also, substantial delays in the PV/T project compromising the commissioning date of the building can often not be tolerated.

- It is an important asset if the architect, building owner, local authorities and other parties in the building process are convinced from the start of the importance of the PV/T system to the project, are motivated to apply and it have sufficient knowledge about it.
- Safety issues, roof mounting and roof integration issues, responsibility issues and warranties may take a substantial amount of time in the project.
- Limit the amount of new components in the project, since the larger the amount of components to be developed within the project, the larger the chance that delays may occur. If the central item in the demonstration is the PV/T, then try to use standard components for the other aspects as much as possible. In addition, be aware that the production of a large number of non-standard components (including possibly the PV/T modules itself) may be costly and not easy to realize.
- Monitoring is crucial to detect errors in the installation, which are often caused by malfunctioning components (sensors, bypasses, etc). This is particularly relevant if these errors substantially reduce the energy saving function of the system, e.g. by requiring too much electrical power for pumps and fans, or compromising the control of the system due to malfunctioning sensors, valves or bypasses. Allow sufficient time and money for monitoring and be aware that in this phase also time should be available to change malfunctioning components and malfunctioning monitoring sensors, and it should be clear whose responsibility it is to make these changes. In addition, it is highly recommended to set up an automated monitoring environment that can be read through a (publicly accessible) website.
- Dissemination is very important and can be realized by various means, ranging from allowing group visits to websites and publications in magazines or conference proceedings.

1 Introduction

PV/T is a solar energy device using PV as a thermal absorber. By using the heat generated in the PV, a PV/T device generates not only electrical, but also thermal energy. PV/T devices can be very different in design, ranging from PV/T domestic hot water systems to ventilated PV facades and actively cooled PV concentrators. Some of these have a wide application while others have a more limited market.

Figure 1: Different types of PV/T modules

Over the last 20 years a number of PV/T demonstration projects has been realised in various countries. Among the earlier systems were the PV/T systems heating both liquid and air, that have been installed by the company Solor since 1991 (later continued by Millennium Electric) and the PV/T air systems that were installed by Atlantis Energy since 1993. Among the most recent projects are a large series of PV/T liquid systems in Thailand and a PV/T concentrator installation realised by the Swedish company Arontis. The aim of this present report is to give an overview of all realized PV/T installations in market introduction projects and demonstration projects. Unfortunately, the available information on most projects is limited; not all projects have been monitored and on some only very limited information is available, while large monitoring reports have been published on others.
The information presented here was collected from manufacturers that are known to be active in this field, complemented with systems that were described in conference papers, scientific papers and EU reports, or that were found though a search on the internet. Although it is expected that the overview assembled in this way will not be complete, it is also expected that the majority of the PV/T systems realized worldwide over the last 20 years is identified and described in this report.
Altogether, 70 different systems were found; 39 systems with PVT air collectors, 15 systems with PVT liquid collectors and 16 systems with combined PVT collectors heating both liquid and air.

- A huge amount of PVT-air installations exists in the form of small autonomous PVT installations for summer cottages, sold by Grammer Solar and Aidt Miljø / Solarventi[1]. On the website of Aidt Miljø, it is indicated that over 11.000 (!) Solarventi modules had been sold in Denmark from the market introduction up to January 2006. Although an example of both products is given in the report, it was clearly impossible to present all these installations. Most PVT air systems in this report were realized by Grammer Solar (10), all but one realized in Germany. Furthermore, 4 systems were realized by Solarwall in the USA and Canada, and 6 by Cenergia in Denmark (in some of the Cenergia projects also Solarwall collectors were used). Also Atlantis Energy should be mentioned, that realised 4 PVT shingle roofs in the 1990's. Furthermore, the Italian company Secco Sistemi has developed, together with the Polytechnical University of Milano, a standardized PVT roof element, that was applied in two projects, while the Spanish company TFM also constructed two ventilated PV systems.
- Most PVT liquid systems were realized by Sunwatt; in the report only 3 installations by Sunwatt are mentioned, but in addition, in the 1980's Sunwatt produced two commercial types of PVT concentrators, the H100 and H150, and states that over 100 of these devices had been made and installed during the period of 1981 to 1989 when the H100 and H150 were produced commercially. Recently, 4 large PVT systems have been developed and installed in demonstration projects by NSTDA in Thailand, while the Dutch company PVTWINS has realized 3 PVT projects in the Netherlands.
- A large number of PVT collectors heating both air and liquid simultaneously has been manufactured and installed by Millennium Electric. In the report, 16 systems are described, all off-grid. Most of these collectors have been installed

[1] The original company name Aidt Miljø was changed to Solarventi in 2006.

in Israel, but also 3 abroad. Recently, also the Danish company Solarventi introduced a PVT module that can heat both air and water; the SV30 hybrid.

- Of all the systems mentioned, only 6 systems are concentrating PVT installations, 5 of which are stationary concentrators produced by Sunwatt and Arontis, and only 1 is a tracking system, realized by the Australian National University. Other manufacturers of concentrating PVT systems are Heliodynamics and Menova Engineering, but no information could be obtained on their installations.

The information on the systems is summarized in Figure 1 and Figure 2.

	project	country	manufacturer or contractor	type of building	size of PVT system	air/liquid	conc/ flat plate	autonomous/grid	hot water / heating
1	Aidt Miljo Summer House package	Denmark	Aidt Miljø	recreational house	1.28 m2	air	flat plate	autonomous	space heating
2	OKA Haus der Zukunft	Austria	OKA?	residential	8.9 m2? (1.1 kW el, 12%)	air	flat plate	grid connected	space heating, tap water heating
3	WASAG Brush	Switzerland	Conserval Engineering	industrial building	500 m2 (part of which PVT)	air	flat plate	grid connected	space heating
4	Chewonki Foundation	USA	Conserval Engineering	lecture rooms?	46 m2 (part of which PVT)	air	flat plate	grid connected	space heating??
5	George Beeler office	USA	Conserval Engineering	residence	22.6 m2	air	flat plate	grid connected	space heating, tap water heating, clothes drying
6	Portable class rooms	Canada	Conserval Engineering	school	15 m2 (part of which PVT)	air	flat plate	grid connected	space heating
7	Riedhammer, Nürnberg	Germany	Grammer Solar	industrial drying	50 m2	air	flat plate	grid connected	industrial drying
8	Delphinarium Nürnberg	Germany	Grammer Solar	delphinarium	75 m2	air	flat plate	grid connected	space heating
9	Tax office in Neu Ulm	Germany	Grammer Solar	office	50 m2	air	flat plate	grid connected	space heating
10	Betriebsgebäude Stadtreinigungsamt Leipzig	Germany	Grammer Solar	office?	90 m2	air	flat plate	grid connected	space heating
11	Brockshill Millenium Park Environment Centre	UK	Grammer Solar	visitor centre	34 m2	air	flat plate	grid connected	space heating, tap water heating
12	Recreational building Pliezhausen	Germany	Grammer Solar	swimming pool	86 m2	air	flat plate	grid connected	space heating, tap water heating?
13	Umweltzentrum DarßerArche	Germany	Grammer Solar	visitor centre	23 m2	air	flat plate	grid connected	tap water heating
14	Fachhochschule Pirmasens	Germany	Grammer Solar	school	14 m2	air	flat plate	grid connected	space heating
15	Depot of the fire brigade in Neustadt-Vogtland	Germany	Grammer Solar	depot	62 m2	air	flat plate	grid connected	space heating
16	Twinsolar systems	Germany	Grammer Solar	recreational house	1.3 to 12.5 m2	air	flat plate	autonomous	space heating
17	Aerni Fenster Factory	Switzerland	Atlantis Energy	factory	530 m2? (53 kW el)	air	flat plate	grid connected	space heating
18	Kirchberg, Scheidegger PVT-facade	Switzerland	Atlantis Energy	office?	180 m2? (18 kW el, part of which PVT)	air	flat plate	grid connected	space heating
19	Shingle roofs Brig & Rigi	Switzerland	Atlantis Energy	residence??	150 m2? and 84 m2? (15 and 8.4 kWp el)	air	flat plate	??	space heating
20	School building Erlach	Switzerland	Atlantis Energy	sports & residential	145 m2? (14.5 kW el)	air	flat plate	grid connected	tap water heating
21	Steinhausen garden house	Switzerland	ETH	garden house	12.3 m2	air	flat plate	??	tap water heating
22	NTNU building	Norway	NTNU & SINTEF	office	192 m2	air	flat plate	grid connected	stack ventilation
23	Doxford Solar Office building	UK	Studio E Architects	office	532 m2	air	flat plate	grid connected	stack ventilation
24	MANCAT building	UK	Walker Simpson Architects	lecture rooms & library	305 m2	air	flat plate	grid connected	stack ventilation
25	CRF eco-canteen	Italy	Secco Sistemi	restaurant	160 m2	air	flat plate	grid connected	space heating, cooling
26	Center of Professional Formation Casargo	Italy	Secco Sistemi	school	23 m2	air	flat plate	grid connected	space heating
27	Lundebjerg multifamily building	Denmark	Cenergia	multifamily house	80 m2	air	flat plate	grid connected	space heating
28	Sundevedsgade multifamily building	Denmark	Cenergia	multifamily house	About 60-75 m2?	air	flat plate	grid connected	space heating
29	Roskilde bank	Denmark	Cenergia	office	45 m2	air	flat plate	grid connected	space heating
30	Lauritz Soerensens Gard	Denmark	Cenergia	multifamily house	67 m2 (part of which PVT)	air	flat plate	grid connected	space heating
31	Vinhaven laundrette	Denmark	Cenergia	laundrette	41 m2	air	flat plate	grid connected	space heating
32	Viktoriagade building	Denmark	Cenergia	multifamily house	75 m2	air	flat plate	grid connected	space heating
33	Silkeborgvej	Denmark	Arkitema	multifamily house	226 m2	air	flat plate	grid connected	space heating
34	Yellow House, Aalborg	Denmark	Esbensen	multifamily house	22.3 m2	air	flat plate	grid connected	space heating
35	Mataro Public library	Spain	TFM	library	603 m2	air	flat plate	grid connected	space heating, cooling
36	Imagina Studios	Spain	TFM	restaurant	1000 m2 (part of which PVT)	air	flat plate	grid connected	space heating
37	Central Carolina Bank in Bessemer City	USA	Innovative design	office	27 m2? (2.7 kWp)	air	flat plate	grid connected	space heating
38	Applebee restaurant in Salisbury	USA	Innovative design	restaurant	39 m2	air	flat plate	grid connected	tap water heating
39	Louisville autonomous system	USA	Sunwatt	residence	25 m2? (2.5 kWp)	air	concentrating	autonomous	space heating

Figure 2: PV/T air projects

	project	country	manufacturer or contractor	type of building	size of PVT system	air/liquid	conc/ flat plate	autonomous/grid	hot water / heating
40	Beaufort court system	UK	ECN/Shell/ZEN/Studio E Architects	office	54 m2	liquid	flat plate	grid connected	space heating
41	Alkmaar residential project	Netherlands	PVTWINS	residence	14 m2 (2.8 m2 per residence)	liquid	flat plate	grid connected	tap water heating
42	Zoetermeer office building	Netherlands	PVTWINS	office	27 m2	liquid	flat plate	grid connected	tap water heating
43	Banglamung Hospital	Thailand	NSTDA	hospital	50 m2	liquid	flat plate	grid connected	tap water heating
44	NSTDA canteen	Thailand	NSTDA	police office	61 m2	liquid	flat plate	grid connected	tap water heating
45	Queen's Sirikit Hospital	Thailand	NSTDA	hospital	152 m2	liquid	flat plate	grid connected	pool heating
46	MOST system	Thailand	NSTDA	office	93 m2	liquid	flat plate	grid connected	cooling
47	Hong Kong City University system	China	City University	office	9 m2	liquid	flat-plate	grid-connected	tap water heating
48	Military Camp 11	Thailand	NSTDA	canteen	48 m2	liquid	flat plate	grid connected	tap water heating
49	Kollum low energy house	Netherlands	PVTWINS	residence	16.5 m2	liquid	flat-plate	grid connected	tap water heating, space heating
50	Sarasota system	USA	Sunwatt	residence	3 m2	liquid	concentrating	grid connected	tap water heating
51	Komp house	USA	Sunwatt	residence	1.8 m2	liquid	concentrating	autonomous	tap water heating
52	Seaborne house trailer	USA	Sunwatt	residence	1.8 m2	liquid	concentrating	??	tap water heating
53	World Heritage Museum in Skule	Sweden	Arontis	museum	10 m2	liquid	concentrating	grid connected	tap water heating, space heating
54	Bruce Hall building	Australia	Australian University of Technology	multifamily house	300 m2	liquid	concentrating	grid connected	tap water heating, space heating
55	Elazari residence	Israel	Solor / Millennium Electric	residence	5.1 m2	liquid	flat plate	autonomous	tap water heating
56	Gan Haim	Israel	Solor / Millennium Electric	residence	5.1 m2	liquid	flat plate	autonomous	tap water heating
57	Nezger family house	Israel	Solor / Millennium Electric	residence	5.1 m2	liquid	flat plate	autonomous	tap water heating
58	Shenar family house	Israel	Solor / Millennium Electric	residence	12.8 m2 (2 systems)	liquid	flat plate	autonomous	tap water heating
59	Hovev family house	Israel	Solor / Millennium Electric	residence	5.1 m2	liquid	flat plate	autonomous	tap water heating
60	Rotem family house	Israel	Solor / Millennium Electric	residence	7.7 m2	liquid	flat plate	autonomous	tap water heating
61	Brown family house	Israel	Solor / Millennium Electric	residence	5.1 m2	liquid	flat plate	autonomous	tap water heating
62	Levy family house	Israel	Solor / Millennium Electric	residence	5.1 m2	liquid	flat plate	autonomous	tap water heating
63	UNosom forces base in Somalia	Somalia	Solor / Millennium Electric	residence	5.1 m2	liquid	flat plate	autonomous	tap water heating
64	Israel convention centre	Israel	Solor / Millennium Electric	residence	5.1 m2	liquid	flat plate	autonomous	tap water heating
65	Dvir family house	Guatemala	Solor / Millennium Electric	residence	2.6 m2	liquid	flat plate	autonomous	tap water heating
66	Alpaca farm	Israel	Solor / Millennium Electric	residence	38.4 m2 (2 systems)	liquid	flat plate	autonomous	tap water heating
67	Suca recreational village	Israel	Solor / Millennium Electric	campsite building	15.4 m2 (2 systems)	liquid	flat plate	autonomous	tap water heating
68	Kryiat Teivon Solor office	Israel	Solor / Millennium Electric	office	2.6 m2	liquid	flat plate	autonomous	tap water heating
69	Chromagen head office	Israel	Solor / Millennium Electric	office	13 m2	liquid/air	flat plate	autonomous	tap water heating, space heating
70	Singapore system	Singapore	Solor / Millennium Electric	residence	41 m2 (8 systems)	liquid	flat plate	autonomous	tap water heating

Figure 3: PV/T liquid projects and PVT combined liquid/air projects

2 PV/T air projects

2.1 Glazed PV/T air collectors

2.1.1 Aidt Miljø (Denmark)

Mass-produced do-it-yourself PV/T packages for summer houses are provided by Grammer (unglazed PV) and Aidt Miljø (glazed PV). The main purpose of these systems is to prevent moisture problems during the winter; during the presence of the owner in the summer, the system may be switched off to prevent overheating. The PV output is used to drive the collector fan, providing heated ventilation air to the cottage. As a typical case, Robert Hastings (1999) gives a description of a system of Aidt Miljø in a Summer House at Slettestrand, Denmark.

