10 years of research on PVT systems at UNSW past, present, and future…

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Acknowledgments

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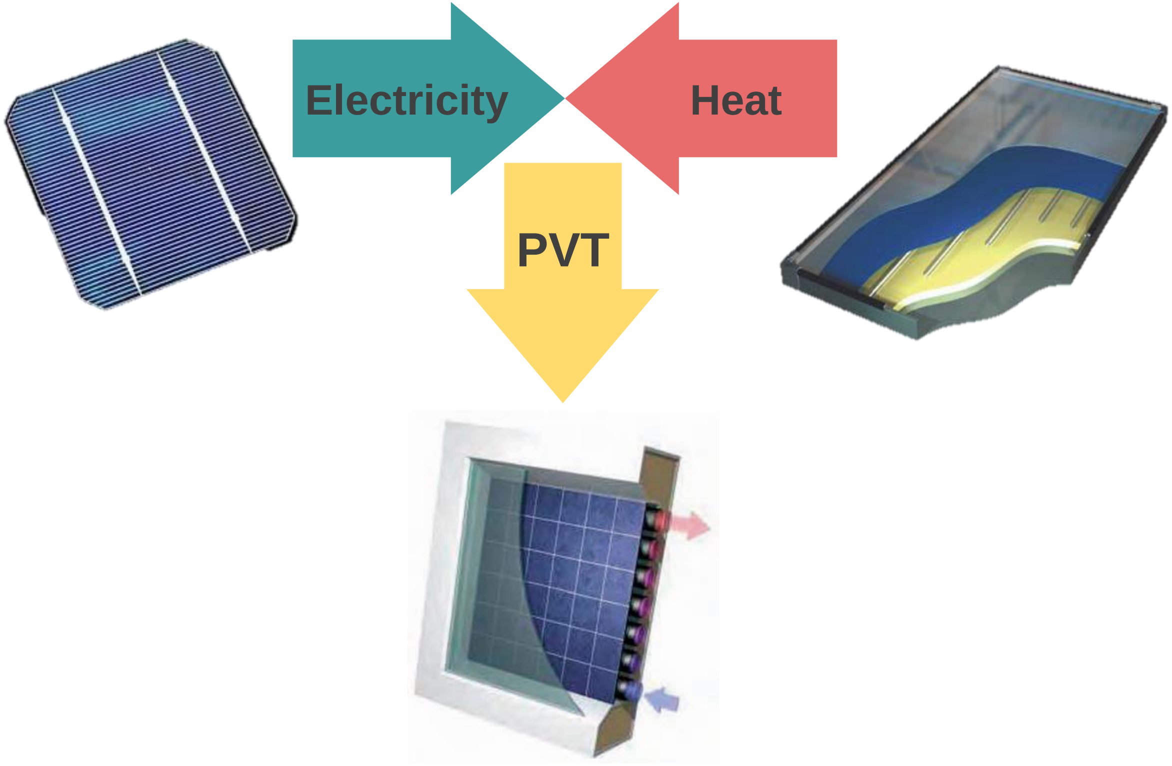
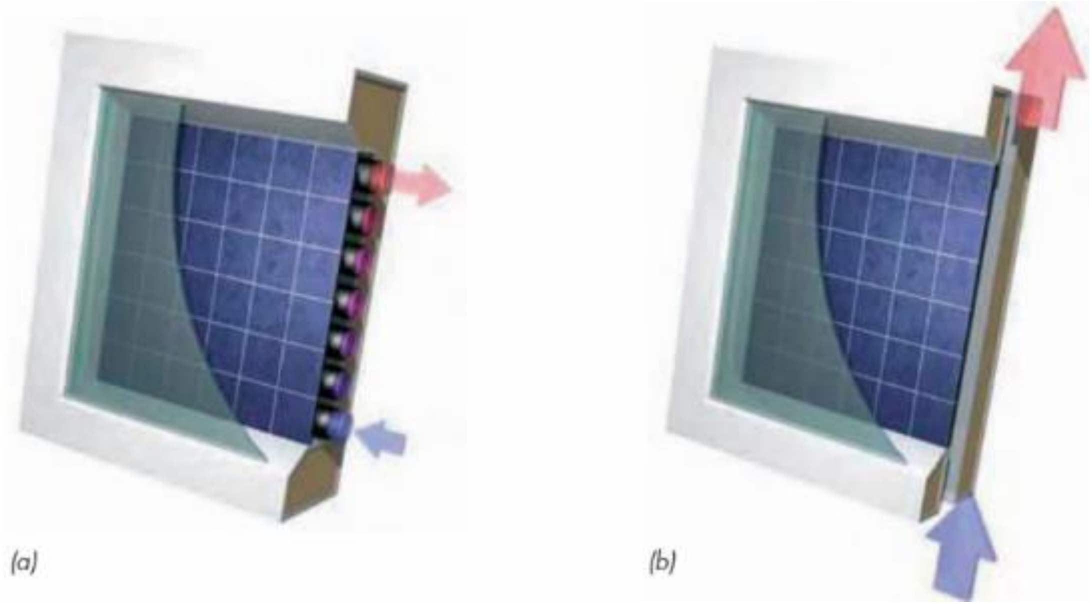
PV + Thermal Collector



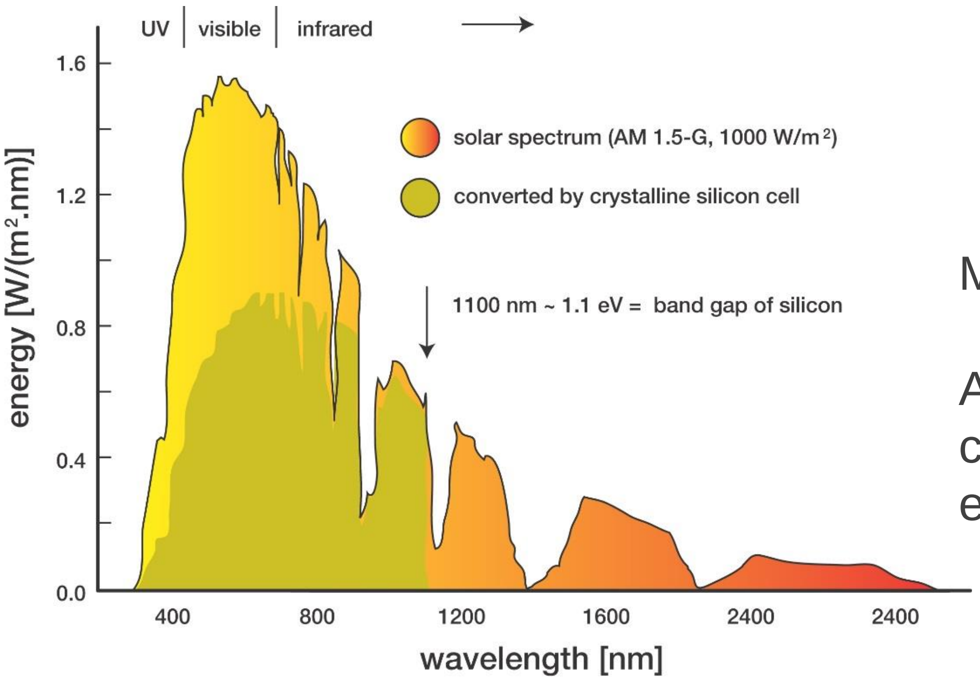


PVT-water
(covered or uncovered)

PVT-air
(covered or uncovered)

Affolter et al. 2006. PVT Roadmap – A European guide for the development and market introduction of PV-Thermal technology, PV Catapult Project.

Shockley-Queisser limit ~ 33% for single junction (32% Si)

