

MARKET, MODELLING, TESTING AND DEMONSTRATION IN THE FRAMEWORK OF IEA SHC TASK 35 ON PV/THERMAL SOLAR SYSTEMS

J. Hansen & H. Sørensen
Esbensen Consulting Engineers A/S, Carl Jacobsens Vej 25D, DK-2500 Valby, Denmark.
Phone: +45 33267308, +45 33267304 ; Fax: +45 33267301,
E-mail: j.hansen@esbensen.dk, h.soerensen@esbensen.dk

J. Byström
Arontis Solar Concentrator AB, Östanbäcksgatan 16, SE-871 31 Härnösand, Sweden
Phone: +46 611-26888; Fax: +46 611-557210,
E-mail: joakim@logosol.se

M. Collins
Department of Mechanical Engineering, University of Waterloo, 200 University Ave. W., Waterloo, Ontario, Canada, N2L 3G1
Phone: +1 519 888 4567; Fax: +1 519 888 6197,
E-mail: mcollins@uwaterloo.ca

B. Karlsson
Energy and Building Design, Department of Architecture and Built Environment, Lund Institute of Technology, Lund University, P.O. Box 118, SE-221 00 Lund, Sweden
Phone: +46 46-2227261; Fax: +46 46-2224719,
E-mail: Bjorn.Karlsson@ebd.lth.se

ABSTRACT: As part of the International Energy Agency – Solar Heating and Cooling Programme, a three-year research work – Task 35 "PV/Thermal Solar Systems" was initiated on 1 January 2005. The objectives of this Task are to catalyse the development and market introduction of high quality and commercial competitive PV/Thermal Solar Systems and to increase general understanding and contribute to internationally accepted standards on performance, testing, monitoring and commercial characteristics of PV/Thermal Solar Systems in the building sector. The activities in the project are carried out in an international collaboration with participation of research and test institutes, manufacturers, consulting engineers and universities. The paper gives an introduction to the PV/Thermal concept and technology followed by a description of the objectives and organisation of the Task. Preliminary results from the work in the Task are presented and include market, modelling, testing and demonstration aspects. The potential and challenges of PV/Thermal Solar Systems are also addressed.

Keywords: PV/Thermal, IEA, Task 35

1 INTRODUCTION

A PV/Thermal Solar System is a combination of photovoltaic components/systems and solar thermal components/systems which produce both electricity and heat from one integrated component or system.

The heart in a PV/Thermal Solar System is a PhotoVoltaic/Thermal module, or PV/T module which is a combination of photovoltaic cells with a solar thermal collector, forming one device that converts solar radiation into electricity and heat simultaneously. Apart from the PV/T module also components as hot water storage tanks, heat exchangers, piping, controllers, inverters, wiring and heat pumps can form part of a PV/Thermal Solar System. As a result of the dual production of electricity and heat, PV/T modules can generate more energy per unit surface area than side by side photovoltaic panels and solar thermal collectors, at a potentially lower production and installation cost. Moreover, PV/T modules share the aesthetic advantage of PV. Because of their high efficiency per unit surface area, PV/T is particularly well suited for applications with both heat and power demand and with limited roof space available. Therefore, the potential of PV/T is especially large in the residential market, both collective and individual. [1]

There are many ways to combine the different PV and Solar Thermal technologies to a PV/T collector: crystalline or amorphous silicon or thin-film PV, liquid or air collectors, flat-plate or concentrating technologies with or without transparent cover, some fully building integrated. So far, most development has been done on silicon technologies with liquid and air, flat-plate type collectors. Furthermore, work has been done on concentrating and combined liquid/air PV/T collectors and on building integrated systems for preheating of e.g. ventilation air. [2]

2 IEA SHC TASK 35 – OBJECTIVES AND ORGANISATION

On January 1st, 2005, a three-year research work – Task 35 "PV/Thermal Solar Systems" – was initiated as part of the International Energy Agency (IEA) Solar Heating and Cooling (SHC) Programme. The objectives of this Task are to catalyse the development and market introduction of high quality and commercial competitive PV/Thermal Solar Systems and to increase general understanding and contribute to internationally accepted standards on performance, testing, monitoring and

commercial characteristics of PV/Thermal Solar Systems in the building sector.

The task is organised in 5 subtasks, each focusing on the key issues identified being important to meet the overall objective of the task.