Slettestrand Summer House. The PV/T system consists of a 1.28 m^2 solar air collector with an integrated 0.28 m^2 (11 W) PV module. The air is sucked through a black fibre cloth heated by the sun. The module is attached to the wall and is connected to the fan by a flexible duct. The fan is mounted on the inside of the wall right behind the collector. No storage is present. The solar cell controls the system, so that the fan only blows when the sun is shining. The annual yield is calculated to be 290 kWh if switched off during the summer months, and 430 kWh if operated year-round (Hastings, 1999). A typical price is about 890 euro for a 1.43 m^2 module.

2.2 Unglazed PV/T air collectors

2.2.1 OKA Haus der Zukunft (Austria)

The OKA Haus der Zukunft was built as the exposition house of Energie AG at a garden exposition in Austria. In the house, 18 air collectors and two PV-air hybrid collectors (containing 4 Pilkington PV panels with a combined peak power of 1072 W) were installed. The hot air is used for water heating (500 liters tank heated through a heat-exchanger) and space heating (concrete hypocaust).
It is indicated that the performance is limited by the small temperature range (from 18 C to maximum 25 C), which allows storage for approximately 3 days. It is indicated that the hybrid system is more economical than the PV only, and that the roof integration of the different solar systems is very harmoniously.

(Robert Hastings, 1999)

2.2.2 Solarwall (Canada)

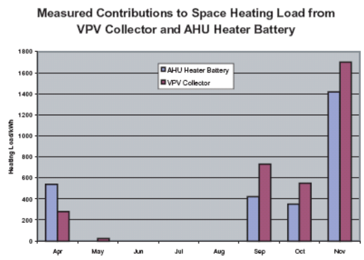
In 1994, a PV/T system was realized at WASAG Brush technology in Switserland. For this project, Conserval Engineering supplied a 500 m^2 Solarwall façade and a PV company mounted the 640 m^2 PV system, of which part is in front of the wall and on an angle. For the façade PV, the warm air from the PV rises both from the top and along the underside of the modules and is drawn into the perforations of the Solarwall panels. At the upper end of the façade the warm air is collected and is used for heating and ventilation air. The building covers most of its energy demand by the sun: · Solar Coverage electricity 30% · Solar Coverage heating energy 75% The building received the Swiss solar prize 1995 for the best integrated solar system.	
Chewonki Foundation, Wiscasset, Maine Center for Environmental Education The entire SolarWall PV/T system covers about 46 m^2 (about 20 kW thermal), with the 42 PV modules (3.5 kWp) occupying about two thirds of the surface area. The electricity that is generated feeds through an inverter, and is also tied into Central Maine Power. The system saves 4300 kWh/year of electrical energy and about 30,000 kWh of thermal energy. (www.solarwall.com)	
SolarWall PV/T system on the home office of George Beeler, architect AIM Associates, California. PV/T area 22.6 m^2, containing 18 150Wp PV modules. The installation consists of two parts: the lower part is a PV-Solarwall system for PV cooling and preheating, while the upper part is a traditional Solarwall system, that is able to provide higher temperatures. The heat is used for space heating and pre-heating domestic water, while the hot air can also be ducted to a clothes dryer to supplement the traditional drying process. (www.solarwall.com)	

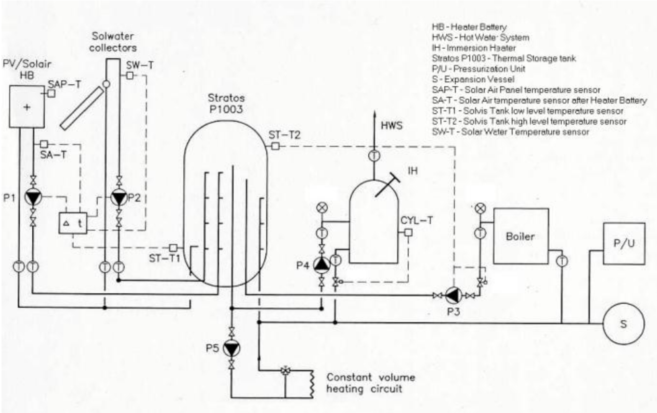
Some portable classrooms in Southern Ontario experienced poor air quality and mold growth. To correct this problem, a 15 m² SOLARWALL was installed with two 60 W a-Si panels that power two variable-speed 340 m³/hr fans bringing solar heated fresh air into the classroom. The air, heated as much as 30°C above ambient, is then distributed in the classroom by two – 150 mm diameter ducts. (www.solarwall.com)	

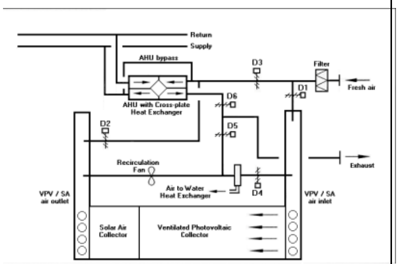
2.2.3 Grammer Solar (Germany)

Riedhammer, Nürnberg (1996), for ventilation air preheating in the drying room and the painting room of an industrial facility. Due to the small temperature rise required, a high volume flow of 100 m^3/m^2h is used, leading to a high annual thermal yield of 270 kWh/m^2. The collector area is 50 m^2 and the nominal electrical peak power is 5,4 kWp. The measured electrical performance 925 kWh per kWp over 1997. (www.grammer- solar.de, www.ecn.nl/egon/extra/extranet/pvt-platform/het-pvt-platform)	
Delphinarium Nürnberg (1999). The PV/T area is 75 m^2, and is combined with 25 m^2 PV and 135 m^2 solar air collectors. The PV/T has 8.4 kWp nominal electrical yield and 30 kWp nominal thermal yield. The collector angle is 51°. The system is used to preheat supply air. (www.grammer- solar.de, www.ecn.nl/egon/extra/extranet/pvt-platform/het-pvt-platform)	
Tax office in Neu Ulm (1999). An autonomous collector system has been installed for preheating of ventilation air, that consists of 300 m^2 air collector area and 50 m^2 PV/T collector area (45°, 5.7 kWp_el), of which 2.2 kWp to drive the fan and 3.4 kWp supplied to the grid. (www.grammer- solar.de, www.ecn.nl/egon/extra/extranet/pvt-platform/het-pvt-platform)	
Betriebsgebäude Stadtreinigungsamt Leipzig (2001). The installation PV/T collectors with a nominal electrical power of 9 kWp and 90 m^2 collector area, to which 30 m^2 air collector area is added. The electricity is fed to the grid, while the hot air is used for space heating. The measured electrical yield of the PV/T is 960 kWh per kWp. The air flow decreases the PV temperature, causing a 7% increase in electrical yield which compensates for the energy use of the fan. The annual thermal yield is 200 kWh/m^2. The installed cost was 7000 euro/kWp, which is only 1000 euro/kWp more than a PV installation. (www.grammer- solar.de, www.ecn.nl/egon/extra/extranet/pvt-platform/het-pvt-platform)	 
Brockshill Millenium Park Environment Centre, Leicester, UK (opened to public in 2001). Cartmell (2001) and Shankland (2001) also report on this project. The PV/T collector is mounted on the lower 35° section of the roof and consists of 20 modules with a total area of 34 m^2 with a 4 kWp nominal electrical yield. The output is boosted by 12 m^2 Gammer solar air collectors. The heated air can be used directly for space heating or provided to the central heat store (a Stratos P1003 stratifying heat store) via an air-to-water heat exchanger. However, since this store is further heated by 20 m^2 Thermomax	

evacuated tube collectors, during summer most of the PV heat will not be needed for water heating and will be vented to the ambient.
Unfortunately, some of the PV modules were vandalized soon after installation so no data is available for electrical output. The calculated payback time was about 19 years.







	Predicted thermal loads (kWh)		Predicted thermal yields (kWh)				
Month	Space & ventilation heating	Water heating	VPV/SA heat available for space heating	VPV/SA heat availabl e to thermal store	Solar water collector	Dual fuel boiler	Available heat not collected or vented to atmospher e
Jan	1828	598	789	-	366	1271	0
Feb	657	524	-	685	504	-	8
Mar	33	556	-	1103	771	-	1285
Apr	35	512	-	1600	800	-	1853
May	0	506	-	1915	962	-	2371
Jun	0	475	-	1852	1009	-	2386
Jul	0	499	-	1955	1004	-	2460
Aug	0	519	-	1839	958	-	2278
Sep	0	528	-	1379	915	-	1766
Oct	14	574	-	935	742	-	1089
Nov	818	575	945	-	505	-	57
Dec	1688	603	627	-	345	1319	0
Total	5073	6469	2359	13263	8881	2590	15551

(www.grammer- solar.de, www.ecn.nl/egon/extra/extranet/pvt-platform/het-pvt-platform/)

Recreational building Pliezhausen (2001), space heating and tap water heating for a sports facility with swimming pool. The PV/T area is 86 m^2, resulting in 4.5 kWp nominal electrical yield. The collector angle is 45°.
(www.grammer- solar.de, www.ecn.nl/egon/extra/extranet/pvt-platform/het-pvt-platform/)

Umweltzentrum DarßerArche in national park near Wieck (2001), water heating. The PV/T area is 23 m^2, resulting in 2.5 kWp nominal electrical yield and 8.5 kWp nominal thermal yield. The collector angle is 80°.
(www.grammer- solar.de, www.ecn.nl/egon/extra/extranet/pvt-platform/het-pvt-platform/)

Fachhochschule Pirmasens (2002), preheating of ventilation air for the atrium. The PV/T area is 14 m^2, resulting in 1.5 kWp nominal electrical yield.
(www.grammer- solar.de, www.ecn.nl/egon/extra/extranet/pvt-platform/het-pvt-platform/)

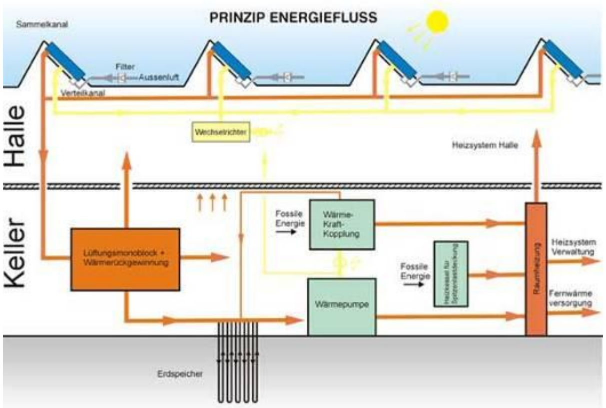
<table>
<tr><td>Depot of the fire brigade in Neustadt-Vogtland, Germany (2007). The system consists of a 62 m² PV/T system (8.3 kWp_el, 25 kWp_th) in combination with a conventional PV system (also 8.3 kWp_el). The system provides preheating of fresh air and/or recirculating air for space heating, dehumidification and drying of wet equipment (e.g. clothes and fire hoses), in combination with a heat recovery system and an electric emergency heating system. The depot function of the building allows a large variation of the indoor temperature.
(www.grammer- solar.de)</td><td></td></tr>
<tr><td>Twinsolar. The Twinsolar is a standard product of Grammer Solar for preheating of ventilation air and prevention of moisture in vacation cottages. A small PV part drives the fan of the attached air collector. Similar to the product by Aidt Miljø, the modules consist but in the Grammer product the PV part is unglazed). Large numbers of these systems have been installed, the smallest commercial system being 1.3 m² (1 module) and the largest system 12.5 m² (7 modules).
(www.grammer- solar.de, www.ecn.nl/egon/extra/extranet/pvt-platform/het-pvt-platform/)
</td><td>

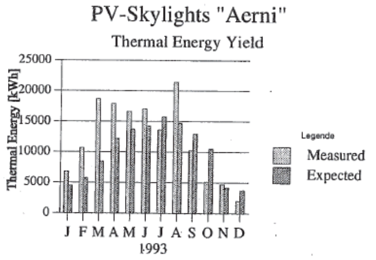
</td></tr>
</table>

2.3 *Building integrated PV with heat recovery*

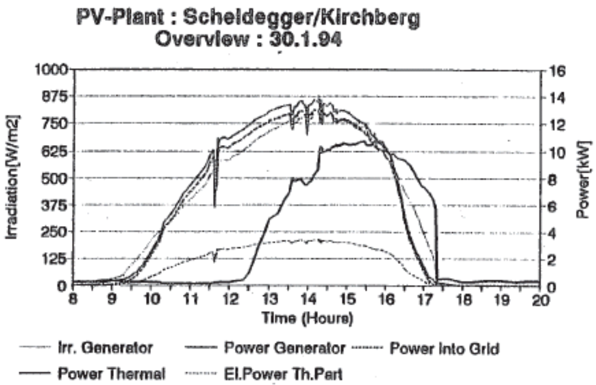
2.3.1 Atlantis Energy (Switzerland)

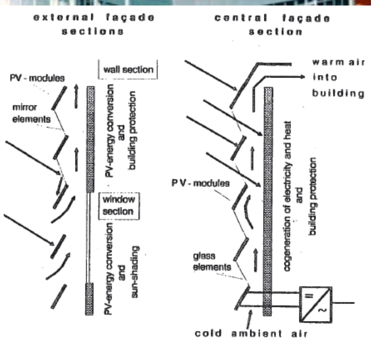
Aerni Fenster Factory, 53 kW electrical & 115 kW thermal PV/T system in the skylights on the roof. The output was measured during 1993; the measured thermal efficiency was between 32% and 45%. The measured thermal peak power was 218 kW. During winter, the hot air is used for space heating of the factory hall or stored in the concrete walls and floors. During Summer, the heat is stored underground for retrieval during winter with a heat pump. In 1993, the PV/T system covered 70% of the energy demand of the factory (Posnansky, 1997).

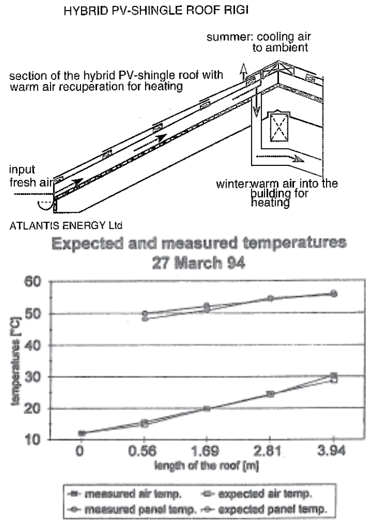
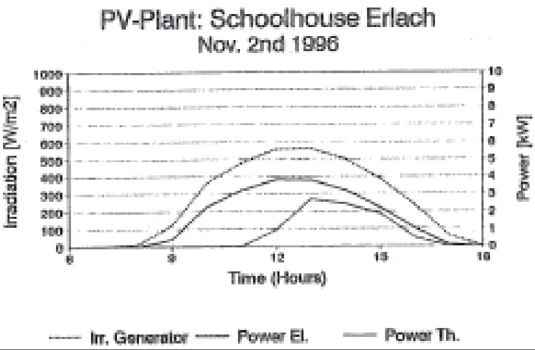
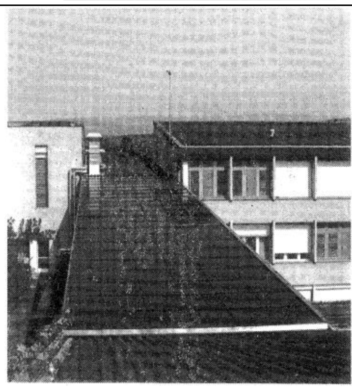




Kirchberg, Scheidegger PV/T-facade. The facade is 18 kW electrical and 12 kW thermal (only the central part is hybrid). Two years of monitoring show a maximum conversion efficiency (el + th) of 40%. The air flow is driven by natural convection and the hot air is used for preheating ventilation air (Posnansky et al., 1997; Posnansky et al., 1994).