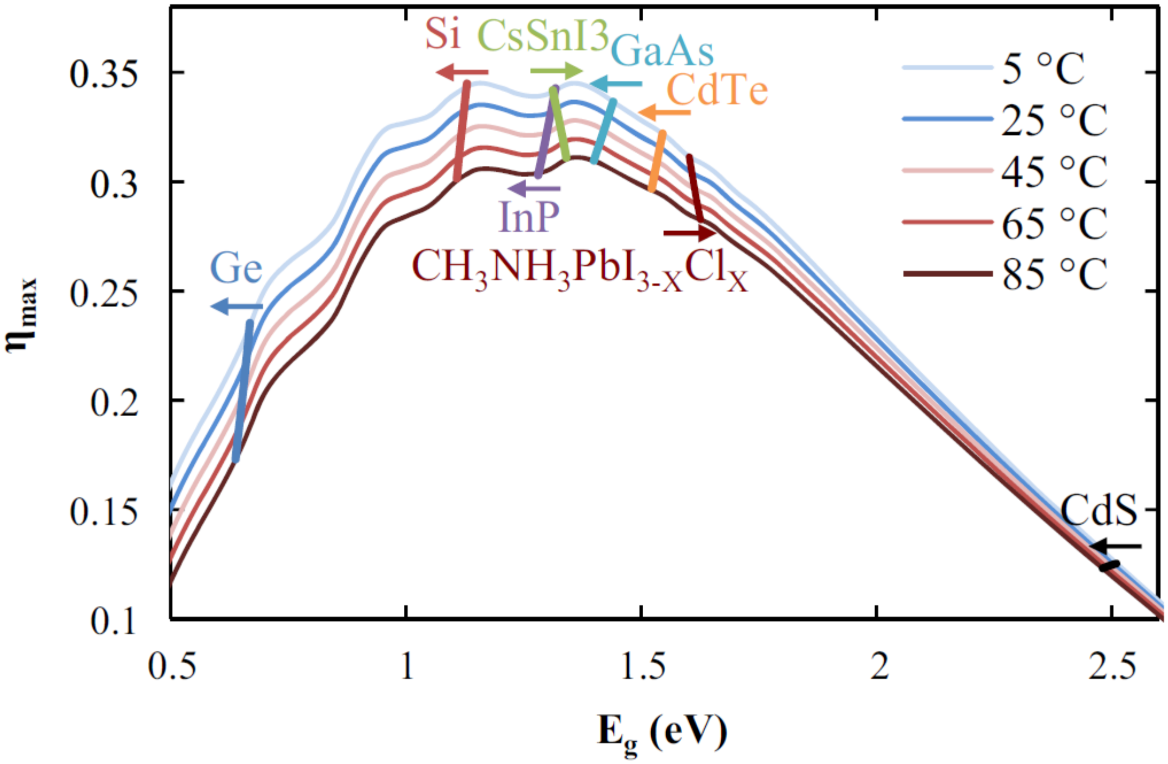


Multijunction SQ limit ~ 49%

At best ~50% of solar energy is converted to heat, not to electricity

http://www.vicphysics.org/documents/events/stav2005/spectrum.JPG

Efficiency (SQ) limit depends on the cell temperature



Generally, the efficiency of solar cells decrease with temperature

Most of the energy is converted to heat → increases cell/module temperature

So, cooling a PV module is a good idea!

Dupré, Vaillon, Green, 2015. Physics of the temperature coefficients of solar cells. Solar Energy Materials and Solar Cells, 140, 92-100

Obviously, PVT is a good idea, right??

1) Decrease the temperature of the cell/module by cooling it with a fluid
2) This increases the efficiency of the cell (more electricity!)
3) We can use the ‘waste’ heat for other purposes (we get heat too!)
4) Profit!*

*In theory yes, but first we need to read the fine print

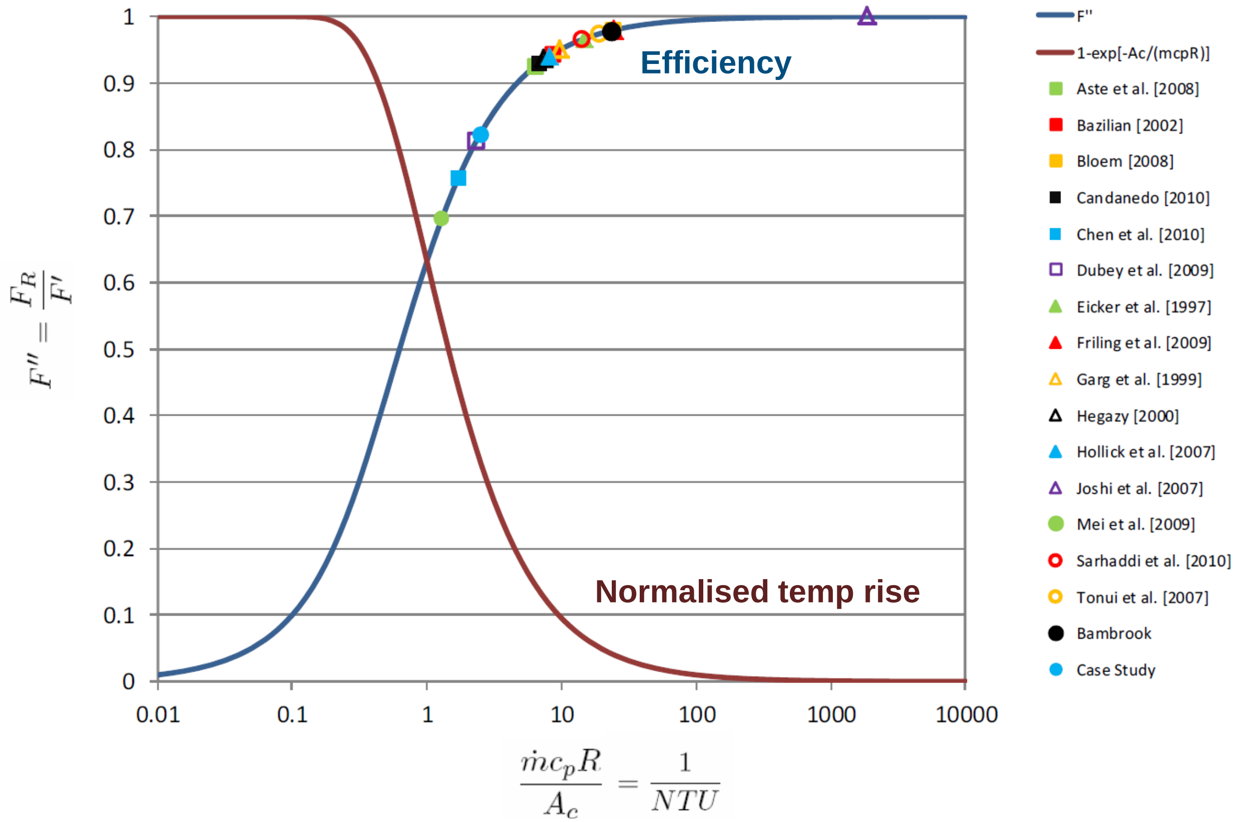
By the way, PVT is not a new idea, the first publication on the subject was by Wolf in 1976 (40 years ago!).

PVT potential

- High energy density: PVT systems use less space to deliver the same energy than syde-by-syde systems (PV + SHW)
- Potential reduction of installation cost
- High combined efficiency between 60-80%
- Lower PBT and EPBT compared to PV
- Generate most of the power for a normal house
- Potential uses in commerce and industry
- Architectural uniformity

Bergene and Lovvik, 1995
Elswijk et al.2004,

How much efficiency do you want?



High temperature rise results in low thermal and electrical efficiency (bad)

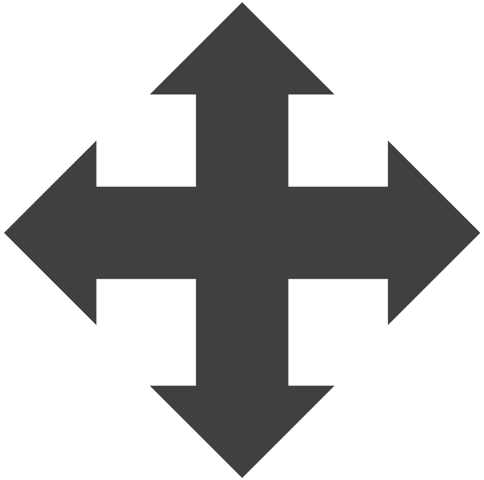
So, it's better to have a low temperature rise, with high thermal and electrical efficiency (good)

But then, how useful is low temperature heat??

Bambrook 2011. Thesis: Investigation of photovoltaic / thermal air systems to create a zero energy house in Sydney

PVT is about trade-offs (the fine print)

Heat



Efficienc
y

Temperature
rise (Exergy)

More useful???

Electricity

PVT/water system for developing countries

A system that could provide electricity and warm water (pre-heating) for houses

Criteria:

- Low cost
- Available materials
- Manufactured on site
- Reasonable performance
- Very low budget for building the system (use existing or low cost tools/materials) ~AUD $200

Important equipment:

- Good weather data (including sky temperature measurement - pyrgeometer)

‘Manufacturing’ steps

Thermocouples

Remove JB of frameless panel (stored in Bay St)

Bond the water channels (collector)

