The ANU Roof Mounted PV-Thermal Concentrator System

John Smeltink and Andrew Blakers
Centre for Sustainable Energy Systems
Australian National University
Canberra ACT 0200
AUSTRALIA
E-mail: John.Smeltink@anu.edu.au

Abstract

The Australian National University (ANU) has commissioned the thermal component of a 300m^2 Photovoltaic-Thermal (PV-T) concentrator system. It is installed at Bruce Hall - Packard Wing, a four storey residential college at the ANU accommodating 98 residents. This installation incorporates the Combined Heat and Power Solar (CHAPS) System developed by ANU. The building is provided with eight CHAPS collectors, Solahart heat stores incorporating 6000 litres of hot water storage, hydronic in-slab floor heating, two gas fired boosters and a 40kW inverter.

A CHAPS collector is a 38X, one axis tracking PV concentrator that is 24 metres long. It uses parabolic mirrors mounted on a tracking support structure to direct light toward a defined focal region. The Bruce Hall installation has been commissioned as a thermal system using painted copper tubing at the focus. This will be replaced with ANU PV/Thermal receivers to produce electricity as well as useable heat. With the PV component in place the projected annual generating capacity for the system is 50 MWhr of electricity and 360 GJ of hot water. This paper details the CHAPS installation and describes the indicative performance of the system.

1. Introduction

The Australian National University, Centre for Sustainable Energy Systems (ANU-CSES) has been actively engaged in the development of PV concentrator technology since 1995. The latest development for ANU-CSES is a photovoltaic thermal (PV-T) technology called the Combined Heat and Power Solar (CHAPS) System. The combined thermal and electrical efficiency of a prototype CHAPS collector exceeds 60%.

Figure 1 Bruce Hall - Packard Wing

During 2002 the Australian Greenhouse Office made funds available through its Renewable Energy Commercialisation Program (RECP) to assist in demonstrating near market ready renewable energy technologies. In partnership with Rheem Australia Pty. Ltd. the ANU was able to access RECP funds to install a CHAPS concentrator system.

The CHAPS system is installed at the Bruce Hall Packard Wing. The Packard Wing accommodates 98 students in self-contained apartments. It is a four-story building that was built during 2003-4. Equipment associated with the solar collection system was installed during construction of the building. Thus the installation is fully integrated. The CHAPS collectors were installed on the roof of the building a short time before occupation in 2004.

2. CHAPS SYSTEM DESCRIPTION

The Bruce Hall CHAPS system comprises eight 24 metre long, single axis reflective solar concentrating collectors. Each collector incorporates a tracking support structure that is controlled by a microprocessor. Heat is removed using a fluid, which flows through the copper tube receiver. The fluid then passes through a heat exchanger that transfers heat to hot water storage tanks.