In Subtask A: Market and Commercialisation of PV/T, the objectives are to investigate and identify the critical design parameters and commercial performance criteria, which determine the targets and conditions for successful new components and systems. The objectives will be achieved by the conduction of a market survey of potential markets for PV/Thermal Solar Systems in the participating countries and identification of the primary commercial parameters.

The objectives of Subtask B: Energy Analysis and Modelling, are to provide the necessary understanding of the energy transfer processes in PV/Thermal Solar Systems in order to define, to model and to predict the energy performance of the systems separately and in a whole building context.

In Subtask C: Product and System Development, Tests and Evaluation, the aims are to develop, test and evaluate PV/Thermal Solar System components and concepts and the experiences from products and components already on the market. The work includes R&D-activities in close collaboration with manufacturers of PV/Thermal Solar Systems in order to improve overall performance and solve generic problems with existing concepts and components.

The aims of Subtask D: Demonstration Projects, are to gain the knowledge from full-scale demonstration of PV/Thermal Solar Systems in order to verify and identify the potential for improvement of energy performance, expectations to reliability, durability and economical feasibility. This will be achieved by dialogue with project stakeholders, monitoring of selected projects and possibly facilitation of workshops for design teams and task participants.

Finally, the objectives of Subtask E: Dissemination, are to provide efficient and targeted information of the task results to all stakeholders of the Task and to make this information available to the target audiences through various media and formats according to the preferences of the target audience.

The Danish Energy Authority, acting through Henrik Sørensen, Esbensen Consulting Engineers A/S, Denmark, is designated as Operating Agent for the Task. Subtask Leaders are:

Subtask A: Ami Elazari, Millennium Electric Ltd., Israel,

Subtask B: Michael Collins, University of Waterloo, Canada, sponsored by Natural Resources, Canada,

Subtask C: Björn Karlsson, Lund University, Sweden, sponsored by the Swedish Energy Agency,

Subtask D: Herbert Zondag, ECN, The Netherlands,

Subtask E: Operating Agent.

2.1 Possibilities of joining

The Task duration period was originally planned to end in 2007 but it is now being investigated whether it would be feasible to extend the Task duration until the end of 2008.

If the Task period is extended, national experts can be assigned to participate in the Task from both SHC and PVPS (Photovoltaic Power Systems) Executive Committee members (www.iea-shc.org or www.iea-pvps.org). The Task would then welcome all experts who would like to join and contribute to the Task – especially industries working in this field are invited to contribute to the planning of the activities and asking the important questions to be dealt with seen from their perspective. Everybody with the interest in PV/Thermal Solar Systems are invited to contact Project Manager Jan Hansen, Esbensen Consulting Engineers A/S, j.hansen@esbensen.dk, +45 3326 7308 or Operating Agent Henrik Sørensen, Esbensen Consulting Engineers A/S, h.soerensen@esbensen.dk, +45 3326 7304, to discuss participation and exchange of information.

More information on the project can be seen at www.iea-shc.org/task35.

3 PRELIMINARY RESULTS OF THE WORK

Activities in the Task include international collaboration on scientific and commercial aspects with current participation of research and test institutes, manufacturers, consulting engineers and universities from Canada, Denmark, Hong Kong, Israel, Italy, The Netherlands, and Sweden. The preliminary results for the different Subtasks are listed in the following.

3.1 Subtask A – Markets and commercialisation

PV/T devices can be very different in design and suitable for different applications. As the PVT roadmap [3] shows, the current design solutions have different advantages, as can be seen in table I.

The PVT Roadmap also shows that the market segments for PV/T systems are similar to normal solar thermal systems, but the characteristics of different types of solutions make them suitable for different types of customers, see table II.

	Module cost	Reliability	Market potential	Building integration	System economics	Aesthetics
Liquid modules glazed			++	+	+	
Liquid modules unglazed		+	+	+	+	+
Air modules glazed	+			+	+	
Air modules unglazed	+	++		+	+	+
Ventilated PV facades	++	++		+	+	+
PV/T concentrators	+				+	

Table I: Overview of benefits of different PV/T design options.