‘Manufacturing’ steps

Collector with polycarbonate channels

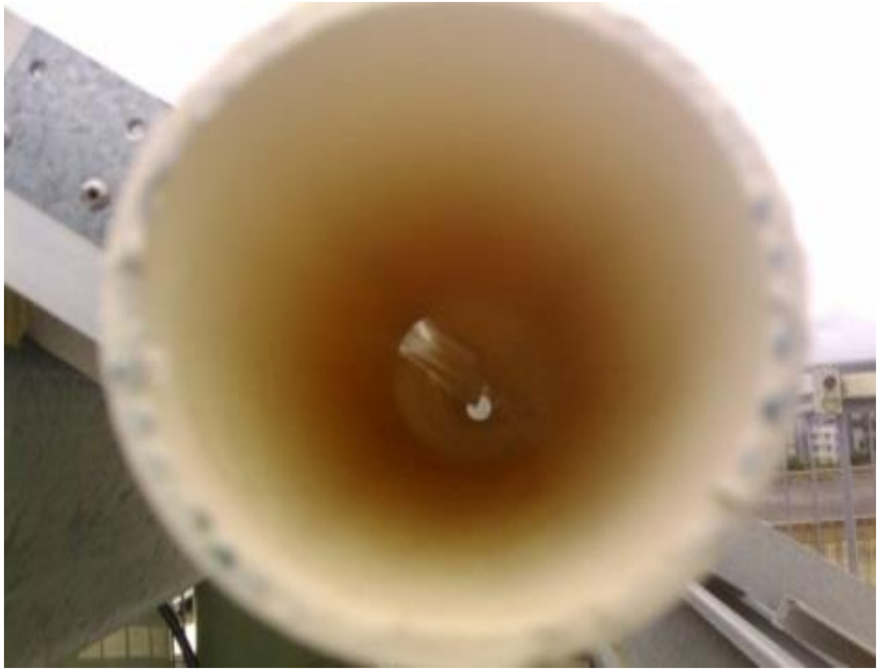
Install back insulation and JB

‘Manufacturing’ steps

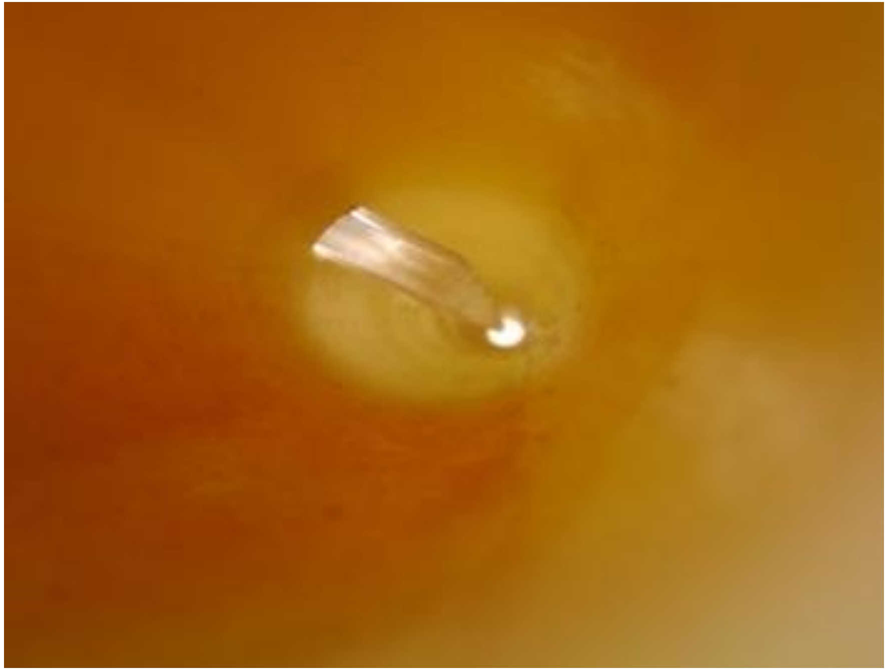
Install new frame

Mount the PVT collector

‘Manufacturing’ steps

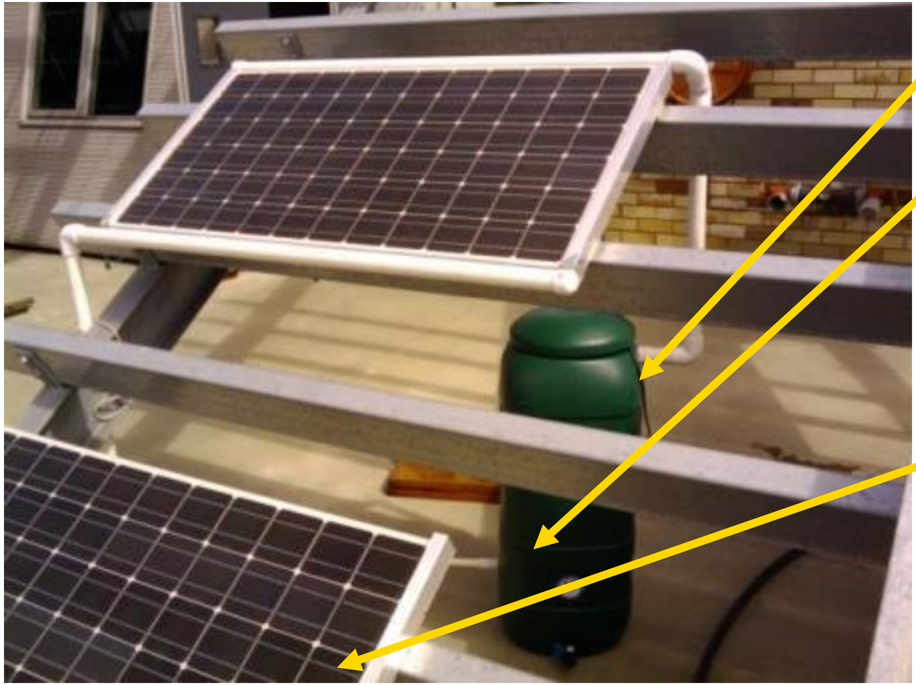


Mount the header pipe



Seal pipe and channels

Finished System



Water tank 100L

20 W submergible pond pump

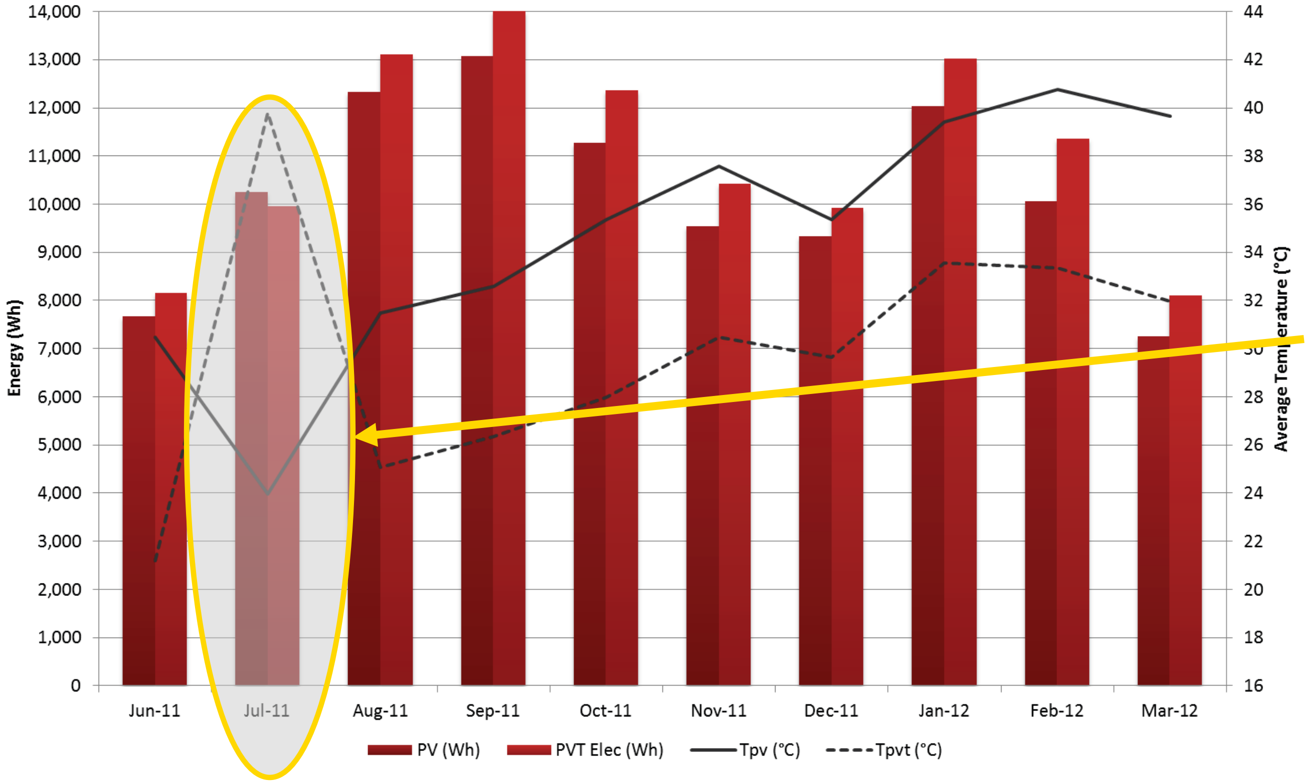
Thermocouples in inlet, outlet, back of panel, flow sensor, Pyranometer, etc…

Standard panel (same model) as control (12% efficiency at STC)

System worked 24/7 – daily reset

(heating water during the day, cooling water during the night)