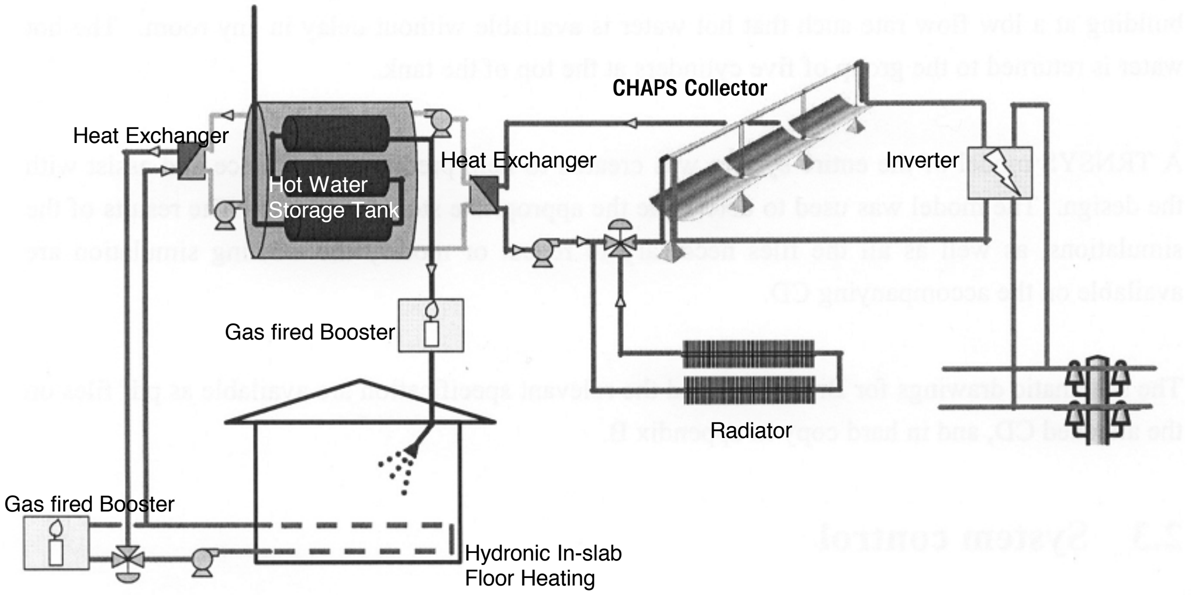


Figure 2 PV Thermal scheme installed in Bruce Hall Packard Wing

Apart from the CHAPS collectors the building incorporates elements common to both solar thermal and solar electric generating systems. Two banks of Solahart central hot water storage tanks are installed in the basement. Heat is transferred from the collector circuit to this hot water store circuit via a heat exchanger. The hot water store has an additional circuit connected to a heat exchanger and may heat the fluid flowing through the hydronic in-slab floor heating. In addition separate gas fired boosters are fitted to both the potable hot water circuit and the hydronic heating circuit to provide heat when there is no solar contribution. The heat flow from the collectors to the building circuits is controlled by the building management system (BMS).

The CHAPS collectors will be retrofitted with PV-Thermal receivers fitted with high efficiency monocrystalline silicon solar cells. Heat is removed using a fluid, which flows through a passage in the cell housings. Receivers are connected to an inverter that has already been installed in the building. The electricity supplied to the grid will be metered separately to provide a concession against the electricity consumed.

3. COLLECTOR STRUCTURE

A CHAPS collector incorporates 17 mirror panels that form a 24 metre long parabolic reflective surface. Each collector is mounted at three points and pivot on pedestals that protrude through the roof. The main beam is also connected to a pulley, which is rotated by means of opposing cables connected to the tilt mechanism that is moved by a DC electric motor. The collector is thus able to tilt through 180° to follow the sun. The mirrors focus light onto the receiver, which transports heat by means of a fluid pumped through the circuit.

The photovoltaic receivers are expensive and will not be installed until control system has been fully implemented. Instead, black painted copper tubing has been installed in the focal region of the collector. Once it has been shown that the system has worked for some time within specification the PV receivers will be installed.

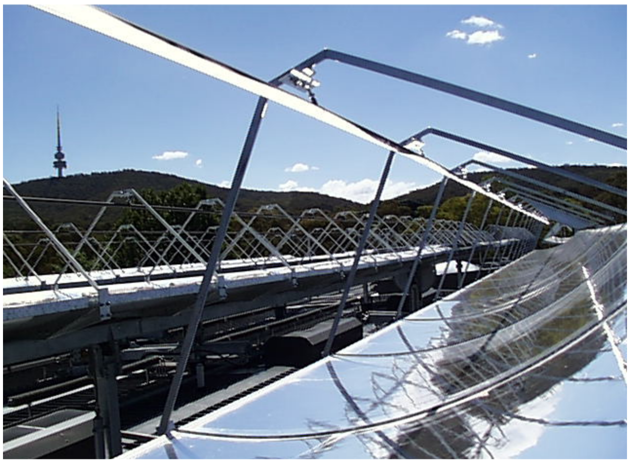


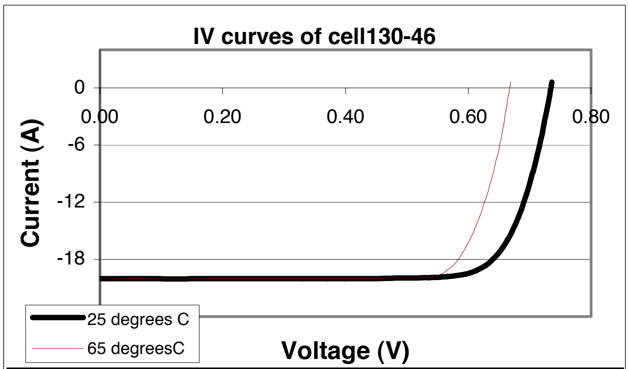
Figure 3 Mirror panels focus light onto a test receiver

Considerable effort has been made to provide a uniform flux distribution on the receiver. Shadow bands induced by the margins around each mirror have been minimized. Finite element analysis has provided a choice of beam section with sufficient stiffness to limit torsional flex to less than 0.5°.