<table>
<tr>
<td>Shingle roofs Brig (March 1993) & Rigi (October 1993). Brig has a nominal PV power of 15 kWp and a thermal power of 30 kW; the thermal energy is used for the heating of the shower rooms during the heating period. Rigi has 8.4 kWp and a thermal power of 12 kW.
The figure shows the measured temperatures along the roof Rigi on 27 March 1994, at an irradiation of 989 W/m^2. It can be seen that a temperature difference of 25-30 C exists between the roof and the air flow. (Posnansky, 1997).</td>
<td>
</td>
</tr>
<tr>
<td>School building Erlach (plant built 1996), ventilated PV-passage between gym hall and schoolhouse. Three PV arrays provide 14.5 kW electrical en about 29 kW thermal. The hot air is used to heat water for the showers of the gym hall and for the caretakers flat. (Posnansky, 1997).

</td>
<td></td>
</tr>
</table>

2.3.2 ETH[2] (Switzerland)

Steinhausen garden house (2003). As part of a PhD project, a pilot project was realized with 12.3 m^2 PV/T slates (Kropf, 2003). The PV/T states were developed by Atlantis Energy. The hot air is fed to the cellar of a nearby residence, in which an air-source heatpump is located that produces hot water. Due to the higher cellar temperature, the heat pump works more efficient and problems with damp air in the cellar are avoided. It was predicted that with an optimised design of the control, such that the functioning of the heat pump would coincide with high solar availability, 20% electrical energy could be saved. (Kropf, 2003)	

[2] Eidgenössische Technische Huchschule Zürich (Swiss federal institute of technology Zurich)

2.3.3 NTNU[3] building (Norway)

BP Solar skin on Trondheim University office building (Aschehoug, 2003). The original building was built in 1970 and was renovated in 2000, also receiving a double facade of 0.8 m width. The PV area (16 kWp; 192 m^2 module area; 55% cell packing density; 16% cell efficiency; covering 43% of total facade area of 455 m^2) is on the outer wall of a double facade. During summer, the PV provides shading of the building and the heat of the PV contributes to the stack effect, used to assist the summer venting of the office. The cavity is vented by motor-operated vents at the top and bottom, controlled by temperature sensors. Calculations showed that during winter, the heat trapped in the facade lowered the heat loss of the building by about 7-8%, in addition to the improved air tightness of the building. Monitoring showed that for certain wind directions, the air flow in the cavity was reversed, resulting in the top floor offices receiving hot cavity air through the windows. Therefore, a revised venting control strategy was implemented. An issue in the design was the influence of the stack effect in the facade on fire safety and smoke propagation, and similarly for noise propagation. BP indicates that the development of the concept cost US$110,000 and the PV System US$345,000, but to replicate this on a new building of a similar area the cost would be 25-50% less.

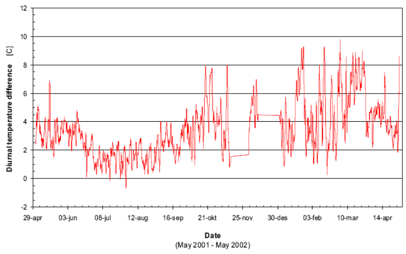
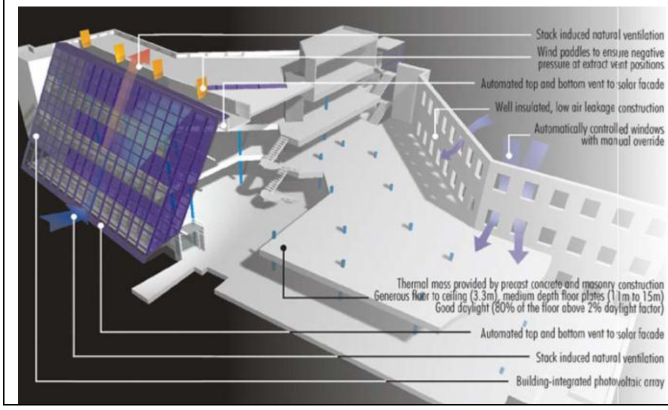


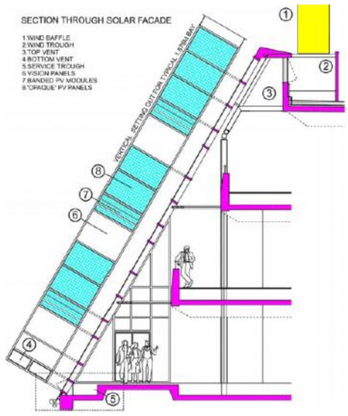
Figure 13 Mean diurnal temperature difference between the cavity and the ambient air for the monitoring period.

[3] Norwegian University of Science and Technology (NTNU) in Trondheim

2.3.4 Doxford solar office building (UK)

Doxford solar office (1998). In this office, the heat of the PV facade (532 m^2 cell area, 352 PV modules, 60°) is used to boost the natural ventilation by means of the stack effect. CFD calculations indicated that during the Summer, an average ventilation rate of 5 to 7 air changes per hour would occur (Lloyd Jones, 1998)



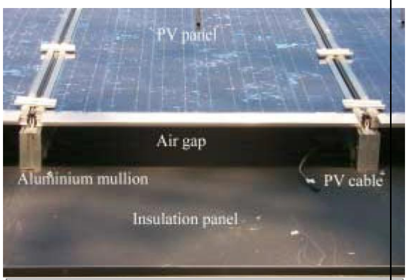


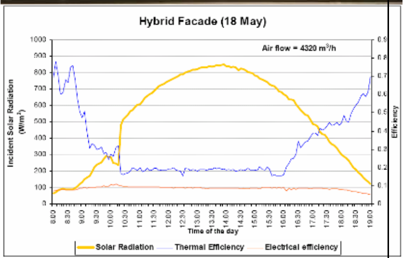
2.3.5 MANCAT building (UK)

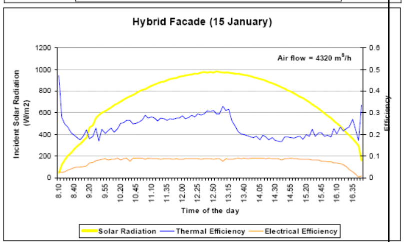
Manchester College of Arts and Technology (MANCAT, 2005). A PV facade was installed (305 m^2; 39 kWp; 482 SHARP c-Si 80 Wp modules) with stack effect behind the PV to increase the ventilation level in the building. On the roof, another 29 kWp of PV is installed. The project was realised by Solarcentury and Walker Simpson Architects. Also Viesmann solar thermal modules were installed.
(www.solarcentury.co.uk)

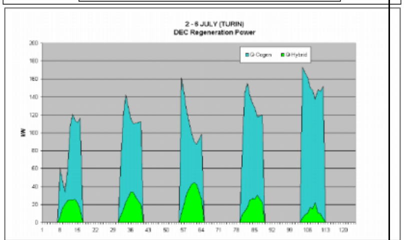
2.3.6 Secco Sistemi (Italy)

Eco-canteen of the Fiat research Centre in Torino (2003), 160 m^2 PV (130 BP modules, 19.5 kWp), 53º. The thermal output of the PV/T is boosted by 32 m^2 of conventional air collectors. The flowrate is variable up to 9000 m3/h and the air is heated up to a temperature varying between 30 C to 60 C, depending on ambient conditions. The system contains a PV/T roof with booster collectors, a cogeneration system and a reversible heat pump. Campanile (2004) indicates that during the winter the hot air produced by the roof preheats the ventilation air for the kitchen, while the waste heat of the cogeneration system preheats the ventilation air for the restaurant and for the kitchen and the heat pump provides the space heating for the restaurant and for the kitchen. During the summer, the hot air that is produced by the roof and the waste heat of the cogeneration system regenerate the desiccant wheel of the desiccant cooling system. Surpluses of the cogeneration system waste heat are used in the kitchen for cooking uses and the heat pump produces cold for the climatisation of the restaurant and the kitchen. Simulations (Adhikari, 2004) indicate that the cogeneration waste heat supplies 72% of the heat required by the desiccant system, while the PV/T roof supplies the remaining 28%. It is estimated that the annual thermal output of the roof is 100 kWh, together with 20 kWh electrical output.
(Butera, 2005; Adhikari, 2004; Campanile, 2004)









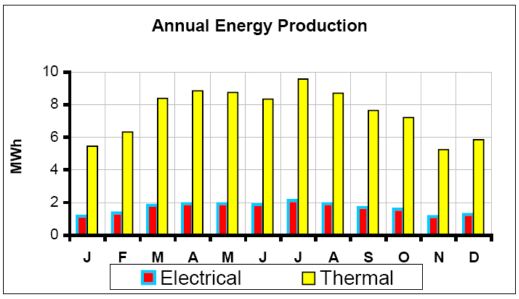
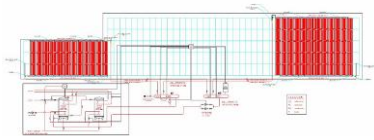
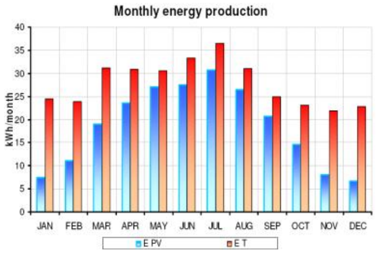
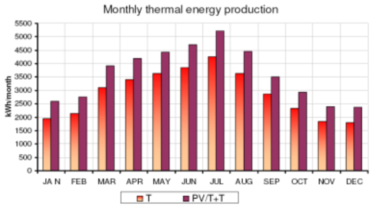


Figure 6. CRF Solar facade – estimated monthly thermal and electrical energy production

Center of Professional Formation (CFP) of Casargo (Lecco) (2005), 26 hybrid photovoltaic thermal panels provide part of electric energy for the building internal loads (23 m^2, 3.9 kWp). The total electrical energy produced by the PV/T plant amounts to about 5 MWh/year and the thermal energy saved amounts to about 8.7 MWh/year.
The output of the hybrid PV/T system is boosted by the solar air system, placed at the top of the roof and used for ventilation preheating. The total thermal energy produced during the year is about 34.8 MWh, that summed to thermal energy produced by PV/T plant reaches 43.5 MWh/year, of which 21.2 MWh during the heating period. Aste (2006) indicates that the total cost of the multifunctional solar roof was about € 250.000; about € 80.000 for the solar thermal air system, € 90.000 for the solar thermal water system and € 34.000 for the hybrid photovoltaic-thermal plant. The graphs (from Aste, 2007) show the calculated monthly electrical and thermal energy production of an individual PV/T module and the added contribution of the PV/T system to the air collector system.





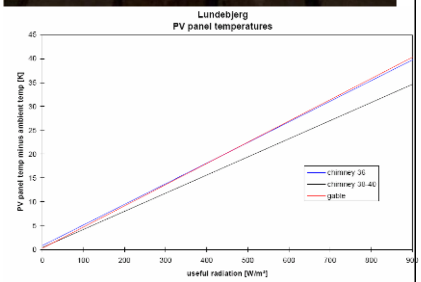


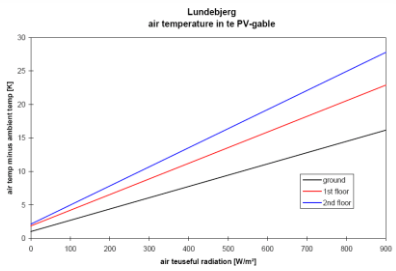
2.3.7 Cenergia (Denmark)

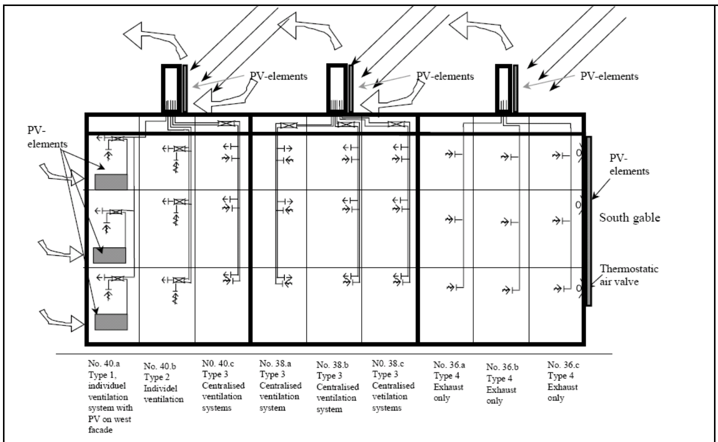
Lundebjerg multifamily building (2000). In this multifamily building (built late '60s, tenants, 27 apartments), that was renovated in 2000 after an architectural competition (when it also received a PV/T system), 5 different types of PV system were tested. The 3 southern apartments receive heat from the gable, 15 apartments receive preheated air from the ventilation inlets, 3 receive ventilation air heated by 1.7 m^2 c-Si facade elements and the remaining 6 apartments do not receive heat but have PV powered exhaust ventilation (see schematic drawing). The ventilation inlet chimneys on the roof contain 7.7 m^2 c-Si each and the gable contains a 52 m^2 a-Si system (2160 Wp). The a-Si system is grid connected (3 arrays with an inverter each) while the electrical output of the c-Si chimney- and facade modules is used to drive the DC ventilation fans (with backup from the grid in case of insufficient irradiance, controlled by a PV mixed developed in the project). Dampers at the top of the gable open if no preheating is needed. A grid is placed at the inlet side of the gable to prevent entering of birds etc. The flow is determined by the under pressure in the apartment (exhaust flow 126m^3/h, the average gable inflow being 60% of this depending on wind and open windows).

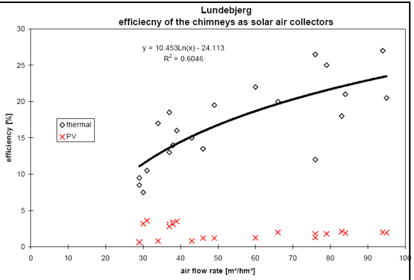
Due to the fact that the forced air flow in the chimneys was of the order 0.5 m/s, the flowrate was similar to the natural convection rate and the imposed flow had little effect on the temperature. This was also found for the gable. Blocking the airflow behind the PV gable resulted in 16% temperature increase.