Experimental data: PVT vs PV electricity output

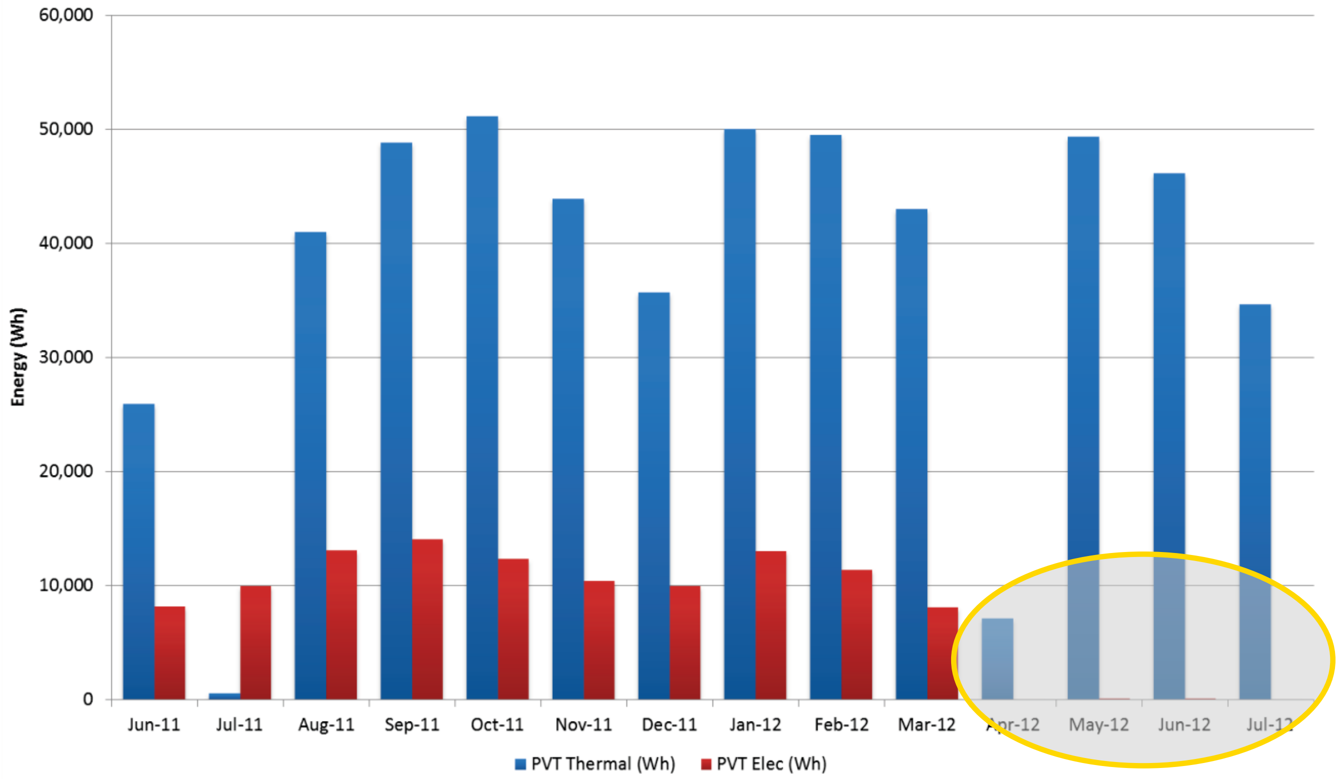


The PVT system outperformed the PV module, due to higher efficiency (cooling)

Except on July (stagnation 'experiment', i.e. no flow)

What to do when no more hear is needed??

Experimental data: PVT thermal and electrical output



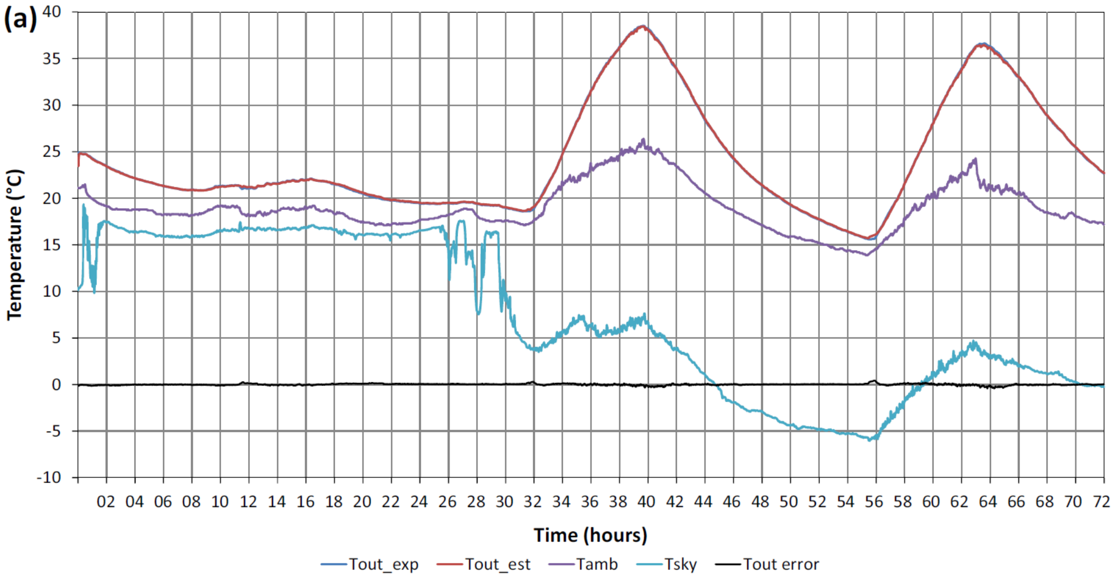
Big gap between thermal and electrical output

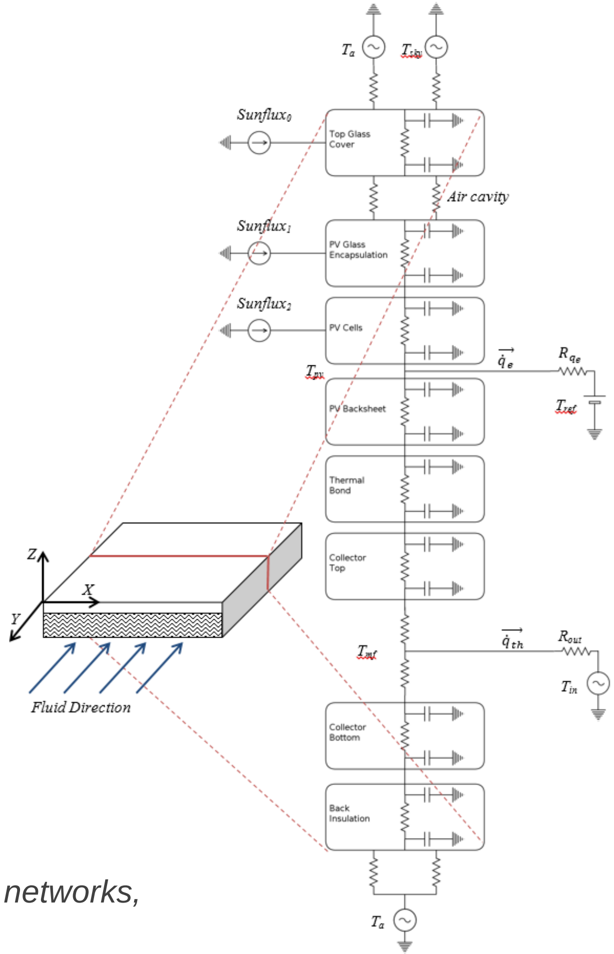
Hence, the application must match the generation profile of PVT systems