Markets (in order of size)	Type of application	Liquid modules glazed	Liquid modules unglazed	Liquid modules unglazed with heat pump	Air modules glazed	Air modules unglazed	Ventilated PV with heat recovery	PV/T concentrators
Consumers	Domestic hot water	+++						
	Domestic space heating & hot water	+		+++	+			
	Collective hot water	++						+++
	Collective space heating & hot water	++						+
	Pool heating		+++					
Tertiary	Collective hot water	++						++
	Collective space heating & hot water	+		+				+
	Office space heating	+		++	+++	+++	+++	
	Solar cooling				+	+	++	++
	Public pool heating	++	++					
Agriculture	Solar drying				+	+		
	Hot water	+	+					
Industry	Industrial process heat	+	+					+
	Industrial space heating			+		+	+	
	Solar cooling							+

Table II: Relation between market segments and PV/T systems. Future main markets are marked with +++, niche markets with ++ and +

In a market survey carried out in Task 35, it has been found that also the different countries markets have their own characteristics and that installers and architects in European countries have different perspective on combined production of heat and electricity.

The survey included interviews with both architects and solar dealers, totally about 65 interviews, mainly on phone or at meetings. Some also responded to a written form by email.

Interviews	USA	Canada	Germany	Denmark	Sweden	Italy	Spain
Architects	x		x	x		x	
Solar Dealers	x	x	x		x	x	x

Table III: Interviews conducted

Solar dealers in USA, Canada, Germany, Italy, Spain and Sweden were interviewed. In general, almost all respondents are very positive to PV/T and see different advantages. The main advantage that the solar dealers are stressing is to make the systems more profitable than normal solar systems. As the profitability of a PV or a solar thermal system often is depending on subsidies like tax reduction or feed-in tariffs, the PV/T system might in some countries benefit from both sources.

In USA/Canada, PV/T air modules are today a part of the solar industry due to the sales of the product SolarWall, but the technology is unknown on all other markets. The priorities of solar dealers could be seen in the survey – several Spanish dealers asked for PV/T combined with solar cooling. Among the Italian dealers, the limited rooftop surface seems to be a problem, and they mentioned compactness of the system as an advantage of PV/T systems.

In Sweden, it is clear that there is a large gap between PV integrators and Solar Thermal dealers in the view on PV/T. All Swedish respondents were worried about the difficulty to combine the two different

professions in installing PV and installing solar thermal. This is not the case in Germany, Italy and Spain where the installers generally install both PV and solar thermal.

In parallel to the interviews with solar dealers, a number of architects in USA, Germany, Denmark and Italy were interviewed. The architects in USA were all aware of PV/T, most of the German and Italian but only one of the Danish. When the architects were asked to list the most important factor for a successful system, all subjects stressed building integration. Also in all four countries, the subjects stressed that the PV/T system should be more economical than side by side systems and that the economy of the system is the main issue. Two of the Italian architect companies were pressing more efficient use of roof space.

The main conclusion of the survey is that the markets are very different, mainly depending on how well PV has become a part of the solar industry, but also due to different experience of solar thermal solutions. Limited roof space seems to be an important technology driver on some markets, but the most important factor is profitability of the system and building integration.

3.2 Subtask B – Energy analysis and modelling

The overall objective of Subtask B is to develop validated and easy-to-use modelling tools for architects and engineers, and building owners, so that they might quickly gauge the energy produced and economic benefits of adding a PV/Thermal system to a building. A systematic approach has been adopted to achieve this objective.

The initial step of Subtask B was to identify and evaluate existing models of PV/Thermal systems and components. TRNSYS [4] was a predominant source of solar thermal, solar electric, and PV/Thermal system models. Further, TRNSYS allowed the group to focus on component models (i.e., the PV/Thermal panel) and not the entire system (inverters, storage elements, pumps, etc). As such, it was decided by the Subtask to focus exclusively on that platform. (A full list of the models found are presented in the Task 35, DB1 document [5] available from the task web site). The TRNSYS Type 50 models, which modelled glazed and unglazed, air and water, and flat plate and concentrating thermal collector types with integrated PV, turned out to be the best option for Task 35. The Type 50d model was adopted for flat plate style collectors, and Type 50h for concentrating collectors. Both the 50d and 50h models were modified to fix errors, and to provide consistency in the inputs required for the systems. A new model was needed to represent a product that is commercially available. A TRNSYS model has been developed at the University of Waterloo (Ontario, Canada) to represent a PV/Thermal collector based on a transpired air collector [6]. Furthermore, at Lund University (Lund, Sweden) a new non-tracking concentrating PV/T collector model is also in development.

While the existing PV/T models were validated on some levels, it was still necessary to compare results to existing products. In collaboration with Subtask C, panels have been tested at a number of test institutes. Modelling activities are ongoing to verify model output. The new PV/Thermal transpired air collector has been prototyped at the University of Waterloo, and is currently being monitored with the intent of validating the new TRNSYS model. Higher level validation is intended by comparing modelled results to large-scale monitored demonstration projects. Since no such demonstrations exist at this time, this objective is currently on hold.