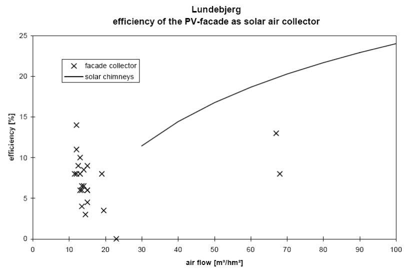
It was concluded that the actual benefit of the preheating to the apartments was low, due to large losses of the unglazed PV/T, good ventilation heat recovery in the apartments and low air speed, due to the necessity to use wide air channels to enable cooling in summer by natural convection flow. (Jensen, 2001a)











Copenhagen multifamily building at Sundevedsgade (2000). This building (20 apartments) dates from 1884 and was renovated in the late '90s, in which all apartments received a ventilation heat exchanger (efficiency 80%) and a solarwall system (each 3 m^2 or 3.75 m^2) for ventilation air preheating. For 12 appartments, the heat exchangers were located outside the building in the central courtyard (integrated into the solarwall system), while the remaining 8 apartments had heat exchangers inside the building or in the attic. The solarwall is partly covered by PV and partially by diffusive glazing, to hide the heat exchangers but allow transmission of irradiance. The fresh air to the ventilation heat exchangers is taken from the solar wall, so the air is preheated by the solarwall, the PV and heat loss through the walls of the building. The inlet to the solarwall is through a grill, while dampers may be opened at the top if preheating is not required. Highly efficient fans were developed within the project. The fans are directly fed by the c-Si PV modules, with backup by the grid using a PV-mixer (see above). The peak power per three panels is 121 Wp or 242 Wp.

In addition, a solar air collector of 19 m^2 was installed on the roof for water and space heating through an air-to-water heat exchanger.

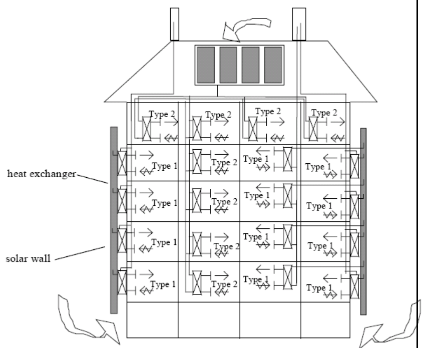
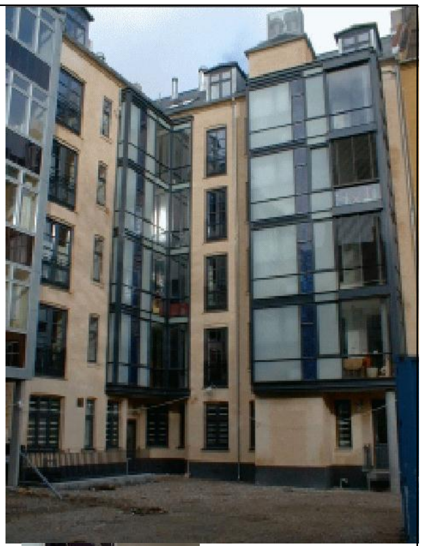


Table 3.2 shows major differences between the two years, which of course is caused by the improper running of the system in 2000.

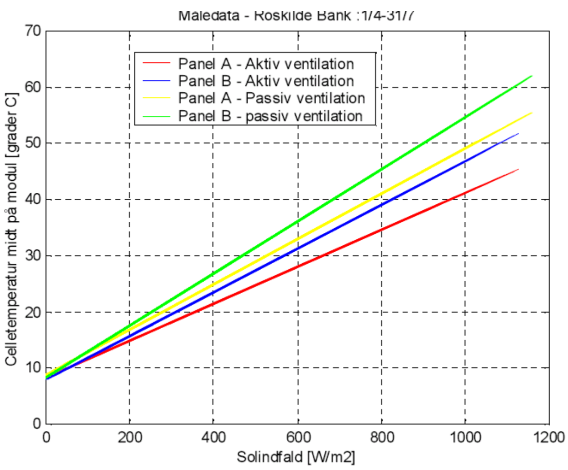
	2000 kWh	2001 kWh	year kWh
Heat exchanger			
Energy in the exhaust air	1640	1217	2857
Energy in the inlet air incl. pre-heating in the solar wall	768	1100	1868
Energy in the inlet air exc. pre-heating in the solar wall	713	993	1706
Benefit of pre-heating in the solar wall [1]	55	107	162
Solar wall			
Energy to the air from the solar wall – day	129	246	375
Energy to the air from the solar wall – night	149	230	379
Total energy to the air from the solar wall [2]	278	476	754
Losses to the solar wall – day	143	139	282
Losses to the solar wall – night	212	221	433
Total losses to the solar wall [3]	355	360	715
Fans and PV			
Energy to the fans from the grid - without PV	159	68	227
Energy to the fans from the grid - with PV	146	60	206
Benefit of PV [4]	13	8	21
PV energy delivered to the PV-mixer	18	9	27
Not utilized PV energy	23	2	25

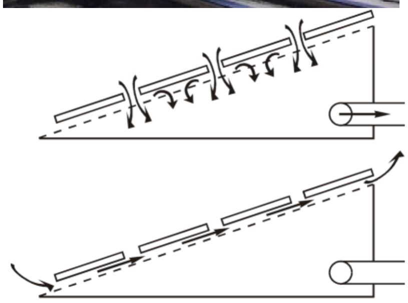
Table 3.2. Yearly measured (and calculated) energy flows in the ventilation system.
[1] energy in the inlet air with pre-heating in the solar wall minus without pre-heating.
[2] energy to the air from the solar wall for both day and night
[3] losses to the solar wall for both day and night
[4] energy to the fans from the grid without PV minus with PV

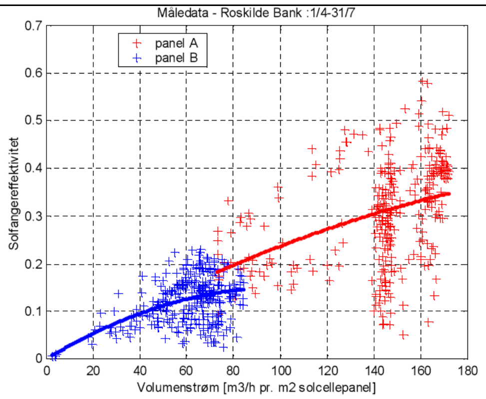
It was concluded that the benefit of the PV/T system was small, especially since the losses to the system were three times as large as the benefits from the system; it was concluded that the system should have been better insulated. The other conclusions were similar to the Lundebjerg case.
(Jensen, 2001b)



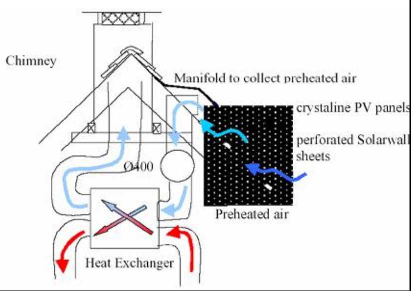
Roskilde bank (2001) Two cases with each 24 c-Si modules (98 Wp; 0.94 m^2) on top of a solarwall system under 15°, installed on flat roof for preheating of ventilation air and cooling of the PV. During summer, the heat is vented to the ambient. Total PV area 22.6 m^2. Unlike case B, in case A the PV has additional cooling riblets (see photo), which were found to have a significant effect. (Jacobsen and Jensen, 2001).

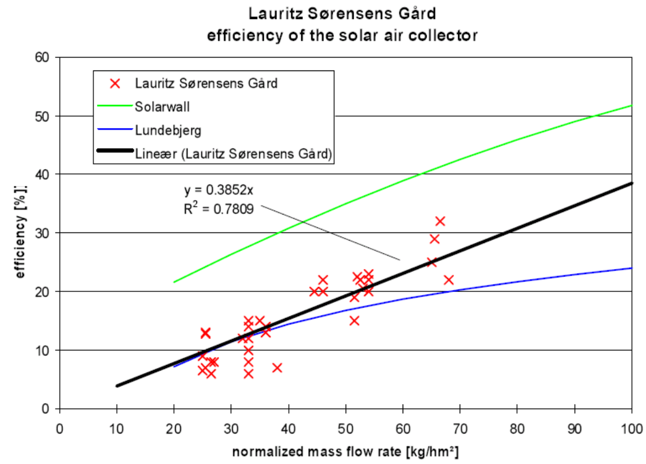


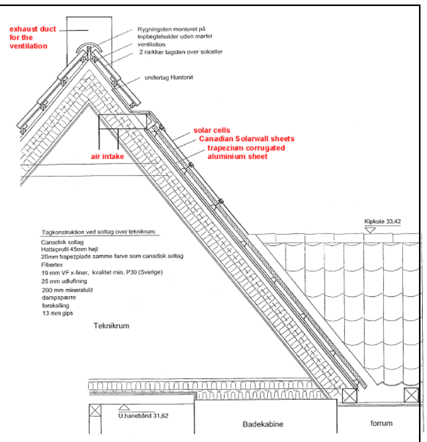




Lauritz Soerensens Gard (2002). The five storey housing block dates from 1930 and was renovated in 2001-2002. Two collector areas were built above the central staircases. The two systems consist of 35.3 m^2 and 31.7 m^2 Solarwall collectors, of which respectively 12.4 m^2 and 11.4 m^2 are covered with PV. The purpose is to preheat ventilation air during winter and to cool the PV. The preheated air is heated further by the ventilation heat recovery system. Jensen (2003a) concludes that (a) the air flow of fresh air to the building has no or minor influence on the temperature of the PV-panels; the air flow of fresh air seems not to increase the cooling of the PV-panels already present by the buoyancy driven air flow. (b) The part of the solar air collector covered with PV-panels does not contribute to the heating of the fresh air to the building. A poor distribution of the air over the solar air collector due to centrally located draw off from the solar air collector decreases the performance of the solar air collector at low mass flow rates. (c) The fresh air to the building is also heated during the night due to the heat loss from the building through the roof. From the annual calculations, Jensen (2003a) finds that the actual benefit of the preheating (day and night) in the solar air collector is 1,235 kWh/year
while the heating of the fresh air in the solar air collector is 7,620 kWh/year. The yield is thus decreased by 84% due to the heat exchanger.
Without the preheating in the solar air collector 80% of the heat in the exhaust air is recovered.
Due to the preheating this is increased to 82.5%. The preheating in the solar air collector increases
thus the savings by 3%. The simulations shows an annual preheating of the fresh air of 7,620 kWh for both systems of which 35% is due to the sun while 65% is due to recovered heat loss through the roof the solar air collector is mounted on. (Jensen, 2003a)

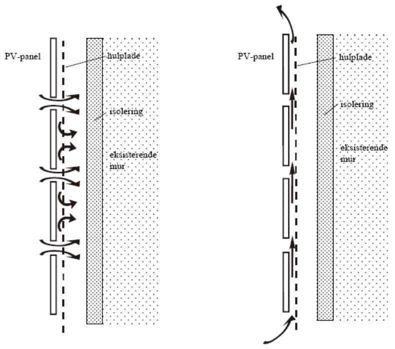


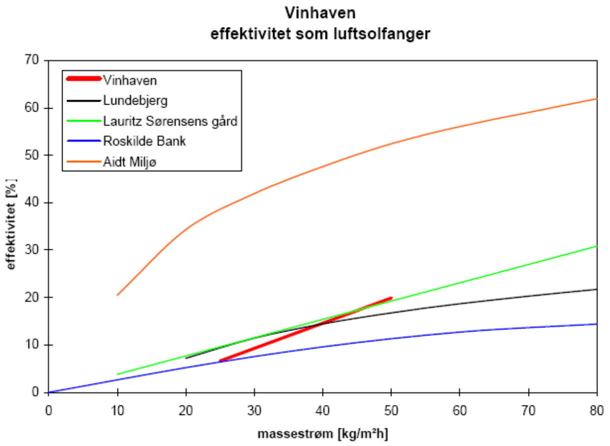




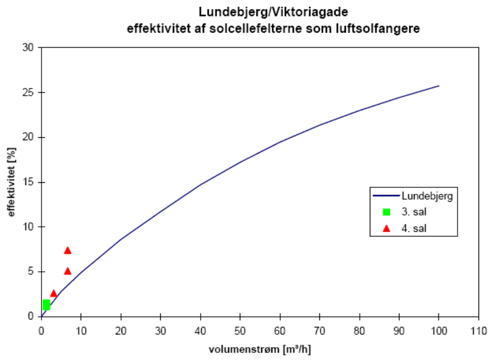
Vinhaven, Valby (2003). A PV/T gable of 41 m^2 was installed in 2002/2003 for preheating of ventilation air for a laundrette. Unfortunately, it turned out to be impossible to connect the gable to the ventilation system, so a different system concept was applied in which the gable was not vented continuously, but the fan was only switched on at a certain temperature level in the gable. After the monitoring, Jensen (2003b) concluded that the thermal performance/saving of the PV-gable on the system level is below zero, because the fresh air temperature from the PV-gable most of the time is below the room temperature in the laundry, which is rather high.

A simulation model indicated that if the PV gable would have been used in the ventilation system, as originally intended, the thermal yield would have been 75 kWh/m^2 without ventilation heat recovery, and 33 kWh/m^2 with ventilation heat recovery. (Jensen, 2003b)





Copenhagen, Viktoriagade (2002). A 75 m^2 monocristalline Si PV gable was erected to an existing five storey building. The gable serves to preheat ventilation air, which is fed to the building either directly, through a mechanical ventilation system (3rd floor) or through a balanced ventilation system with heat recovery (4th floor). Dampers at the top of the gable can be opened if preheating is not required. The thermal efficiency was low due to very low flow rates. However, the airgap is expected to lower the temperature of the PV at the top of the gable by 20 C. (Jensen, 2002).