PVT used only as a solar collector

Transient model

Example of outlet temperature – model vs experiment

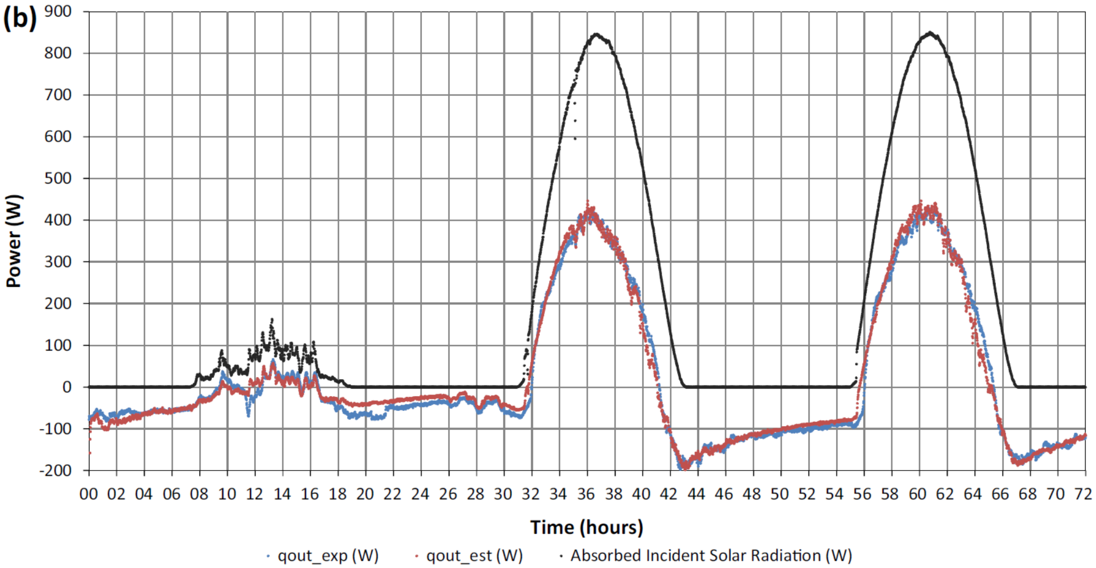


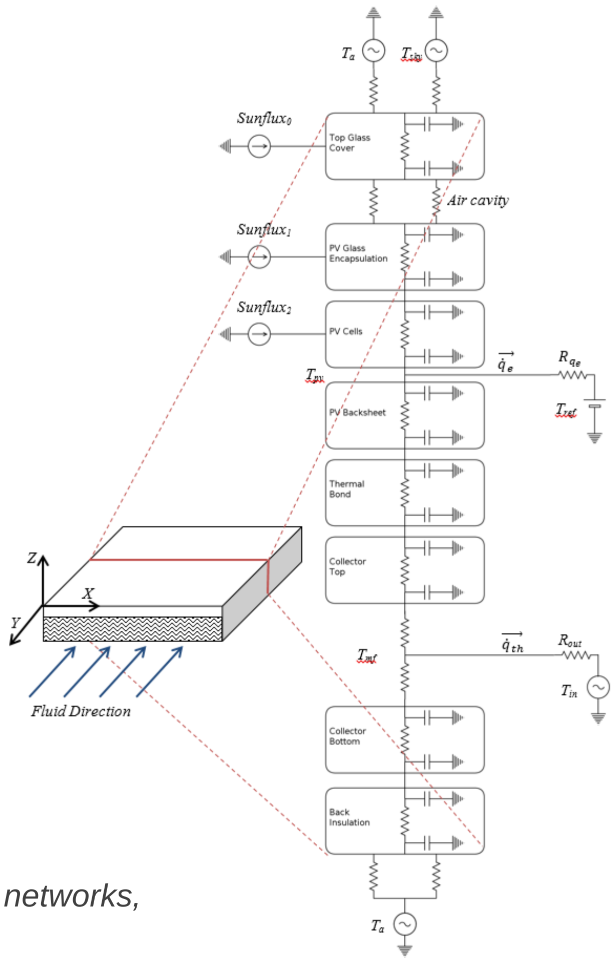


Bilbao & Sproul 2015. Detailed PVT-water model for transient analysis using RC networks, Solar Energy, 115, 680-693

Transient model

Example of thermal energy – model vs experiment

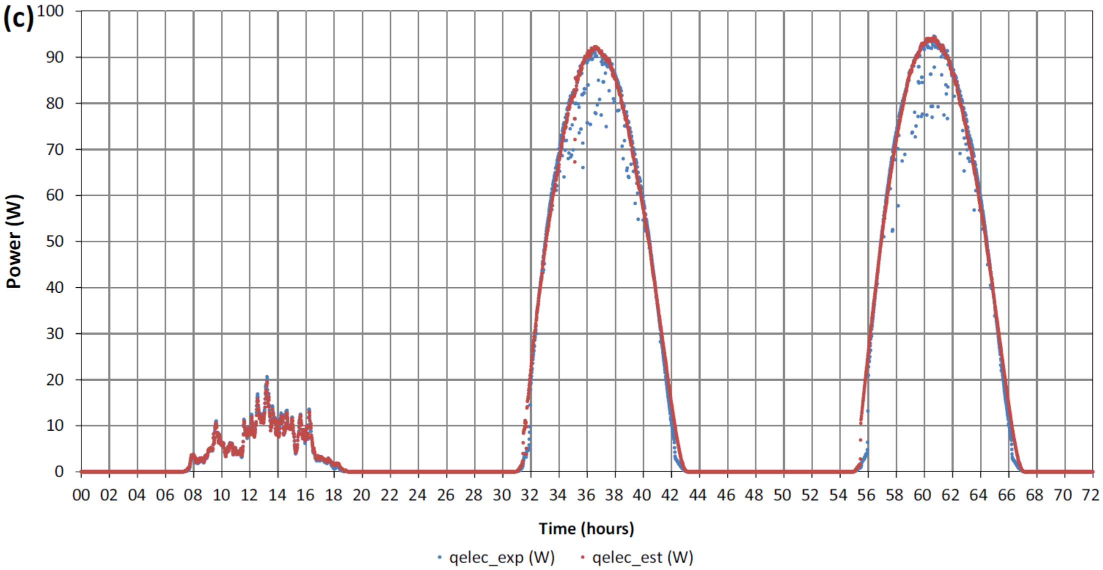


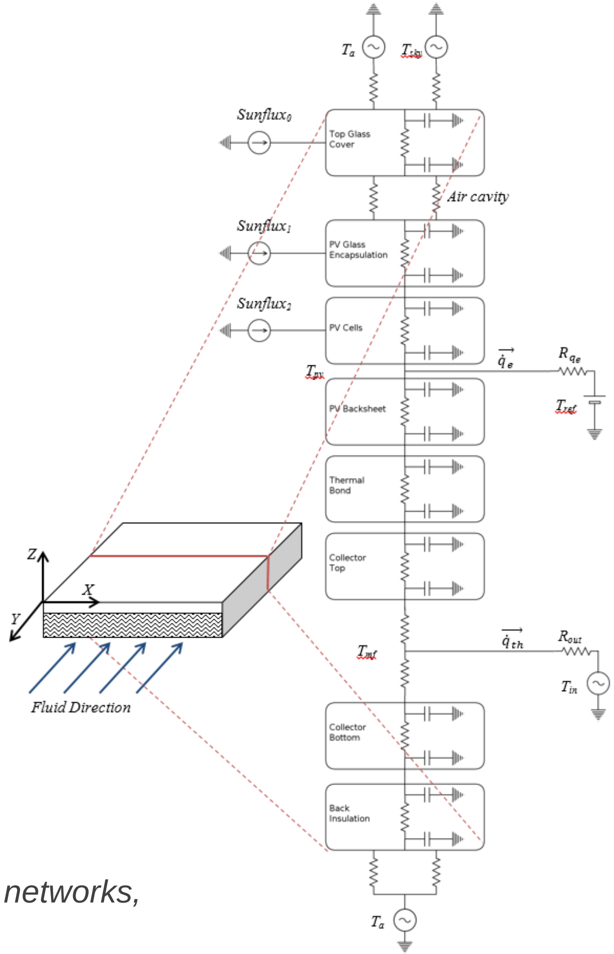


Bilbao & Sproul 2015. Detailed PVT-water model for transient analysis using RC networks, Solar Energy, 115, 680-693

Transient model

Example of electrical energy – model vs experiment





Bilbao & Sproul 2015. Detailed PVT-water model for transient analysis using RC networks, Solar Energy, 115, 680-693

Transient model vs Steady state model

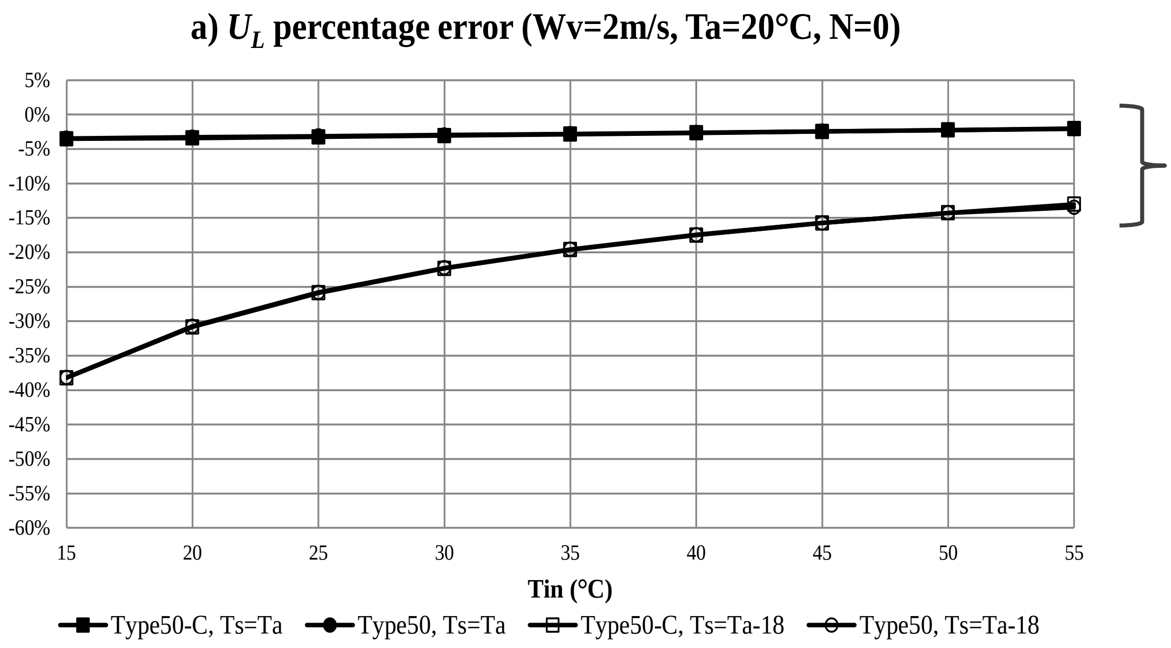
- Transient model was hard to use (Microcap)
- Steady state model was developed in TRNSYS (Fortran)
- Model used a single iteration plus an empirical relation (Akhtar and Mullick, 1999) to estimate cover temperature (Type850)
- Both models were compared against experimental data

Statistical comparison between steady state model and RC model – (full data set of 195840 points).