Task B is required to present a method by which the thermal and electrical output of PV/Thermal collectors can be quantified. It was decided that *marketing, rating, and design* schemes would be presented. The *design* scheme is intended for individuals well versed in PV/Thermal system design, testing, and operation. It will contain the most significant level of detail, and will also be the most complex. The *rating* scheme is a simplification of the design scheme. It will be fairly easy to use, and will allow for convenient comparison of systems and good approximations of system output. The *marketing* scheme will simply be a comparative analysis of systems intended for policy and marketing documents. The schemes are still being developed, and will be made available from the Task web site.

The final goal of Subtask B is to produce a downloadable package of models. Fortunately, TRNSYS contains a stand-alone format (TRNSD) which would enable the group to make models accessible to

individuals who do not have access to the TRNSYS software. Task B will be following the example of IEA Task 32: “Advanced storage concepts for solar and low energy buildings” and combining the panels with various storage systems and building loads, and in different geographical locations. Efforts in this regard are ongoing.

3.3 Subtask C – Product and system development, test and evaluation

The overall objective of this Subtask is to develop, test and evaluate PV/Thermal Solar System components and concepts based on the findings in Subtask A and the experiences from products and components already on the market. The need for development for PV/T components will be investigated, key problem areas will be exposed and development of new materials for PV/T will be catalysed.

The most important task is to suggest and evaluate a standard method for performance testing of the PV/T collectors. A certification process for PV/T systems is also to be discussed.

It is very important from an application point of view to compare the performance and output from a PV/T collector with the output from separate thermal collectors and PV-modules. The absorber in a PV/T collector has a high thermal emittance and thereby a higher U-value than the standard thermal collector. The optical efficiency is usually also lower since the absorptance of the silicon cell is lower than the absorptance of the thermal absorber. When an electric load is connected to the PV-cells, the thermal efficiency is further decreased, since a fraction of the radiation is converted to electricity. This effect is clearly demonstrated in figure 1.

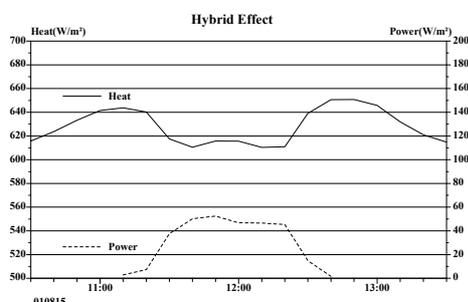


Figure 1: Monitored thermal and electrical power for a PV/T collector. At 11.15 an electric load was connected to the solar cells, which means that the thermal output is decreased. At 12.30 the electric load was disconnected.

The PV/T collectors (several of them commercially available) which are tested in the project are presented in table IV. They produce electricity and heat as hot water or warm air. They are flat, concentrating, or tracking and concentrating.

Table IV: PV/T collectors tested within IEA Task 35.

PV/T collector	Type	Geometry	Country
PVTWIN	Water-PV	Flat plate	The Netherlands
SolarWall	Air-PV	Flat plate	Canada
MSS-Multi Solar	Air-Water-PV	Flat plate	Israel
COGEN	Water-PV	Flat plate	Italy
RA-Cell	Water-PV	Flat plate	Denmark
MaReCo	Water-PV	CPC non tracking	Sweden
Solar 8	Water-PV	Parabolic tracking	Sweden

The PVTWIN collector from The Netherlands is shown in figure 2. The thermal efficiency measurements at different temperatures with or without an electric load are presented in figure 3. [8]



Figure 2: The PVTWIN PV/T collector tested in the project. [8]

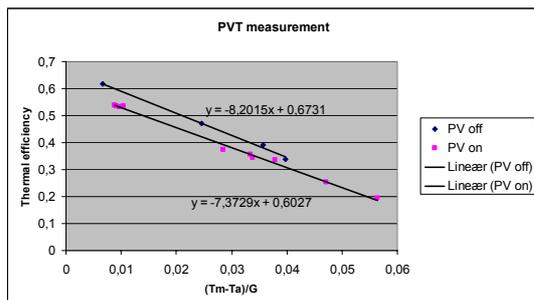


Figure 3: Thermal efficiency of the PVTWIN PV/T collector with linear trend curves with or without electrical load. T_m = mean fluid temperature. T_a = ambient temperature. G = Total irradiance (W/m^2). [8]

Long term measurements were collected with the inverter connected to the PV modules, together with the measurement of thermal performance. The electrical power at different temperatures and irradiances is presented in figure 4. As expected a linear relation is found for the DC power as a function of irradiance and there is a reduction in power as temperature rises.