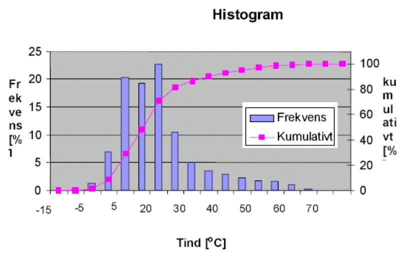


2.3.8 Arkitema (Denmark)

Silkeborgvej, Arhus (2003). The system contains 84 facade integrated cSi modules of 2.79 m^2 (totaling 226 m^2; 15 kWp), combined in 12 groups of 7 modules to the 12 inverters. The intention of the system was preheating ventilation air and cooling of the PV. The annual thermal yield of the PV/T integrated over the entire facade was measured to be 13 kWh. (Katic, 2003)

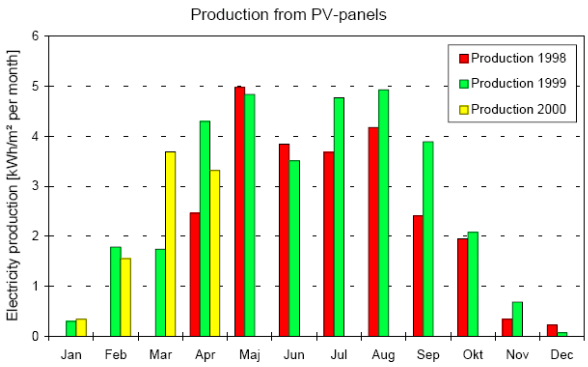
	Graddage	Maksimum Indblæsningstemperatur [°C]	tilført termisk energi i målelejlighed A [kWh/m²]	tilført termisk energi i målelejlighed B [kWh/m²]
apr-02	289	55,7	7,582	7,589
maj-02	133	50,6	7,227	6,483
jun-02	60	53,3	4,972	2,212
jul-02	36	60,6	6,410	7,234
aug-02	1	64,6	4,451	6,695
sep-02	93	66,9	1,640	4,297
okt-02	322	60,9	4,277	4,282
nov-02	391	44,9	1,101	1,478
dec-02	530	37,3	1,023	1,147
jan-03	521	36,6	3,771	2,650
feb-03	514	56,6	7,695	7,520
mar03	415	62,9	7,696	9,411
sum	3305	66,9	57,843	60,999

Tabel 4: Den tilførte termiske energi for de to målelejligheder



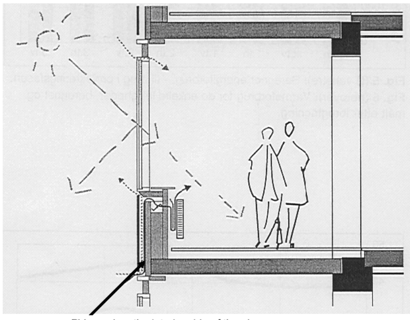
2.3.9 Esbensen (Denmark)

Yellow House, Aalborg (1996). The yellow house was part of a number of urban renewal projects initiated by the Danish Ministry of Housing, among which were also the 'blue house', the 'green quarter' and the 'ecological new building'. The yellow house, a 4 storey building with 8 apartments built in 1900, was renovated in 1996. Among other measures, the balconies were glazed and PV modules were applied as a front cover of the parapet (Voss, 2000). The PV modules that were integrated in solarwall systems integrated in the facade and the system was used to preheat ventilation air. The total PV size is 22.3 m^2. There is a glazing in front of the PV panels. Below the glazing there is an inlet for the fresh air to the apartments and over the glazing there is a 4-8 mm wide opening. Due to the under pressure created by the air extraction in the kitchen and bathroom the fresh air flows along the front and rear side of the PV panel before it enters the room (Hansen, 2006; Joergensen, 2000).



Principle for ventilated solar wall with integrated PV panel in The Yellow House

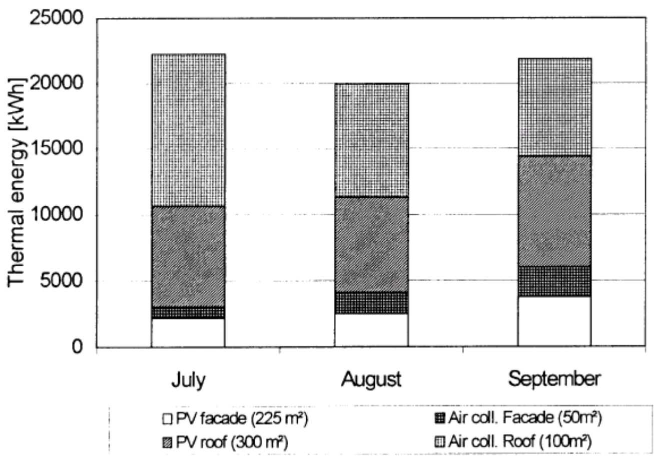
Note that the PV Panel is placed on the inside of the air gap

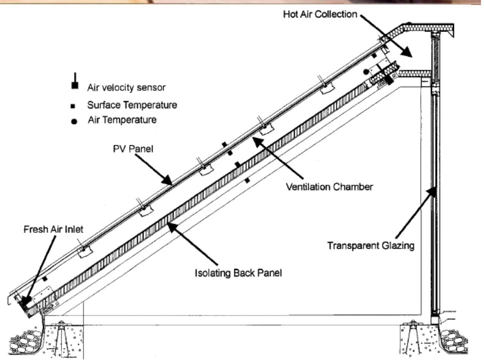


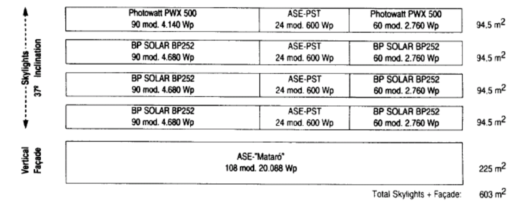
PV panel on the interior side of the air gap

2.3.10 TFM (Spain)

Mataro Public library (1995-2002). The Mataro project is quite extensive, since 3 (!) successive EU projects have been carried out on the optimization of the system. In the first project, the building was fitted with a semitransparent ventilated PV facade of 225 m^2 (6 ×37.5 m^2; 20 kWp), containing 108 PV modules with ASE c-Si cells. Each column of 3 PV modules forms one hybrid module. On the roof, 378 m^2 PV skylights (37º) produce another 33 kWp (30.1 kWp c-Si and 2.4 kWp a-Si). (Lloret, 1998).
In a second project, an additional booster row of 60 m^2 Grammer solar air collectors was added on top of the PV/T facade (see photo) to increase the suitability of the heated air for space heating, as well as ventilation air preheating. The air flow rate through the façade is very low (less than 0.5 m/s, due to the large channel width of 12 cm, matching the air gap behind the original PV panels), resulting in a thermal efficiency of 12-15%. Also, it is susceptible to influence by ambient wind induced pressure gradients (Infield, 2000).
In a third project (Eicker, 2000; 2002), solar cooling was added to be able to use the heated air also during summer. Also 105 m^2 of Grammer solar air collectors were added on the roof (34º). Measurements over June indicated a saving of 69% of the primary energy compared to the conventional cooling system. A special encapsulated fan was designed to handle the peak temperatures around 150°C from the solar air collectors. The installation costs for the complete system were 179,300 Euro.

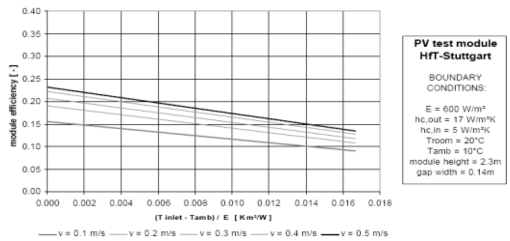


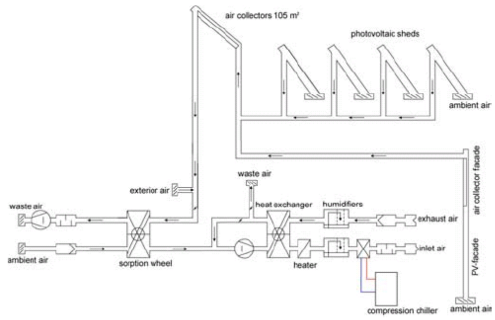




Modules			Num.	Wp/mod.	Wp	Converters	
ASE-"Mataró"	Poly-crystalline	Semitransp.	108	186	20.088	3 SOLWEX 5076	5kVA
BP SOLAR BP252	Mono-crystalline	Opaque	450	52	23.400	3 SOLWEX 5076	5kVA
Photowatt PWX500	Poly-crystalline	Opaque	150	46	6.900	1 SOLWEX 5076	5kVA
ASE-PST	Amorf	Semitransp.	96	25	2.400	1 SOLWEX 2065	2kVA

Total Peak Power: 52.788





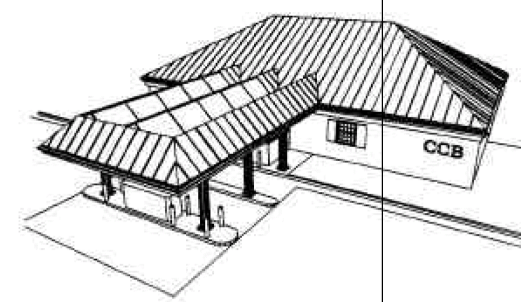
		ESTIMATED RESULTS CONVENTIONAL SYSTEM / SAME COOLING LOAD	MONITORING RESULTS NEW SYSTEM
		diari	diari
SOLAR PRODUCTION			
PV solar product.+air	kWh	0	338
FINAL ENERGY – Cooling			
Cooling load	kWh	151	151
Cooling production-DCS	kWh	115	132
Auxiliary cooling production	kWh	36	20
ENERGY CONSUMPTION			
Cooling electricity	kWh	43	6
Additional electricity ventilators	kWh	0	7
PRIMARY ENERGY	kWh	126	36
CO_2 EMISSIONS	$kgCO_2$	39	11
PRIMARY ENERGY		**69 %**	
CO_2 EMISSIONS		**69 %**	

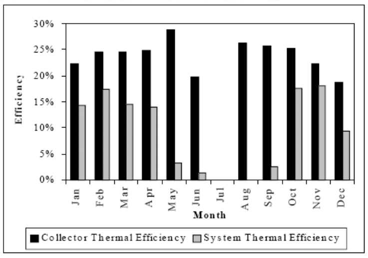
Imagina Studios (2004). A 1000 m^2 ventilated horizontal PV roof was installed on the Imagina studios in Barcelona (Aceves, 2005). The PV heat is mostly vented to the ambient; only the part of the roof above the restaurant is used for preheating ventilation air during the winter. The thermal yield is not monitored.

2.3.11 Innovative design & NCSC[4] (USA)

Central Carolina Bank in Bessemer City (1996), NC.
The drive-in canopy contains V-troughs, consisting of mirror elements on the north side and PV modules on the south side (45°). The mirrors increase the insolation by roughly 10%. The systems contains 10 c-Si PV modules, resulting in a nominal power of 2.7 kWp. A DC fan is directly coupled to one of the modules. During summer the heat is vented to the ambient, while during winter, ventilation air is preheated, resulting in a useful thermal output of 3500 kWh/year. (Fitzpatrick, 1999).
(www.innovativedesign.net/solarcommercial.htm)

Month	Solar Resource (kWh)	PV Energy (kWh AC)	Thermal Energy Gain (kWh)	Demand Reduction (kW)
Jan.	2,486	147	355	0.16
Feb.	2,563	168	448	1.28
Mar.	3,422	233	495	1.29
Apr.	3,393	228	474	1.04
May	3,857	251	122	1.25
Jun.	3,731	218	24	1.02
Jul.	3,750	220	0	1.09
Aug.	4,216	260	3	1.12
Sep.	3,738	236	70	1.20
Oct.	3,806	245	672	1.23
Nov.	2,632	133	474	0.02
Dec.	2,611	150	245	-0.11
Total:	40,205	2,489	3,382	10.59



Applebee restaurant in Salisbury, NC (1997). The roof contains 32 semitransparent a-Si PV modules (39 m^2), with a black metal absorber underneath. Through the passages, air is vented. The hot air is used for water heating. The output power of 8 PV modules is used to drive the fan. A 20 kWh battery storage is used for emergency backup.
The total PV system cost was around \$215/m^2. This is only about \$54/m^2 higher than the cost of the conventional Applebee roofing material. A notable feature of the PV system was the installation time; even though this was a new system, workers were able to complete the entire roof and the ductwork in less than three days (Sheinkopf, 1998)
(www.innovativedesign.net/solarcommercial.htm)



[4] North Carolina Solar Centre

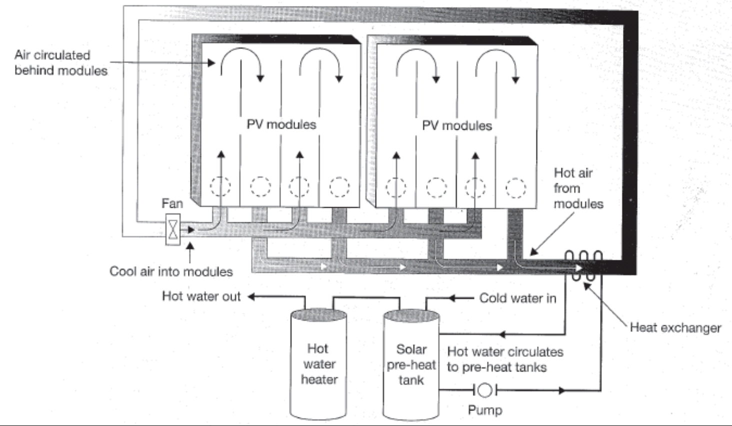
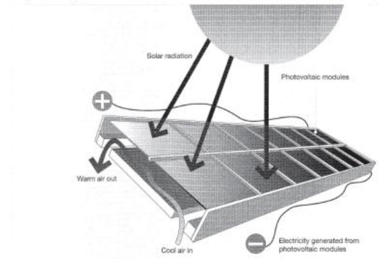


Diagram showing detail of the PV roof.



2.4 Concentrating PV/T air collectors

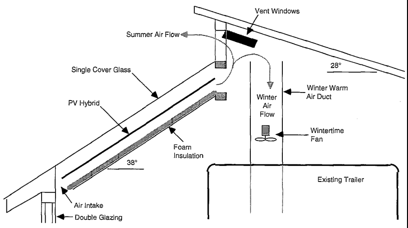
2.4.1 SunWatt Corp. (USA)

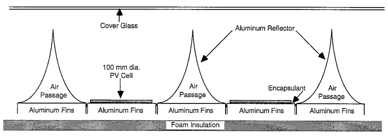
Louisville, Kentucky. In 1987, Sunwatt installed a roof integrated concentrating thermosyphon PV/T air collector system in an off-grid dwelling, consisting of a house-trailer covered by a sunspace. A 3.5 kAh battery bank stores the electricity, which is used for household appliances, a computer and a plastic molding machine used for income generation. In the winter, the warm air is drawn down to floor level by means of a PV powered fan. In the summer, the hot air exits through the open upper windows and the draft draws cooler air from the ground level into the dwelling.
The total cost of the installed PV hybrid system was less than $9,000, but this cost is unrealistically low since the cells were purchased surplus from a solar company shut down by its oil company parent and all the module assembly work was done on site.
No monitoring was carried out, but expected thermal and electrical outputs of the system are presented below. (Komp and Reeser, 1987)

Collector Tilt= 38° • Rated Output= 2500 Watts • System Voltage= 12 VDC
Battery Storage=10.7 days • Battery Capacity= 3500 Amp-hrs. • Electric Cost= 9¢/kW.-hr.

Month	kW.-hrs./ Month Geometric	Percent Sun	kW.-hrs./ Month Expected	Amp.-hrs./ Month	Output Value	Hybrid Heat Output in kW-hrs.
JAN	394	41	162	13468	$14.55	1713
FEB	384	47	180	15025	$16.23	1911
MAR	443	52	230	19204	$20.74	2443
APR	420	57	240	19967	$21.56	2540
MAY	405	64	259	21613	$23.34	2749
JUN	372	68	253	21057	$22.74	2678
JUL	393	72	283	23580	$25.47	2999
AUG	423	69	292	24337	$26.28	3096
SEP	429	68	292	24321	$26.27	3094
OCT	434	64	278	23146	$25.00	2944
NOV	390	51	199	16606	$17.93	2112
DEC	384	39	150	12476	$13.47	1587
Totals	4872		2818	234801	$253.59	29867

Total value of hot air with hybrid= $2,688. Dollar values are based on current Louisville, KY utility rates and do not include the avoided cost of installing the power lines to the home site.