Model	Data	Q_{out}			Q_{elec}			Computational time (s)
		MBE (%)	cv(RMSE) (%)	R^2 (%)	MBE (%)	cv(RMSE) (%)	R^2 (%)	
Steady state	Minute data	−1.4	16.6	92.2	0.2	9.8	98.5	46
RC model	Minute data	0.2	10.4	97.0	0.0	9.9	98.5	235

Bilbao & Sproul 2015. Detailed PVT-water model for transient analysis using RC networks, Solar Energy, 115, 680-693

Importance of sky temperature

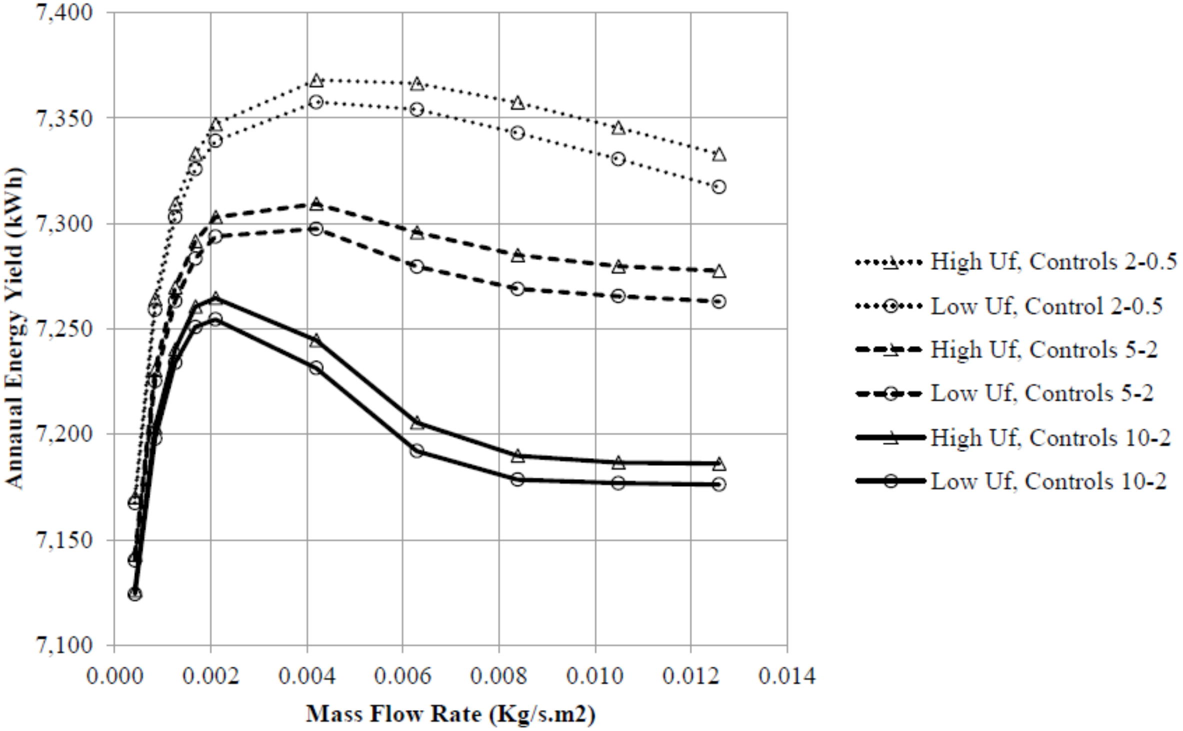


Difference between PVT models calculating heat loss coefficient (U_L) when sky temperature is considered

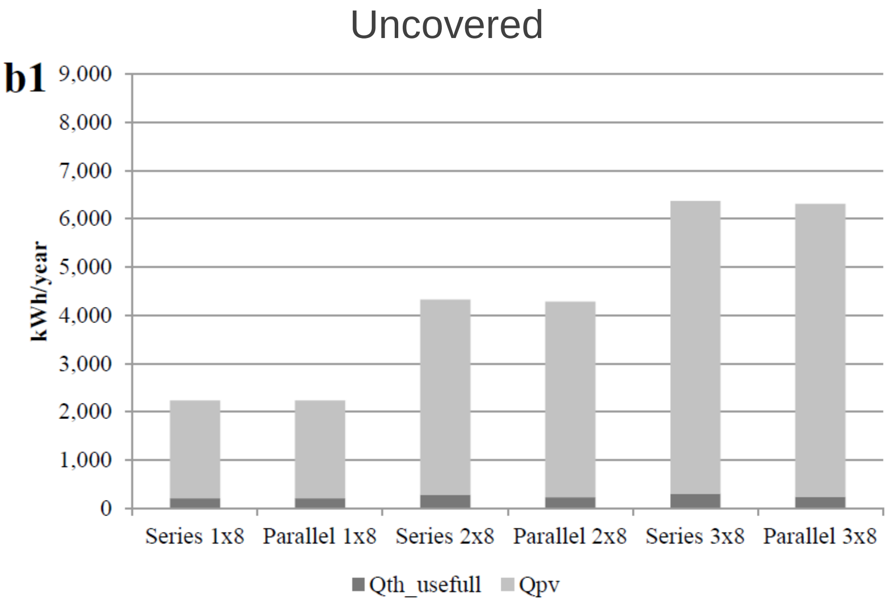
Sky temperature is particularly important in PVT collectors, due to the high emissivity of its surfaces

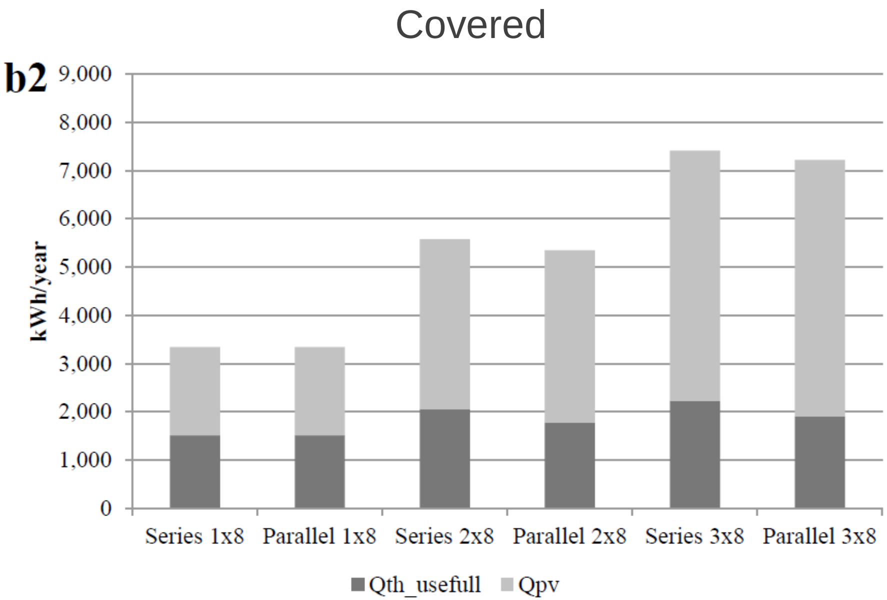
Bilbao & Sproul 2012. Analysis of flat plate photovoltaic-thermal (PVT) models. World Renewable Energy Forum, Denver.