Mirrors for the collector are manufactured by laminating mirrored glass to a galvanized steel sheet. Stamped tab ribs fitted to each end of the sheet impart the correct parabolic profile. This construction provides a mirror that is both lightweight and durable. Extensive laboratory and field testing has proven that the mirrors maintain the required physical characteristics.

4. CONCENTRATOR SOLAR CELL

A robust technique has been developed to produce mid-range concentrator cells at ANU. Cells are made using high-purity, monocrystalline, p-type (boron), float-zone wafers. These are chemically polished and then textured to provide random pyramids to increase light trapping. A sheet emitter (n-type) diffusion is performed to produce the p-n junction, and then two more specific-region diffusions are performed. Metal is evaporated onto the wafer and then silver is electrodeposited for electrical contacts. Wafers are passivated and then diced. Each cells has a blue silicon dioxide anti-reflective coating etched to the optimal thickness.



T (°C)	Voc (V)	Isc (A)	Vmp (V)	Imp (A)	FF	Power (W)	Eff (%)
25	0.73	20.0	0.61	19.2	0.80	11.8	20.1
65	0.67	20.4	0.54	19.2	0.77	10.4	17.8

Figure 4 I-V curve for ANU concentrator cell at 30 suns

Every cell is tested by generating I-V curves at illumination levels of 5, 10, 20 and 30 suns. I-V test results are shown for a typical 40mmx50mm cell illuminated at 30 suns (see Fig. 4). Note that efficiency declines with increasing temperature. At the STC of 25°C the efficiency is 20%. At a normal operating temperature of 65°C efficiency drops to about 18%.

5. PHOTOVOLTAIC THERMAL RECEIVER

The PV-Thermal receiver is assembled in the following way (see Fig. 5). Electrical contacts are first soldered to the concentrator cells. The cells are bonded to the receiver body then connected in series by interconnecting cell tabs. Once assembled the cell string is encapsulated to exclude moisture and covered with glass for protection. The receivers are fitted with wiring, mounting brackets, packed with dense glass fibre insulation and finally an aluminium cover is installed.

The receiver body is an aluminium extrusion that incorporates several functional features. A fluted passage is integrated with a profiled solar cell mounting tray. Additional features provide a mounting surface for hardware and wiring. Before assembly both ends of each receiver are drilled and tapped to accept couplings. When mounted on the collector the receiver ends are coupled together to provide a continuous passage for the circulation of heat transfer fluid.

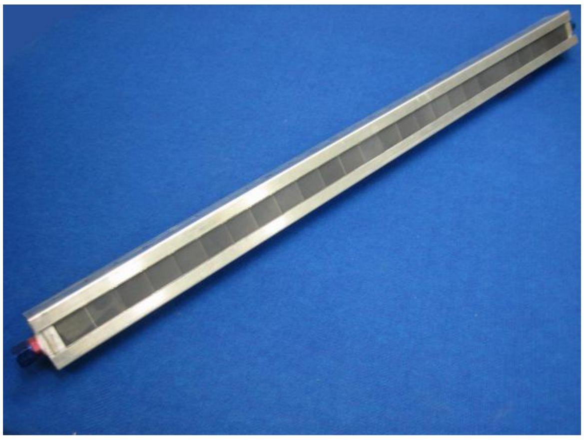
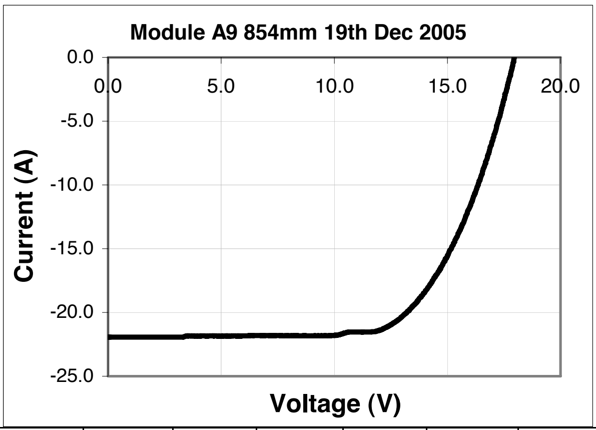