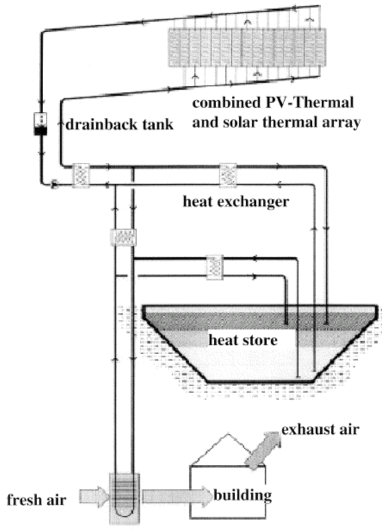


3 PV/T liquid projects

3.1 Glazed PV/T liquid projects

3.1.1 Beaufort Court building (UK)

Beaufort Court, the head office of Renewable Energy Systems, was completed in November 2003. This office complex has been created by renovating a former egg farm built around 1930 and designing it with an integral energy concept in which renewable energy is used for electricity, heating and cooling, which was carried out within an EU project led by Studio E Architects. The office displays a number of renewable energy techniques, such as biomass, a wind turbine, solar thermal collectors and a PV/T array. The solar thermal collectors and the PV/T array are installed side-by-side in a long row on the biomass drying barn. The PV/T modules were developed within the project by ECN, Shell Solar and ZEN. The heat produced by the PV/T and the solar thermal collectors is fed to a large underground water store (1400 m3), and is used during the winter for the air heating system. Unfortunately, the irradiance is not measured, so it is not possible to give a clear statement on the efficiency of the system. However, it is possible to compare the PV/T collectors to the conventional thermal collectors and the PV in the system. The figures show that in 2003-2005 there were problems with the system. Initially, stagnation occurred, while later the PV/T yield was absent. However, since the start of 2006 the storage temperature clearly increases and the PV/T's give more or less consistently about 20% of the yield of all thermal collectors. In addition, the electrical yield of the PV/T is roughly 20% of the thermal yield of the PV/T. Assuming that the electrical efficiency would be about 10%, this indicates an average PV/T thermal efficiency of 50% which is consistent with the fairly low absorber temperatures. Since the PV/T area is 54 m^2 and the solar thermal array is 116 m^2, this is consistent with an average conventional collector efficiency that is 60% larger than the PV/T efficiency. If the thermal PV/T efficiency would indeed be about 50%, the solar thermal efficiency would roughly be 80%. This is in accordance with expectations.
(Zondag, 2005; Lloyd Jones, 2004) (www.beaufortcourt.com)



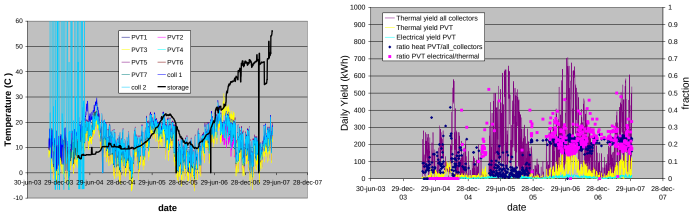


Figure 4: (a) Average temperatures of the RES PV/T absorbers, conventional collector absorbers and seasonal storage (b) Daily thermal yield of all collectors and PV/T collectors, daily electrical yield of PV/T collectors

3.1.2 PVTWINS

Alkmaar (2007-2008), single family houses owned by a housing association, that receive a PVTWINS collector as part of a renovation scheme. At this moment, as a trial, 5 PVTWINS collectors have been installed of 2.75 m^2 each (mono crystalline Si cells, nominal output 300 W electrical and 1540 W thermal). During 2008, more residents will be able to choose for PV/T as an option in the renovation scheme. (Manufacturer information, www.pvtwins.nl) 	
Zoetermeer (2007), Office building owned by Governmental housing administration; hot water is used for the showers and the kitchen. Six PVTWINS collectors are installed with an aperture area of 3.84 m^2 each. The total area is 27 m^2 of PV/T, combined with 4 m^2 PV and 15 m^2 solar thermal. (Manufacturer information, www.pvtwins.nl)	

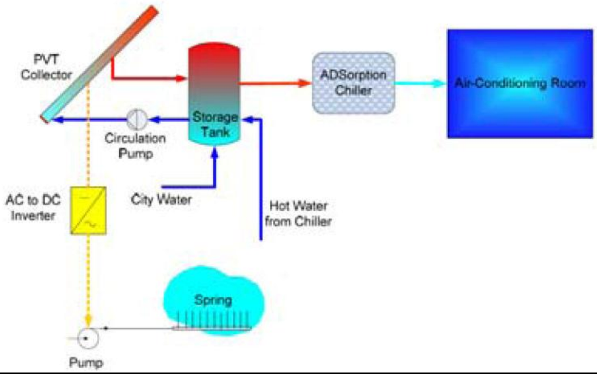
3.1.3 NSTDA[5] (Thailand)

Banglamung Hospital, Chonburi Province, Thailand (2003). A 48 m^2 a-Si PV/T (3kWp electrical) was installed, together with a 2500 liter storage tank to provide hot water for 3 washing machines and dishwasher. The PV/T collector is a glazed collector with a tefzel PV top surface.
(NSTDA information, NSTDA presentation 2006)

NSTDA, Thailand (2004). A 41 m^2 a-Si glazed PV/T collector system was installed (12 modules on the left, showing some mirroring in the photograph), together with a 20 m^2 a-Si PV system (6 modules on the right) and a 3000 liter storage tank. The PV system and the PVT system are together 4 kWp electrical. The hot water is used for cooking and dish washing. For this system, total energy saving is about 70,000 kWh per year.
(NSTDA information, NSTDA presentation 2006)

Queen's Sirikit Hospital, Chonburi Province, Thailand (2004). A 152 m^2 a-Si PV/T collector system (9.7 kWp electrical) was installed, together with three 3500 liter storage vessels. The heated water is used for the hydrotherapy pool. Monitoring data provided by Nualboonrueng indicate a thermal PV/T system efficiency of 55-60% and an electrical PV/T efficiency of 4-5%.
(NSTDA information, NSTDA presentation 2006)

PV/T Air-Conditioning system at MOST[6] (2005). A 93 m^2 a-Si PV/T system (5.5 kWp electrical) was installed, together with a 500 liter storage vessel. The heat from the PV/T is fed to a silicagel based adsorption chiller with a COP of 0.4 at an input temperature of 70 °C.
(NSTDA information, NSTDA presentation 2006)



[5] National Science and Technology Development Agency (NSTDA)
[6] Ministry of Science and Technology

3.1.4 Hong Kong City University

Hong Kong (2007). A thermosyphon PVT system was installed on a refurbished office building of the Hong-Kong City University, consisting of 6 PVT modules, module area 1.4 m^2 (9 m^2 overall aperture area) and 0.5 m^3 water storage. The PVT absorber consists of an aluminium channel-plate. Typical summer thermal efficiency is 40%, the hot water is used for pantries and toilets. Each module has 72 c-Si cells in series with a packing factor of 58%. PV efficiency 8%; the electrical output is stored in batteries and through an inverter fed to the LED exit signs of the building Chow, 2007).	

3.2 Unglazed PV/T liquid projects

3.2.1 NSTDA[7] (Thailand)

Military Camp 11, Yotee Road, Bangkok, Thailand (2004). An unglazed 41 m^2 aSi PV/T collector was installed (2.8 kWp electrical), together with a 2000 liter storage vessel. Hot water has been used for cooking and for dish washing. This system use PV modules with glass surface but without glass cover. For this system, total energy saving is about 57,000 kWh per year. (NSTDA information, NSTDA presentation 2006)	

[7] National Science and Technology Development Agency (NSTDA)

3.2.2 PVTWINS

Kollum (2008). PVT was installed on a low energy house. The PVT system consists of 3 unglazed PVT modules (highest row on the photograph; 1.9 kWp). In addition, 3 PV modules (middle row; 1.9 kWp) and 6 glas-glas PV modules (lowest row, 0.7 kWp) were also installed. From the similarity of the upper two rows, it can be seen that the combination of unglazed PVT and PV gives a very homogeneous appearance. The thermal system also contains a heat pump boiler with borehole. The project was commissioned by project developer VDM. (Manufacturer information, www.pvtwins.nl)	

3.3 Concentrating PV/T liquid collectors

3.3.1 SunWatt Corp. (USA)

Sarasota, Florida (1987). This system was installed on the home of Michael Holahan in Sarasota, Florida in 1987. It is 1.22 m x 2.44m box size and 20 cm tall (aperture area of 2.82 m^2). The electrical output is 150 watts, using Photowatt cells, and it has a thermal output of 1500 watts at AM1 conditions. In 2005, it was calculated that the hybrid had paid for its $1200 cost (including installation) three times over up to that time, just from the savings in the electrical bill for running the electric hot water heater, which serves as the backup for the solar system. The system performed well, until it was disconnected in 2006 to replace the asphalt shingles on the roof. No local craftsman was willing to reconnect it, so it was finally reconnected by the manufacturer end 2007 (Komp, 2007)	
Komp house (2001). PV/T module installed on the off-grid house of Richard Komp near Jonesport, Maine. This module is 0.91m x 1.98m and 20 cm deep (aperture area of 1.60 m^2). It produces 100 watts of electrical output and 1000 watts of thermal output at AM1 conditions using polycrystalline Solarex PV cells. It is the main supplier of hot water to the home, with an LP gas heater as a backup for the winter months. The home also has 4 thermosyphon solar air heaters and passive solar windows with a “hypocaust” heat storage system under the floor. This PV-hot water hybrid module was originally built and installed in 1995 on a remote home near Bar Harbor, Maine but was removed from there in 2001 when the home was remodeled and expanded, and was then installed in its present location. (Komp, 2007)	

Seaborne house trailer (2004), Jonesport. This module is 0.91m x 1.98m and 20 cm deep (aperture area of 1.60 m^2). It produces 110 watts of electrical output and 1000 watts of thermal output at AM1 conditions using monocrystalline Si cells from Astropower. Initially, the system had some stagnation problems due to a problem with the plastic tubing that was used, and the high stagnation temperatures caused some solder joints in the ribbons between the PV cells to come loose, but these have now been fixed and the system is operating satisfactorily.	

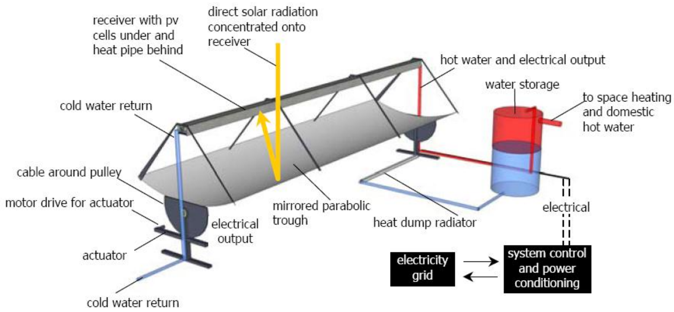
3.3.2 Arontis (Sweden)

World Heritage Museum in Skule (2006). The system is a wood pellets with complementary solar, both 20 m^2 of flat panels and 10 m^2 of the Solar8 PV/T. It is used both for hot water and space heating. The demonstration project was realized within the cooperation of Arontis with the regional authority in the County of Västernorrland. (www.arontis.se/1140a-case_solar_pvt_concentrator.php)	 

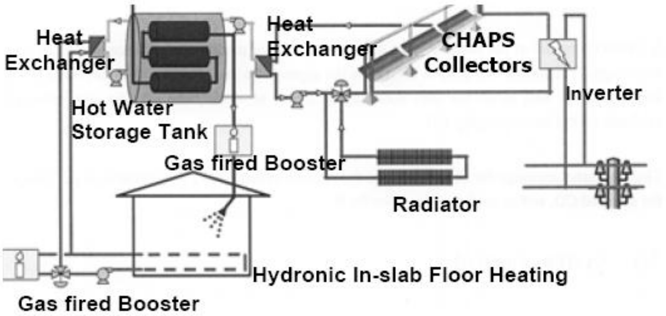
3.3.3 Bruce Hall building (Australia)

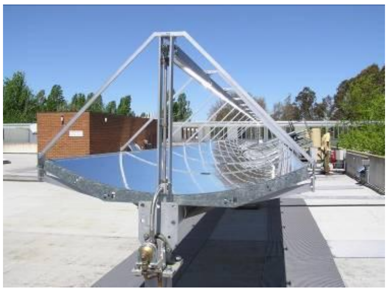
Bruce Hall (2004). CHAPS system. The 300 m^2 system provides electricity, hot water for an in-floor heating system as well as domestic hot water for 98 student apartments. There are eight collector rows, each 24.5 m long consisting of 17 individual mirrors with a 38X concentration, 6000 liters of hot water storage, and a 40kW inverter.

In a PV-Thermal system, it is not desirable to move the collector off focus once the heat store is up to temperature, as electricity production ceases as a result. To prevent overheating under stagnation conditions, the Bruce Hall CHAPS system employs a radiator (finned tube) to remove heat by natural convection (Smeltink, 2005).



In 2006, the CHAPS system was commissioned only for the thermal part, and thermal receivers were installed (Smeltink, 2006). The system was monitored by the BMS. In June 2007, the thermal receivers were replaced by PV/T receivers (Smeltink, 2007).





Characteristic	Specification
Mirror aperture	2.18 m^2
Number of Mirrors	136
Total aperture Area	297 m^2
Total Solar Cell Area	6.8 m^2
CHAPS Collector Rotation	± 90°
Tracker accuracy	0.1°
Geometric Concentration	38 x
Mirror Efficiency	83%
Cell Efficiency	21%nom
Receiver Efficiency	94%
Hot Water Storage	6000 liters
Nominal DC_{peak} Output	32 kW
Nominal Heat $Output_{peak}$	160 kW

4 PV/T combined air&liquid projects

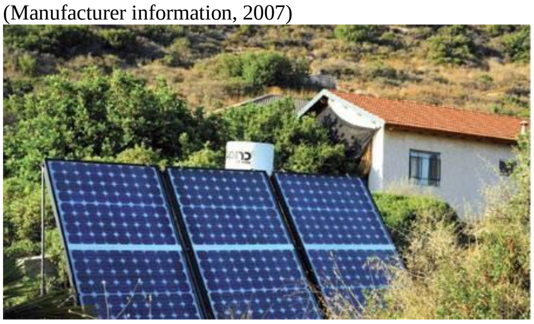
4.1 Millennium Electric & Solor (Israel)

All PVT collectors produced by Millennium Electric and previously by Solor are unglazed PVT collectors that can produce both hot water and hot air. However, in most realized projects until now, only the hot water output was used, while the hot air was extracted and vented to the ambient in order to cool the PV. Only in one project (the Chromagen headquarters project in 1998, described below), was the hot air used for space heating.

Figure 5: PVT collector from Millennium Electric, showing both air and water connections.