Domestic Hot Water (DHW) system optimization



DHW system in Sydney - Covered vs uncovered



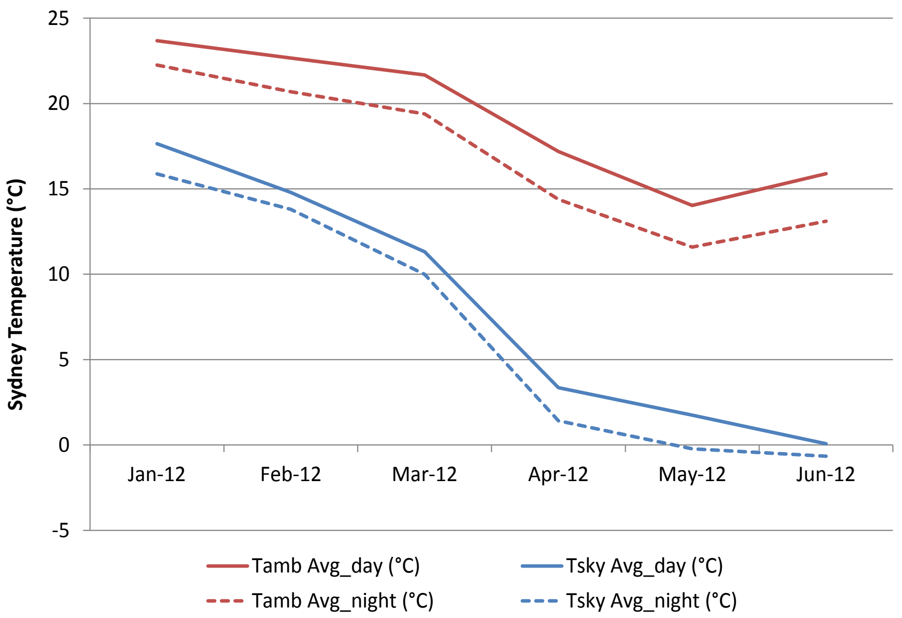


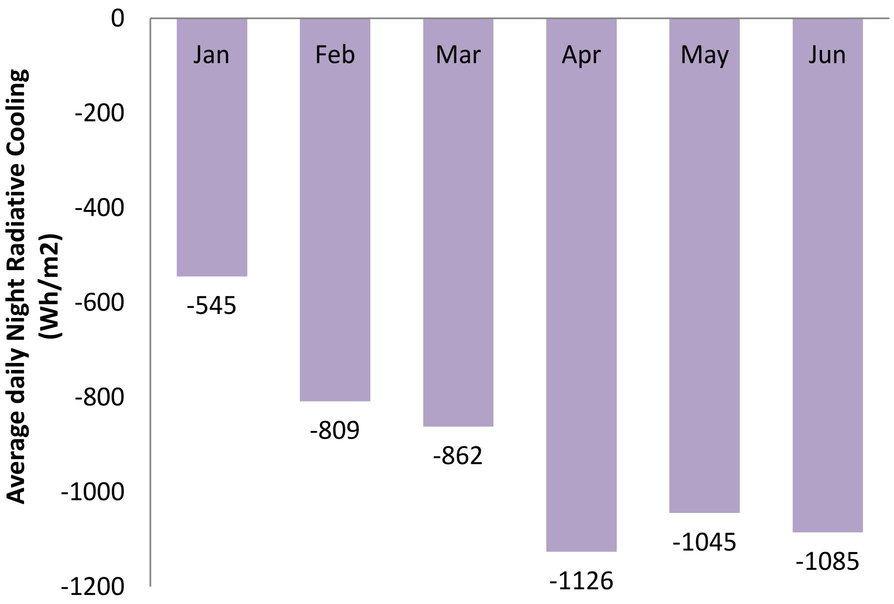
Series or parallel (thermal) configuration does matter, but effect is small

Covered system provide a higher combined output (but electricity output is greatly reduced)

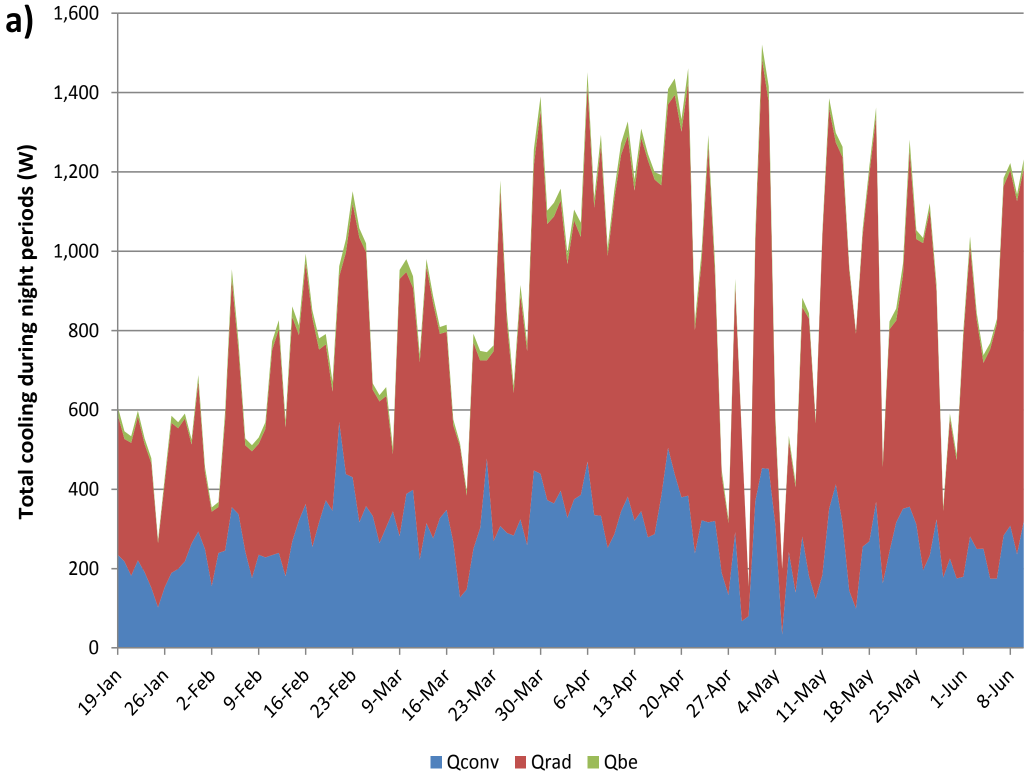
PVT works, but it really depends on the application!

Sky cooling (measured data)





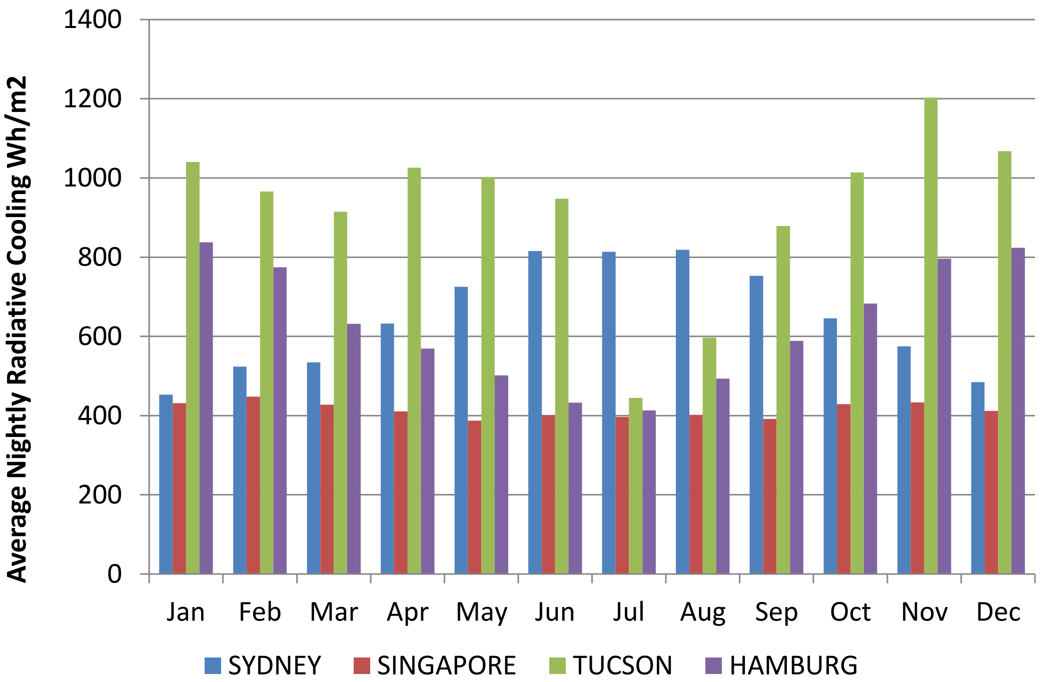
Radiative vs Convective losses



Simulated data from the tuned model

Goal was to determined how much cooling was due to radiative losses and convective losses