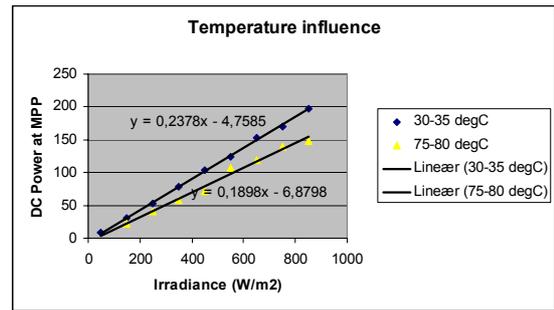


Figure 4: Electric power of the PVTWIN PV/T collector as a function of irradiance and temperature. [8]

The figures 5, 7, and 8 show some of the other PV/T collectors which are tested in IEA Task 35, subtask C. The different functions and different geometries of these collectors complicate the task to formulate a common standard procedure for testing.



Figure 5: Testing of Solar 8 concentrating PV/T collector for electricity and hot water. [7]

Figure 6 shows the I-V curves for the concentrating Solar 8 collector at different temperatures of the cooling water [3]. The high currents which are typical for a concentrating system are identified.

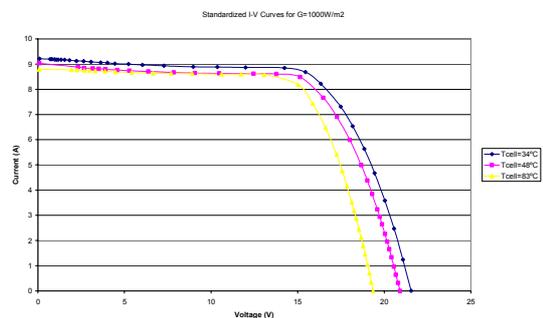


Figure 6: Standardized I-V curves, $G=1000W/m^2$, at different temperatures for the Solar 8 collector.

The Canadian SolarWall PV/T collector for electricity and hot air is shown during testing in figure 7. It is tested with a standard thermal collector without solar cells and a PV module as references.

In figure 8, the Israeliian MSS Multi Solar PV/T collector for electricity, hot air and hot water is shown during testing.



Figure 7: Testing of the SolarWall PV/T collector for electricity and hot air together with a standard solar thermal collector and PV module as references. [9]



Figure 8: Testing of the MSS Multi solar PV/T collector for electricity, hot air and hot water.

The main principal problem with testing of a PV/T collector is to take the interdependence between the production of heat and electricity into proper account. This can conveniently be done if the module is connected to a MPP-tracker and the thermal output and electric output is monitored.

This however requires that the MPP-tracker has an ideal performance or at least known for different points of operation. Another more reliable and transparent but also more complex method is suggested and developed within the task. [10] This means that the method does not rely on the proper function of a MPP-tracker.

The electronic load shown in Figure 9 is continuously connected to a constant voltage in the chain of diodes and simultaneously the thermal performance is monitored as for a solar collector. The constant voltage is selected for being close to the point of maximum power. At relatively short intervals, IV-curves are scanned and the logger selects the ideal mp-point. The ideal maximum power and the power at the constant voltage point that actually was dissipated in the electronic load are monitored. At longer intervals the time averages of the monitored electrical power, the ideal electrical power, the thermal power, the irradiance and the instant IV curve are stored. This IV-curve is very useful in identifying flaws, like the effect of partial shadowing, in the performance. The difference between the ideal and monitored constant voltage powers is normally very small, but can be used as a correction factor during electrical and thermal

evaluation.

It would be possible to let the logger dynamically select the optimum load point in the chain of diodes from each monitored IV-curve. However, if the load is fixed, several solar panels could be monitored with the same control output on one logger connected to separate electronic loads for each module.