Elazari residence, Tel Aviv. In 1990, the first MSS prototype demonstration system was realized on the residence of Ami Elazari, founder of the company Solor. The system consists of 2 collectors of 2.56 m2 each under 45°, one with multicrystalline cells (180 Wp) and one with moncrystalline cells (195 Wp). The system also contains 10 Batteries of 100 Ah, 12 V, and a storage tank of 200 litres. The hot water is used for residential purposes. (Manufacturer information, 2007)	
Gan Haim system (1991). The systems contains two collectors of each 390 Wp and 2.56 m^2 under 45°. The system also contains a battery of 800 Ah, 12 V, and a storage tank of 200 liters. The hot water is used for residential purposes. (Manufacturer information, 2007)	

Klil village. In 1992, 6 residences received a PV/T system (the houses of the families Nezger, Shenar, Rotem, Hovev, Brown and Levy). In addition, the Shenar family received a second system in 1995. Klil village is located in the mountains in the North of Israel and is not connected to the national grid. Most of the systems consist of 2 PV/T modules of 2.68 m^2 area each, but two systems consist of 3 PV/T modules (the system of the Rotem family and the second system of the Shenar family). The systems all have a water storage of 200 liters and a 12 V, 800 Ah battery to provide the energy demand of the families autonomously. The electricity is used for electric lighting, a TV, a refrigerator and a washing machine, while the thermal output is used for residential use (e.g shower). The PV/T modules are 320 Wp electrical, have a thermal production of roughly 1200-1500 Wp thermal and have been installed under an angle of 55°.
(Manufacturer information, 2007)


Rotem family house


Brown family house

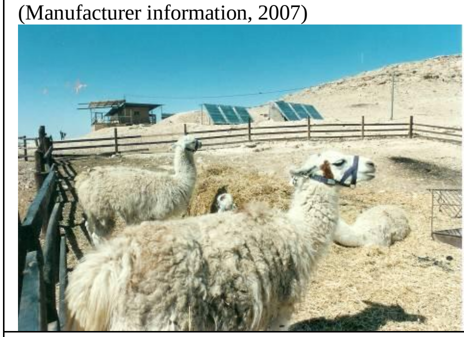

Nezger family house

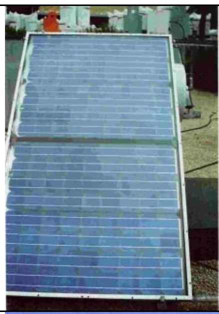
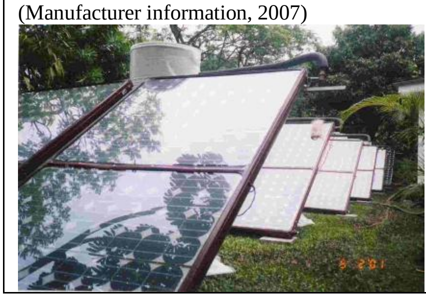

Shenar family house (system 1)


Hovev family house


Levy family house

At the UNosom forces base in Somalia in 1993, a MSS PV/T system was installed consisting of 2 modules of 2.68 m^2 each under an angle of 30°, with a 200 liters storage vessel and a 12 V, 800 Ah battery. The thermal output is used for residential purposes.
(Manufacturer information, 2007)

Israel convention Center - the Solar House (1994). The systems contains two collectors of each 300 Wp and 2.56 m^2 under 55°. The system also contains a battery of 800 Ah, 12 V, and a storage tank of 200 litres. The hot water is used for residential home use in the solar house. (Manufacturer information, 2007)	
System of mr Yossi Dvir, Guatemala (1995). The systems contains one collector of 300 Wp and 2.56 m^2 under 30°. The system also contains 4 batteries of 100 Ah, 12 V, and a storage tank of 150 liters. The hot water is used for residential purposes. (Manufacturer information, 2007)	 
At Alpaca farm in the Negev desert, in 1995, 2 PV/T systems have been installed; the main system of 9 PV/T modules, 6 batteries and 4 storage tanks of 200 liters, and a top system consisting of 6 PV/T modules, 3 batteries and 3 storage tanks of 200 liters. The PV/T modules are 2.68 m^2 area each (320 Wp) and the collector angle is 45°, the batteries are 12 V, 800 Ah. The thermal output is for residential use, while the electrical output is used (among other things) for the satellite system and the lighting system. (Manufacturer information, 2007) 	  
In the recreation village Suca in the desert, consisting of 18 lodges for about 50 persons, 2 PV/T systems were installed in 1995. One system is a hybrid system in which 2 PV/T modules (2.68 m^2 each) were combined with a conventional solar thermal system to provide hot water for the central showering facility. The other system consists of 4 PV/T modules (2.68 m^2 each) for hot water generation. Both systems have a 200 liter storage and a 12 V, 800 Ah battery. The recreational village is in use all year round. (Manufacturer information, 2007)	 

Demonstration system at the Solor offices in Kryiat Teivon (1996). The systems contains one collector of 300 Wp and 2.56 m^2 under 45°. The system also contains a battery of 800 Ah, 12 V, and a storage tank of 200 liters. (Manufacturer information, 2007)	
Chromagen headquarters, 1998. This system is producing both hot water and hot air. The hot water is used for tap water heating, while the hot air is used for space heating during the winter; the hot air is fed directly to the meeting room and in addition is supplied to the main air conditioning unit of the building. The system contains 5 PVT collectors of 2.56 m2 each, vertical orientation., containing a-Si PV (Unisolar) with an electrical power of 150 Wp. The system further contains an 800 Ah, 12 V battery, and a 200 liter storage tank. (Manufacturer information, 2007)	
Singapore (2001), in a large scale demonstration project, 8 PV/T systems, consisting of 2 PV/T modules (2.68 m^2 each) and a 200 liter storage tank each, were installed at a residence of a scientist. The hot water is used for residential application. The total system delivers 3.6 kWp el and is connected to a battery bank of 24 V, 1200 Ah. The efficiency is somewhat lower than for the other systems due to the large amount of shading. (Manufacturer information, 2007) 	 

5 PV/T project experiences – lessons learnt

It is not only useful to make an inventory of the projects themselves, but also of the issues that have influenced these projects. In general, it can be expected that in the first market preparation projects, many lessons are learnt that provide experience to the project partners and allow future projects to be carried out much more smoothly. Information was collected from EU reports and publications, as well as interviews carried out with a number of companies involved in these projects. Especially some reports were very candid on what went wrong in the project, e.g. when delays had to be explained. A number of issues is summarized here:

Preparation phase

- It may be important to consult the municipality in an early stage, to obtain their cooperation and to make sure that no objections exist to the way in which the PV/T will be integrated. It also helps if the client and/or the architect have some information on the PV/T, are motivated to apply it and have good contacts with external parties such as the municipality.

Time schedule

- Often, a demonstration project is coupled to a planned renovation or building scheme. This has the risk that the demonstration project may have delays, e.g. due to the development of new components within the demonstration project, increased complexity of the installation related to the demonstration project, or due to extensive contract negotiations for the demonstration project. If, as a result, there is a perceived risk that the building scheme will be delayed due to the demonstration project, the building owner or the main contractor may decide that the entire demonstration project will be cancelled. This led e.g. to the termination of the PV/T demonstration project at Haileybury (Lloyd Jones, 2004).
- Delays in the building or renovation scheme may lead to problems, especially if there are external project deadlines for the PV/T part (e.g. from the EU or other financing organization). In the PV/T demonstration project at RES, delays occurred due to the complicated renovation and the development of the ground heat store (Lloyd Jones, 2004). These delays, in combination with the fixed EU deadline, caused a significant reduction of the period available for monitoring and consequently a reduction of the EU funding since the monitoring had not been fully completed within the project. In the PV-Vent project in Lundebjerg, the tenants blocked the new building design for aesthetic reasons, leading to a change in architect and a new renovation design. The subsequent renovation lasted almost a year instead of the foreseen 4 months, resulting in a reduced time for monitoring (Jensen, 2001a). In the third Mataro project, it turned out that the roof had to be reinforced to allow for the additional weight of the new system, causing an unforeseen delay (Eicker, 2002).

Application of new components & techniques

- New developments within the projects sometimes take more time than expected. Examples are the development of a PV-mixer[8] in the PV-Vent projects (the initial prototype was found to be faulty and a new company was found to redesign the component) or the ground heat storage in the RES project (the completion of which took 6 months instead of the anticipated 6 weeks (Lloyd Jones, 2004)). Also, these components may be less energy saving, more costly or more difficult to apply than expected due to unanticipated problems (such as unanticipated material characteristics, leaking or a non-optimal control strategy).
- Additional requirements may come up during the project related to e.g. safety. In the RES project, for the design of the ground heat store, after it was decided that this would have a floating lid, a substantial amount of time went into the issue of designing the system thus that the water reservoir is absolutely safe (against the risk of injury or drowning to people including trespassing children for example), which made it essential that there should be no chance of anyone easily being able to enter the water even in the case of partial or total collapse of the floating lid following unplanned loss of water (Lloyd Jones, 2004). In the third Mataro project, a legionella crisis in Mataro retarded the installation of the solar desiccant cooling. For almost a month, the system was stopped to disinfect the humidifiers in accordance with the legionella legislation, but the report indicates that the worries about legionella problems could finally be rebutted since it was found that it is impossible to bring bacterias from humidifier water into the air flow due to the fact that legionellas can't survive at the low operation temperature of about 18°C (Eicker, 2002).
- The fact that innovative techniques are used in a demonstration project may require the use of non-standard components. Since these components may be new and little experience is acquired with them, this may lead to mistakes or other problems, as well as long delivery times. As an example, in the RES project, since it was decided to keep the voltage of the PV/T collectors low (to prevent the use of bypass diodes), special low-voltage inverters were used that later turned out to give problems. By that time, however, the inverter manufacturer had decided to stop the development of these inverters, and had no infrastructure left to solve these problems. The problems were only solved when the inverters were replaced. Due to the fact that the new invertors had different specifications, a redesign of the electrical connections of the PV/T system was required (Lloyd Jones, 2004).
- The fitting of the PV/T installation to the existing installation may turn out to be more problematic than expected. In the Third Mataro project, the air volume flow was limited by the existing ducting system (Eicker, 2002). Another example is the ecological launderette in Valby, Copenhagen, that was fitted with a PV/T-air gable. It turned out that it was not possible to connect the PV/T-air gable to the existing ventilation installation. Instead, the PV/T system was redesigned such that a separate fan, leading the heated air from the gable to the building, was only switched on if the gable temperature was high enough. In practice, however, this solution turned out to be much less energy saving than the original design; even to such an extent that the savings were

[8] A device that was developed within the project to feed the fan of the ventilation systems as much as possible directly by the PV, but that allowed backup by the grid in case of insufficient solar supply.

actually negative due to the high room temperatures in the launderette (Jensen, 2003).

- When going from a prototype collector to a full system installation, if a one-of-a-kind system is installed, many practical issues may come up. As an example, in a publication on the ANU project (concentrating PV/T system with tracking), several faults were described that were encountered and rectified during commissioning: pivot mount interference, cable durability, guide sheave seizure, faulty temperature sensors, leaks, actuator noise and BMS calibration. In the Sørensensvej PV/T-air project, an always-open bypass was found in a ventilation air heat exchanger, while in another the ducting was connected wrongly. Also in liquid collector systems, heat exchangers connected in reverse are a classical installation error. Sometimes such errors are discovered in the commissioning phase, sometimes they can only be found after monitoring of the actual system performance.
- The mounting of the system is frequently problematic, due to special demands for the integration from the architect, adaptations that have to be made due to specific building characteristics or the issue of guaranteeing rainproof integration of the PV/T system. Also discussion on stability of the mounting construction at high wind load may occur. In the Sørensensvej project, the following description is given: "It was originally the idea to use the principles in the BPS guidelines for integration of solar collectors into the roof. There rainproof solutions are obtained by using roofing-felt as under roofing. However, in practice it has been difficult to convince the architects about these solutions [..]." Nevertheless, since the uniform visual aspect of PV/T is an important selling point, it is important to think of good integration options.
- The production of substantial numbers of in the project developed components, such as PV/T modules, may be difficult to realize. Since the production of these special components in standard production lines may cause too much interference, often the prototype production technique and production facilities have to be applied (possibly in a slightly adapted form to allow a significant quantity), and consequently the products are expensive. In the RES project, this was also reason to reduce the number of PV/T collectors from 22 to 7, and to add 15 conventional solar-thermal collectors to compensate for this reduction (Lloyd Jones, 2004).

Monitoring and troubleshooting

- The fact that during the building process many actors may be only for a short time at the building place and have a limited responsibility may give problems. The RES report gives the following description: "The commissioning and monitoring of the systems has taken almost a year due to the sequential nature of problem solving in novel technologies. The resolution of one issue often leads to the discovery of another. The reasons for the defects are sometimes not clear, and responsibilities are blurred. The commitment to getting these issues resolved well after the end of the building contract is difficult to maintain. The contractors are expected to solve problems on a fixed price contract. It is possible that a separate budget should be allocated for this input." (Lloyd Jones, 2004)
- The monitoring may have problems due to malfunctioning or wrongly calibrated sensors, as well as data loss e.g. due to the effect of power cuts on the monitoring computer. An example is the monitoring of Sørensensvej,

which the report author describes as follows: “The systems at Lauritz Sørensensvej 24 have from a measuring point of view been a nightmare. Nearly all possible errors that can be imagined were present in the systems after the installation and they were corrected very late – almost a year after installation.” In the PV-Vent project at Sundevedsgade (Jesen, 2001b), it was found that the 4-quadrant analogue multiplier was very sensitive to temperature and gave unreliable measurements. In the RES project, it was decided not to install a pyranometer to reduce the transgression of the budget.

- Often, little or no funding and time is left for the monitoring, so often no reliable data on the system performance are available and possible installation errors may go unnoticed. At the other hand, in some projects fully automated monitoring systems have been set up, also making the monitored data directly publicly accessible trough a website, as is the case in the RES project. Although the project was finished years ago, newly monitored data still becomes available every day, which was found to be very useful.
- The energy savings of the PV/T system may be less than anticipated due to the fact that the design of the module or system is not optimised. Shading may reduce the performance, especially the electrical output. In building integrated PV/T-air systems, this is often related to the wide air gap that is present behind the PV, to allow sufficient cooling of the PV by natural convection during the summer, when preheating ventilation air is not useful, as is e.g. the case in the first Mataro library project (Infield, 2000) and in the PV-Vent projects at Lundebjerg (Jensen, 2001a) and Sundevedsgade (Jensen, 2001b). The wide air gap results in very low flow velocities, that are largely determined by the natural convection flow and that are very susceptible to ambient wind pressure; in the Mataro library project, it was even found that for an Easterly wind direction, the airflow through the cavity is downwards (Infield, 2000). In addition, in the PV-vent project, it was found that the electrical benefits of the cooling of the PV were insignificant. The PV-Vent studies also indicate that the potential of preheating ventilation air is substantially reduced if a good ventilation heat exchanger is used (Jensen, 2001a). Finally, the Sørensensvej project (Jensen, 2003) indicated a reduced performance at low mass flow due to a poor flow distribution caused by central draw off of the air. Also, pressure drops may be higher than expected, e.g. due to too dense filters, as found in the second Mataro library project (Infield, 2000), or wrongly placed sound absorbers, as was found in the third Mataro project (Eicker, 2002). This leads to increased fan power consumption and may also increase the noise level of the fan, requiring additional sound absorbers. At the other hand, it was also found that the yield was in some projects higher than anticipated, due to the fact that also the heat losses from the building were recaptured by the PV/T; because of this effect in the PV-Vent project the PV/T-air façade system saved energy even at night (Jensen, 2001a). However, this effect is reduced if the building insulation is improved.
- Important in PV air systems for preheating ventilation air, is that the air is only preheated during the heating season. In practice, it may happen that the bypass is not functioning properly, resulting in preheated air also during summer, as was found in the monitoring in the third Mataro project, leading to an increase in the cooling energy required (Eicker, 2002).