Figure 5 ANU PV-Thermal receiver assembly



Voc (V)	Isc (A)	Vmp (V)	FF	Imp (A)	Pout (W)	Eff (%)
18.0	21.9	13.0	0.67	20.3	264	15.1

Figure 6 I-V curve for PV-Thermal receiver at STC

6. COMMISSIONING

A prototype CHAPS system has been operating for several years at ANU. This unit is self-contained and the electrical and thermal outputs are not utilized. Many design improvements were incorporated into the Bruce Hall collectors. In addition the balance of system components were introduced for the first time. Several problems were encountered and required significant effort to resolve.
The faults rectified during commissioning include.

- Pivot mount interference
- Cable durability
- Guide sheave seizure
- Refit temperature sensors
- Sundry leaks
- Actuator noise
- BMS Calibration

The calibration of the tracking affects the precision with which each collector follows the sun. The tracking controller has recently been re-programmed to allow iterative calibration. This modification will provide a means to make subtle changes to parameters and home in on accurate calibration.

The design provides for the BMS to monitor several fault conditions. Recognition of these fault conditions will cause the collectors to stow. At this stage the interface between the BMS and the tracking control has not been connected. The delay means that the collectors can only be operated under supervision.

7. Thermal Performance

The collectors have been operated only when staff have been available to monitor for faults. Unfortunately, only limited amount of data has been gathered but it does provide an indication of the thermal performance of the system. Receiver temperature is measured using a thermistor mounted halfway along each collector. The thermal performance of each collector has been monitored using the BMS. The thermal performance of all eight collectors has been plotted for the period from 23 January to 15 March 2006 (see Fig. 7).

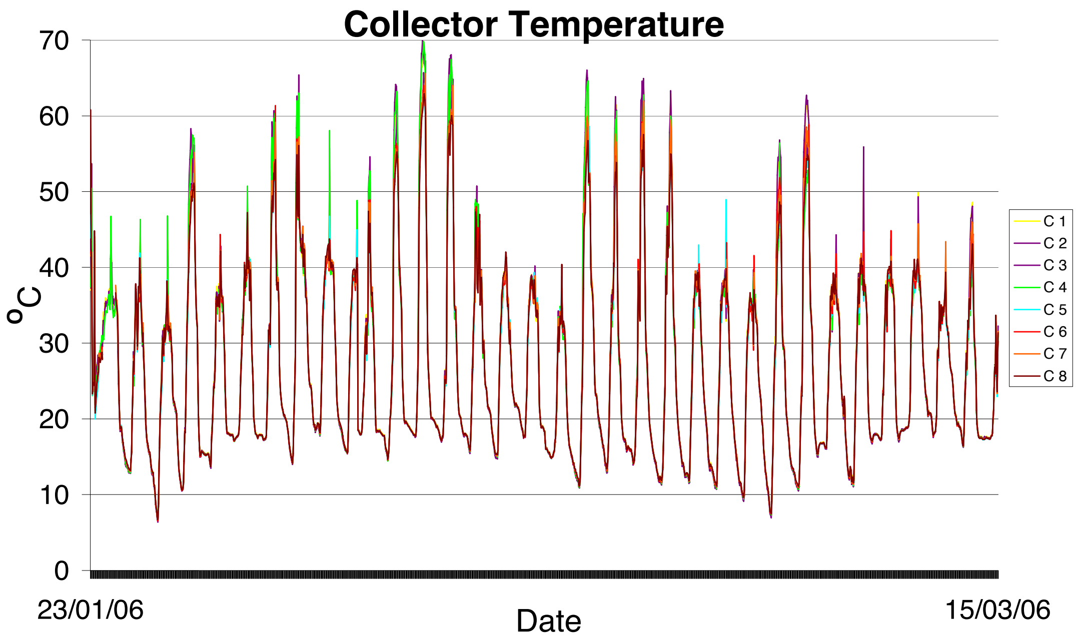


Figure 7 Collector Temperature 15 min intervals

There are two significant characteristics of the graph. Firstly, one can see that there are several days when the receiver temperature rose above 50 °C. This is indicative of the days when the collectors were operational. Also of note is that the temperatures of all eight collectors are within a few degrees. This is even though several collectors are not tracking accurately. In fact the associated receivers are shedding heat from the system. Though compromised the thermal performance of the collectors is clearly adequate.