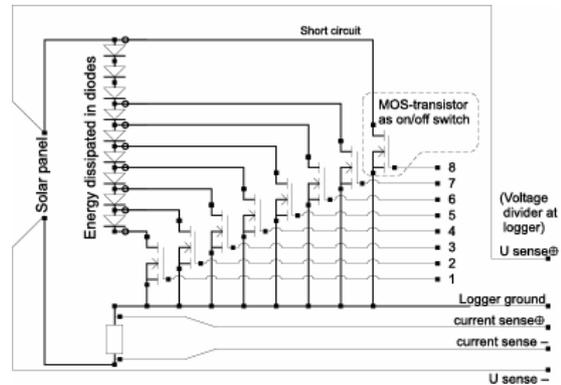


Figure 9: The electronic circuit with the load of diodes for the IV-curve and the transistor switches for controlling the numbers of diodes connected to the PV/T module. [10]

The results of the testing of the different PV/T collectors are now being analyzed and will help to achieve a more detailed understanding of the performances of the PV/T collectors and to suggest a standard method for performance testing of PV/T collectors.

3.4 Subtask D – Demonstration projects

A number of demonstration projects with different categories of PV/T collectors have been realised in various countries in the past. Interviews of stakeholders for selected realised PV/T systems are being carried out for Canada, Denmark, Germany, The Netherlands, United Kingdom, USA, and other countries might be included. The aim is to learn from their experience and to make recommendations for next generation of demonstration projects. Monitoring results for existing PV/T projects will be collected where available. A description of all the realised projects is being drawn up and will be made available at the Task website.

New PV/T demonstration projects are also being realised. In July 2007 a PV/Thermal system with an overall collector aperture area of around 9 m² was put into service at an office building at the City University of Hong Kong. The system is partially supporting the electricity supply to the EXIT signs of the building, as well as the warm/hot water supply to the pantries and toilets.

In the Netherlands three projects have been initiated, all with glazed flat plate liquid PV/T collectors.

On an office building in Zoetermeer, a PV/Thermal system of 27 m² is being implemented as part of a building renovation and is expected to be functional in September 2007. The system will supply hot water for showers and for a kitchen. The PV/T system will be installed together with 4 m² PV and 15 m² solar thermal and the combination of PV/T, PV and solar thermal on the same building will give an opportunity to compare

the different types of systems with each other.

In Alkmaar, 156 single family houses are being constructed and systems with 2.6 m² PV/T collectors for domestic hot water will be implemented to each house in the course of the construction period running until March 2009. The first PV/T collectors will be implemented in September 2007.

Finally, an apartment complex in Enschede will as part of a low energy concept be equipped with a PV/Thermal system with 19 m² PV/T collectors. The application is domestic hot water and space heating. The project is expected to be completed in April 2008.

Monitoring of the above mentioned projects will be carried out.

4 OUTLOOK

PV/T is a very promising technology, it has a large potential and PV/T systems can be applied in a large part of the present solar thermal market, including domestic hot water systems.

In the short term, multi-family buildings may be an important market, due to the limited roof area available per household, which promotes area efficient renewable energy applications.

In the medium and long term, the most promising application for PV/T systems seems to be domestic water heating and space heating. For space heating, it is especially true for advanced houses aiming to cover a large part of the energy needs with solar energy. Combination of a heat pump and PV/T could be a promising concept.

In the long term, professional application (industry, agriculture) and applications such as solar cooling will become interesting for PV/T. [3]

Some of the challenges in order to ensure a successful implementation of PV/T to the market are to agree on performance and reliability standards for PV/T. Furthermore financing schemes and dedicated PV/T subsidies should be set up. Awareness of PV/T should be raised and work has to be done to improve the thermal efficiency and the long-term reliability of PV/T. Module- and installation costs should be reduced and it is also necessary to develop solutions so PV/T can become an integral part of the building design ensuring an easy integration into the building construction and the heating and electrical systems. [3]

5 CONCLUSION

Work is being carried out in an international collaboration in the Task 35 project on PV/Thermal Solar systems as part of the IEA Solar Heating and Cooling Programme. Market survey interviews with architects and solar dealers showed that the most important factor for PV/T is profitability of the system and building integration. Modelling activities are ongoing and one of the final products will be an easy-to-use PV/T modelling tool. Test of different PV/T collectors have been carried out and will facilitate the suggestion to a standard method for performance testing of PV/T collectors. An overview of realised PV/T demonstration projects including interviews of stakeholders is being made and at the same time new demonstration projects are being realised.

PV/T collectors can generate more energy per unit surface area than side by side photovoltaic modules and solar thermal collectors, at a potentially lower production and installation cost. PV/Thermal is a very promising technology, it has a large potential and PV/Thermal Solar Systems can be applied in a large part of the present solar thermal market. However, to ensure a successful large scale implementation of PV/T to the market, a number of actions have to be undertaken.

6 ACKNOWLEDGEMENTS

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