Installation phase

- In glazed PV/T systems, the issue of high temperatures may be significant. A lengthy stagnation period may occur during the period in which the collectors are present on the building site but not yet connected. In the RES project, the manufacturer requested the coverage of the PV/T collectors during this period, to minimize any chance of trouble (Lloyd Jones, 2004). Another issue was raised in the third Mataro project, in which the glazed booster air collectors could at times supply peak temperatures of 150 C, while the maximum temperature of the sorption wheel of the solar cooling system was 90 C; this was solved with an additional bypass (Eicker, 2002).
- Although in principle it is possible to control and monitor the PV/T collector system by the BMS[9], it is often more convenient for the collector system to have its own control and monitoring. Problems may result due to a long BMS setup period extending significantly beyond the installation of the PV/T collectors, BMS failures, incorrect control procedures or insufficient sampling rate. In the ANU project, the BMS was programmed to recognize fault conditions for the concentrating PV/T system, but since the interface between the BMS and the collector was not connected for a significant time, during which time the collectors could only be operated under staff supervision (Smeltink and Blakers, 2006).

Dissemination

- Dissemination is important and may be realized by means of flyers, brochures, a website (where the abovementioned leaflets can also be downloaded), and group visits to the PV/T installation, if applicable. Furthermore, monitoring reports and conference papers are very worthwhile to spread information on the project. Unfortunately, the dissemination of project- and monitoring reports (e.g. final technical reports from EU supported projects) is often far from optimal. Often, information on the project can be incorporated in a broader public relations scheme of one or more of the parties involved.

A number of lessons can be retrieved from this list:

- Realize beforehand that the planning of the existing building or renovation project has its own dynamics; substantial delays may occur during this process and it is wise to allow for these in the planning of the deadline of the PV/T project. Also, substantial delays in the PV/T project compromising the commissioning date of the building can often not be tolerated.
- It is an important asset if the architect, building owner, local authorities and other parties in the building process are convinced from the start of the importance of the PV/T system to the project, are motivated to apply and it have sufficient knowledge about it.
- Safety issues, roof mounting and roof integration issues, responsibility issues and warranties may take a substantial amount of time in the project.
- Limit the amount of new components in the project, since the larger the amount of components to be developed within the project, the larger the chance that delays may occur. If the central item in the demonstration is the PV/T, then try to use standard components for the other aspects as much as possible. In addition, be aware that the production of a large number of non-

---

[9] Building Monitoring System

standard components (including possibly the PV/T modules itself) may be costly and not easy to realize.

- Be aware that a lengthy installation period (including BMS programming if relevant for the PV/T) should not compromise the PV/T reliability or performance too much.
- Monitoring is crucial to detect errors in the installation, which are often caused by malfunctioning components. This is particularly relevant if these errors substantially reduce the energy saving function of the system, e.g. by requiring too much electrical power for pumps and fans, or compromising the control of the system due to malfunctioning sensors, valves or bypasses. Allow sufficient time and money for monitoring and be aware that in this phase also time should be available to change malfunctioning components and malfunctioning monitoring sensors, and it should be clear whose responsibility it is to make these changes. In addition, it is highly recommended to set up an automated monitoring environment that can be read through a (publicly accessible) website.
- Dissemination is very important and can be realized by various means, ranging from allowing group visits to websites and publications in magazines or conference proceedings.

6 Conclusions

The market development for PV-Thermal systems is still in an early stage, which is in marked contrast to the large application potential of these systems, in particular on multifamily buildings where the available space is limited. Very important at this early stage is the generation of awareness for PV/T systems and the establishment of best practices and confidence through realized PV/T installations. The results of demonstration projects should be published widely.

A large amount of PV/T systems has been installed over the last 20 years. All together, the report presents information on 70 realised PV/T installations. Most of these systems are PV/T-air systems (39 systems), but also 15 PV/T-liquid systems were found, as well as 16 PV/T-liquid & air systems. Most of the PV/T-air projects have been built by the German manufacturer Grammer Solar using their unglazed PV/T-air collector. Another large number of projects was realized in national Danish projects led by the Danish consultant Cenergia, applying ventilated PV facades with heat recovery, as well as Solarwall systems. The oldest residential PV/T air installation found in the project was realized in the USA by Sunwatt in 1987; it is still in operation.

With respect to liquid collectors, a number of systems was realised recently in Thailand, in which 5 large-scale PV/T systems were installed on various governmental buildings over a period of about 2 years (2003-2004). These systems have been developed by NSTDA and are mostly unglazed PV/T collectors using amorphous silicon, but in one project also glazed PV/T collectors were used. The largest of these systems is a 152 m^2 system on the Queen Sirikit hospital in Chonburi. Other projects to be mentioned are a 54 m^2 glazed PV/T liquid project that was realised by the Dutch companies ECN, Shell Solar and ZEN Solar in the UK in 2003. This PV/T work has been continued by the ECN spin off company PVTWINS, that in 2007 has realized a 27 m^2 glazed PV/T liquid system on a Dutch governmental building and five 2.8 m^2 systems in a residential renovation project, while more market introduction projects have been planned for 2008.

With respect to the PVT systems heating both liquid and air, a large number of systems was realized by the company Solor, that has realized projects with unglazed PV/T collectors from 1991 onwards, among which several PV/T systems installed at 6 off-grid residences in Klil village, 2 PV/T systems in a recreation village in the Negev desert and 2 PV/T systems on an alpaca farm. Since 1999, the PV/T activities of Solor have been taken over by Millennium Electric, that is now marketing these systems.

Concluding, it can be stated that PV/T is an interesting technique with a large potential and a large amount of experience on PV/T is available. After a long market preparation phase in PV/T development, we hope that the results obtained in this task will contribute to the final take-off of the PV/T market.

Finally, while some demonstration projects run smoothly, others may be plagued by various unforeseen problems. From the reports on the various demonstration projects, a number of lessons has been learnt:

- Realize beforehand that the PV/T project is in many cases additional to an existing building project or renovation project, that has its own dynamics; substantial delays may occur during this process and it is wise to allow for these in the planning of the deadline of the PV/T project. Also, substantial delays in the PV/T project compromising the commissioning date of the building can often not be tolerated.

- It is an important asset if the architect, building owner, local authorities and other parties in the building process are convinced from the start of the importance of the PV/T system to the project, are motivated to apply and it have sufficient knowledge about it.
- Safety issues, roof mounting and roof integration issues, responsibility issues and warranties may take a substantial amount of time in the project.
- Limit the amount of new components in the project, since the larger the amount of components to be developed within the project, the larger the chance that delays may occur. If the central item in the demonstration is the PV/T, then try to use standard components for the other aspects as much as possible. In addition, be aware that the production of a large number of non-standard components (including possibly the PV/T modules itself) may be costly and not easy to realize.
- Monitoring is crucial to detect errors in the installation, which are often caused by malfunctioning components (sensors, bypasses, etc). This is particularly relevant if these errors substantially reduce the energy saving function of the system, e.g. by requiring too much electrical power for pumps and fans, or compromising the control of the system due to malfunctioning sensors, valves or bypasses. Allow sufficient time and money for monitoring and be aware that in this phase also time should be available to change malfunctioning components and malfunctioning monitoring sensors, and it should be clear whose responsibility it is to make these changes. In addition, it is highly recommended to set up an automated monitoring environment that can be read through a (publicly accessible) website.
- Dissemination is very important and can be realized by various means, ranging from allowing group visits to websites and publications in magazines or conference proceedings.

7 References

1. Aceves, O., Llorach, E., Barbat, E., Genard, P., Hentschel, D., Orti, A., Berga, E. (2005), "1000 m^2 of Hybrid PV-Thermal ventilated semi-transparent roof in a TV studios Imagina Visual Center (Esplugues-Barcelona)", last news presentation at PVSEC 2005, Barcelona.
2. Aschehoug (2003), BP SOLAR SKIN, a facade concept for a sustainable future, report Sintef.
3. Aste, N. (2007), Retrofit solare: l' esperienza del centro di formazione professionale di Casargo - A multifunctional solar plant, Next Energy conference 2007, Turin, Italy. www.nextenergy.biz/wvAttachments/695_Aste.pdf
4. Butera, F., Aste, N., Adhikari, R.S. and Bracco, R (2005), Ecomensa project at CRF: Performance of solar façade, 600 Congresso Nazionale ATI, Rome
5. Campanile, P., Parodi, M.L., Menardi, L., Mola, S., Bracco, R (2004), Efficient integration of solar energy, trigeneration and desiccant cooling: the 'ECO-canteen' of CRF, DAME-BC Warshaw workshop
6. Cartmell, Shankland, Fiala, Hanby (2004), A multi-operational ventilated photovoltaic and solar air collector: application, simulation and initial monitoring feedback, SE 76 (2004), pp 45-53.
7. Coventry, J.S. (2004), A solar concentrating photovoltaic / thermal collector, PhD thesis Australian National University.
8. Eicker, U., Fux, V., Infield, D., Mei, L. (2000), Heating and cooling potential of combined photovoltaic-solar air collector facades, 16th EPSEC Glasgow
9. Eicker, U. (2002), Adsorption cooling of buildings with integrated PV/solar air heating facades - AIRCOOL final report for project ERK6-CT1999-00010
10. Eicker, U., Huber, M., Schürger, U., Schumacher, J., Trinkle, A. (2003), Desiccant cooling technology powered by solar thermal air collector systems ISES Solar World Congress, Goteborg
11. Elazari, A. (1997), Solar multimodule for electrical and hot water supply for residentially building, SES Solar World Congress Korea
12. Infield, D. (2000), Design, study and experimental evaluation of an integrated solar facade, final report for project JOR3-CT97-0185.
13. Jacobsen, T.D, Jensen. S.Ø. (2001), Solassisteret ventilation – målinger på PVT-anlæg hos Roskilde Bank. report Solar Energy Centre Denmark, Danish Technological Institute. www.buildvision.dk/pdf/solassisteret_ventilation_maalinger_paa_pvt_anlaeg_hos_roskilde_bank.pdf
14. Jensen, S.Ø. (2001a), Results from measurements on the PV-VENT systems at Lundebjerg, report Solar Energy Centre Denmark, Danish Technological Institute. www.buildvision.dk/pdf/results_from_measurements_on_the_pvvent_systems_at_lundebjerg.pdf.
15. Jensen, S.Ø. (2001b), Results from measurements on the PV-VENT systems at Sundevedsgade/Tøndergade, report Solar Energy Centre Denmark, Danish Technological Institute.
16. Jensen, S.Ø. (2002), Måling af den termiske funktion af en multifunktionel solcellegavl, report Solar Energy Centre Denmark, Danish Technological
17. Jensen, S.Ø. (2003a), Results from measurements on a roof integrated PV system with preheating of fresh air. Lauritz Sørensens Gård, report Solar Energy Centre Denmark, Danish Technological Institute. www.buildvision.dk/pdf/results_from_measurements_on_a_roof_integrated_pv_system_with_preheating_of_fresh_air.pdf.

18. Jensen, S.Ø. (2003b), Måling på solcellegavl med forvarmning af ventilationsluft Økologisk vaskeri - Vinhaven, Valby, report Solar Energy Centre Denmark, Danish Technological Institute.
19. Jørgensen, O.B., Nielsen, L.T. (2000), Monitored results from the yellow house, Eurosun 2000 conference, Denmark.
20. Katic, I., Badran, J. (2003), Solcelleanlæg på Silkeborgvej i Århus Målerapport for perioden april 2002 til marts 2003, report Solar Energy Centre Denmark, Danish Technological Institute.
21. Komp, R., Reeser, T. (1987), Design, construction & operation of a PV/Hot air hybrid energy system, ISES Solar World Congress Hamburg.
22. Kropf, S. (2003), PV/T Schiefer, Optimierung der Energieeffizienz von Gebäuden durch gegenseitige Ergänzung von Simulation und Messung am Beispiel der Hinterlüftung gebäudeintegrierter Photovoltaik, PhD report ETH Zurich
23. Lloret, A., Andreu, J., Merten, J., Puigdollers, J., Aceves, O., Sabata, L., Chantant, M., Eicker, U. (1998), Large grid-connected hybrid PV system integrated in a public building, PIP 6, pp. 453-464
24. Lloyd Jones, D., Matson, C., Pearsall, N.M. (1998), The solar office: a solar powered building with a comprehensive energy strategy, 2nd WCPEC, Vienna, Austria.
25. Lloyd Jones, D. (2000), The solar office Doxford International, ETSU report www.berr.gov.uk/files/file17275.pdf
26. Lloyd Jones, D. (2004), Renewable Energy Systems head office and visitors' facility, Final Technical Report EU contract NNE5-1999-00352.
27. NSTDA (2007), PVT Solar system in Thailand, presentation NSTDA.
28. Phongsitong, J., Jaikla, S., Nualboonrueng, T., Sichanugrist, P. (2006), The Performance of a-Si Photovoltaic / Thermal Solar Air-Conditioning System Working With Compressed Refrigerant Air-Conditioning System, PVSEC, Dresden.
29. Posnansky, M., Gnos, S. and Coonen, S. (1994), The importance of hybrid PV-building integration, WCPEC 1994, Hawaii.
30. Posnansky, M., Eckmanns, A. and Szacsvay, T. (1997), Cogeneration of electricity and heat on building integrated PV-power systems: practical results, 14th PVSEC, Barcelona.
31. Robert Hastings, S. (1999), Solar Air Systems - Built examples, James & James
32. Shankland, Lomas, Carmell, Reeve, Dotzler (2001), A Ventilated Photovoltaic and Solar-Air Collector for Space and Water Heating, CISBE national conference, UK.
33. Sheinkopf (1998), PV system with thermal heat recovery, CADDET newsletter, May 1998.
34. Smeltink, J.F.H., Blakers, A.W. and Coventry (2005), A 40kW roof mounted PV Thermal concentrator system, PVSEC Conference, Barcelona.
35. Smeltink, J.F.H. and Blakers, A.W. (2006), 40kW PV Thermal roof mounted concentrator system, WCPEC Conference, Hawaii.
36. Smeltink, J.F.H. and Blakers, A.W. (2007), Performance monitoring of a PV Thermal concentrator system, PVSEC Conference, Milan.
37. Voss, K. (2000), Solar energy in building renovation — results and experience of international demonstration buildings, Energy and Buildings 32 (2000) pp. 291–302.

38. Zondag, H.A., Bristow, N., Gramsbergen, E., Helden, W.G.J. van, Lloyd-Jones, D., Nelson, S., Soerensen, H., Watts, B., Zolingen, R.J.C. van (2005), The Beaufort Court energy system - PVT and solar thermal for the preheating of ventilation air, ESTEC 2005 Freiburg.
39. www.solarwall.com
40. www.ecn.nl/egon/extra/extranet/pvt-platform/het-pvt-platform
41. www.beaufortcourt.com
42. www.grammer-solar.de
43. www.innovativedesign.net/solarcommercial_a.htm
44. www.pvtwins.nl