As noted previously fluid leaving the roof mounted collectors transfers heat to the hot water storage tanks via a heat exchanger. This scheme is also proving to work effectively. The temperature profile for the collector supply fluid and the hot water store is presented for 22 February 2006 (see Fig. 8). As can be seen the collector supply temperature rose to 66°C. The storage tank temperature stood at 35°C as the circulating pump started. The storage tank temperature rose quickly to 44°C as fluid moved from the hot side of the store. The storage tank temperature then rose steadily over the course of the day being heated by the collector fluid. The tank achieved a maximum temperature of 59°C during the six hours that the CHAPS collectors operated.

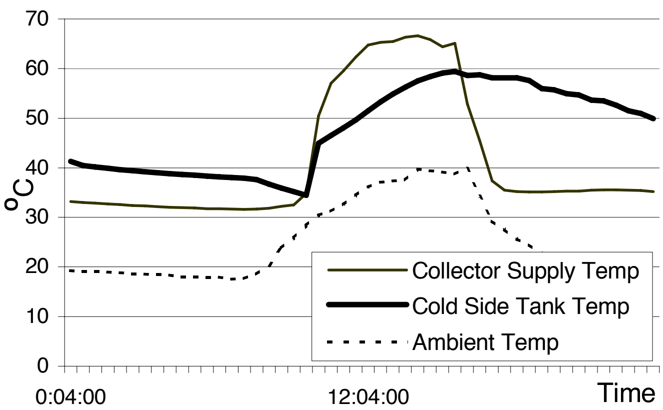


Figure 8 Temperature Profile 22 February 2006

8. Lessons Learned

The Bruce Hall CHAPS project provided significant opportunities. It allowed the ANU to forge a partnership with a major company to further develop the design of the CHAPS system. This affiliation with Rheem Australia also allowed access to funding through the Australian Greenhouse Office. Several commercial relationships were established with subcontractors and suppliers. And the ANU was able to set up a production facility for concentrator solar cells.

As the Packard Wing was a new building it afforded another advantage. All of the balance of system equipment was chosen to exactly match the requirements of the solar collectors. Plus the installation of pipe work, wiring and controls could be tailored to the system. Much of the detailed design for this was carried out by the building design engineers resulting in a totally integrated solar package.

The budget for the project covered only the capital works. Other parties must meet the costs for activities such as maintenance and monitoring. The commissioning of the system has also been drawn out due to a significant number of changes. Having this first system on the ANU campus is very convenient, reducing these un-funded costs and allowing close scrutiny of the system in operation.

The collectors have been operating intermittently. The solar contribution to the water heating has been insignificant at times. This replicates overcast conditions over a protracted period. Although undesirable this situation has confirmed that at least the gas boosted heating system is correctly sized for the comfort of the residents. Thus minimizing the impact of the teething problems experienced in commissioning.

The building design engineers had gathered information in relation to both the initial design and ongoing operation of the equipment. The responsibility of the engineers extended only to the construction phases. Unfortunately much of the operational information has not been passed on.

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	20%nom
Hot Water Storage	6000 litres
Nominal DC_{peak} Output	36 kW
Nominal Heat $Output_{peak}$	160 kW

Table 1 Specified system performance
SOC: DB:1000W/m^2 Amb:20°C Wind:1m/s

9. CONCLUSION

The CHAPS system is a more complex scheme for harnessing solar energy than the industry standard. The challenge posed in making a leap from prototype to full-scale deployment was large. The support of the funding organization and commercial partner was vital. The ANU plans to license this technology. To minimize the perception of risk it is important to demonstrate a real world system and sort out the bugs

The installation of eight CHAPS collectors and the compatible balance of systems equipment was successfully completed during the construction phase of the Packard Wing. Currently the thermal component of the system is operational for commissioning to take place. This step has been taken to ensure proper function of the infrastructure and to make adjustments to the control systems. Faults that became apparent during commissioning have mostly been rectified. It is expected that commissioning will be completed during 2006 with the installation of the PV-Thermal receivers.

10. REFERENCES

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