Night sky cooling simulation results

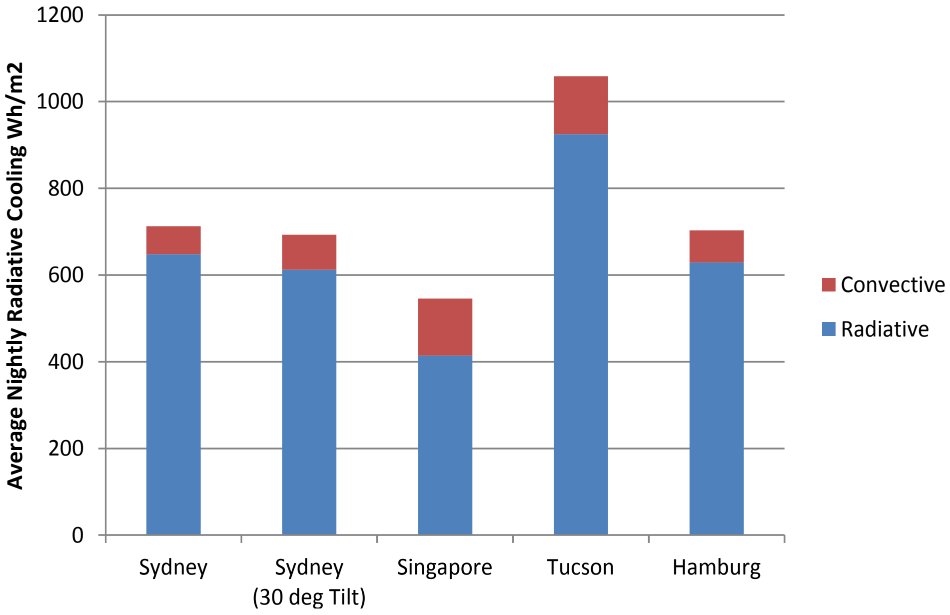


Assumptions

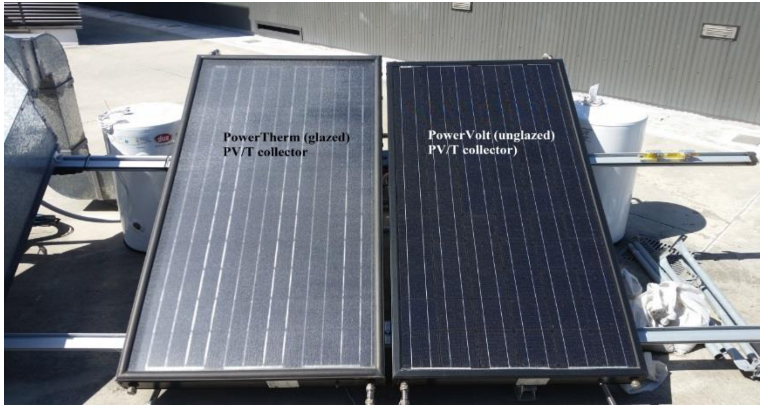
- TMY2 weather files for all locations.
- PVT modules at 10 degrees tilt.
- Effects of surroundings were excluded (rooftop installation ensures good sky view factor).
- Constant flow rate of 0.02 kg/s.m2
- Singapore (Af), Tucson (BSh), Sydney (Cfa), and Hamburg (Dfb).

Night sky cooling simulation conclusions

- Uncovered PVT systems can be used for night radiative cooling.
- Night radiative cooling potential from 400 Wh/m^2 to 900 Wh/m^2 per night.
- It is possible to provide cooling through the whole year.
- The percentage of radiative and convective cooling depends on many variables (+10% to 20% can be obtained from convective cooling).



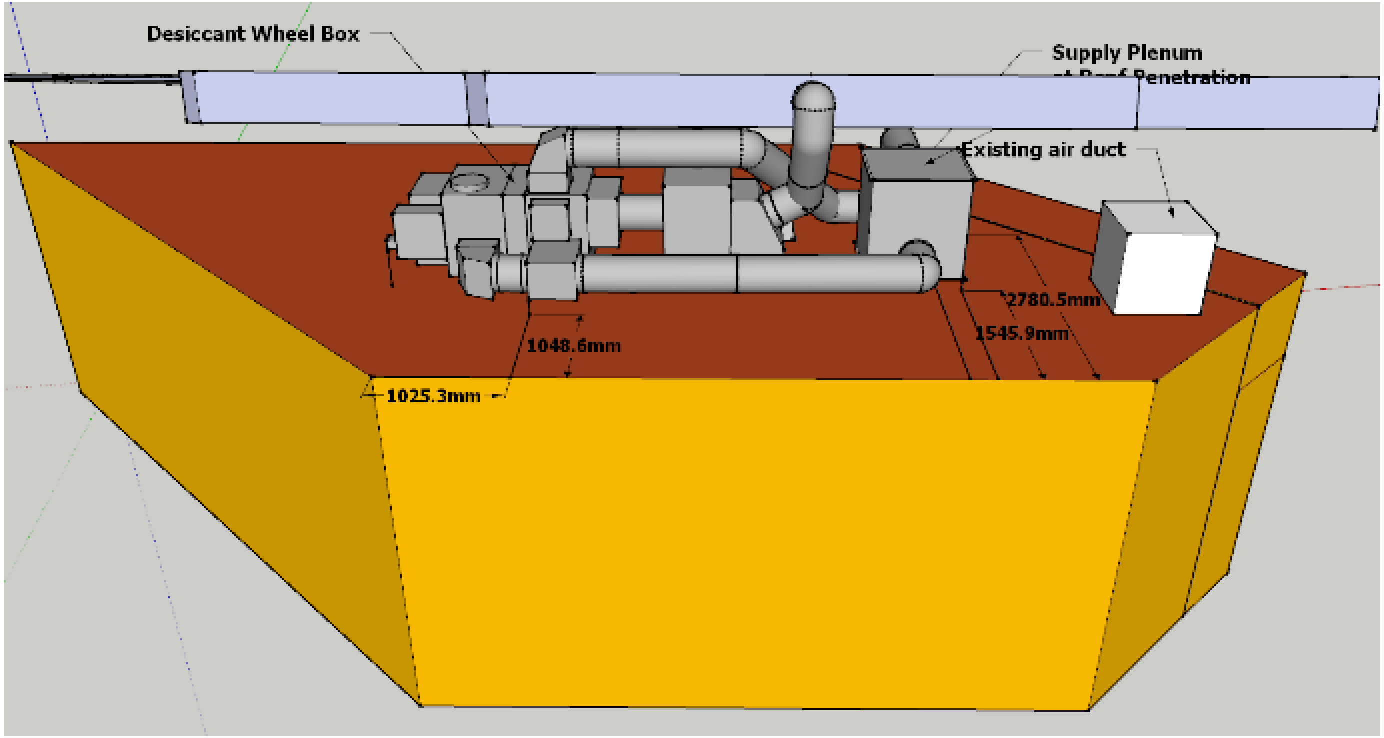
Updated PV/T hot water setup



PVT collectors donated by Solimpeks

New PVT/air roof

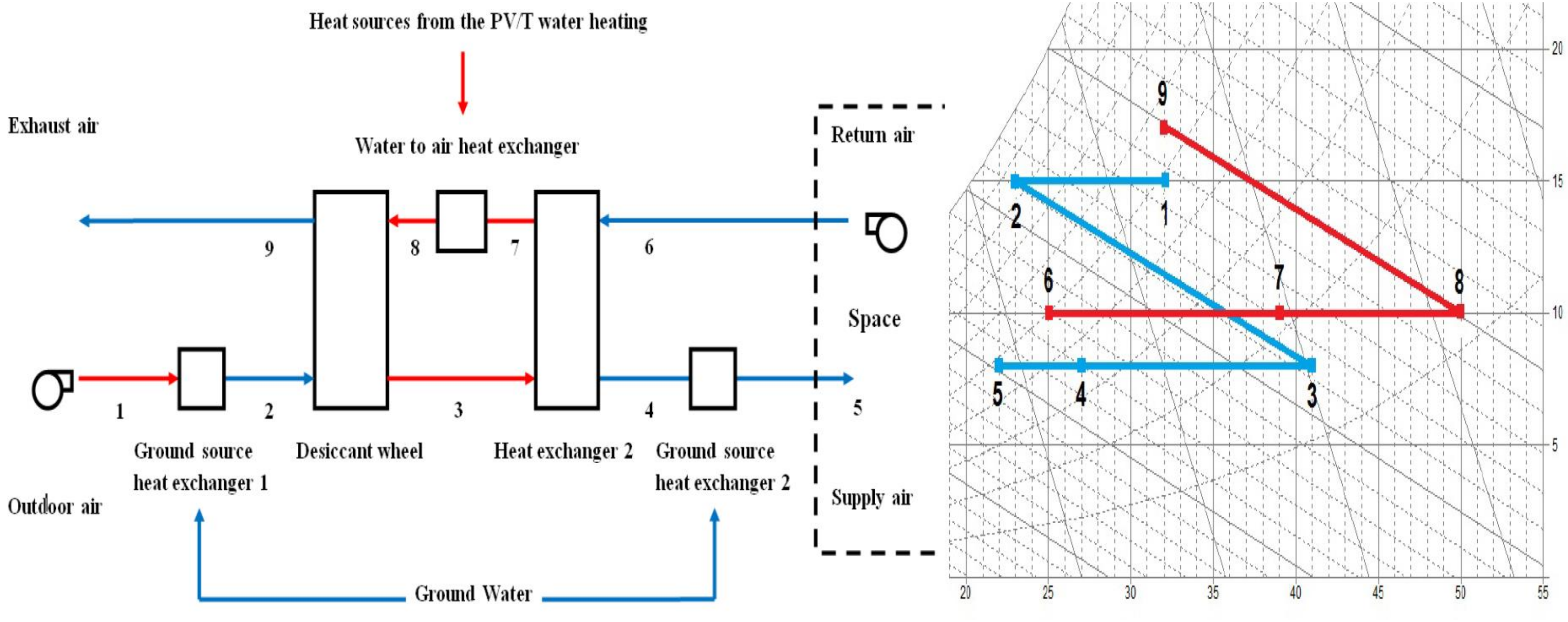
Desiccant solar PVT cooling system



PVT roof will provide heating during winter

Cooling in summer via desiccant and IEC

Ground coupled PV/T desiccant air cooling cycle



Guo, Bilbao, Sproul. Ground Coupled Photovoltaic Thermal (PV/T) Driven Desiccant Air Cooling. 2014 Asia-Pacific Solar Research Conference

PVT seems like a very good idea

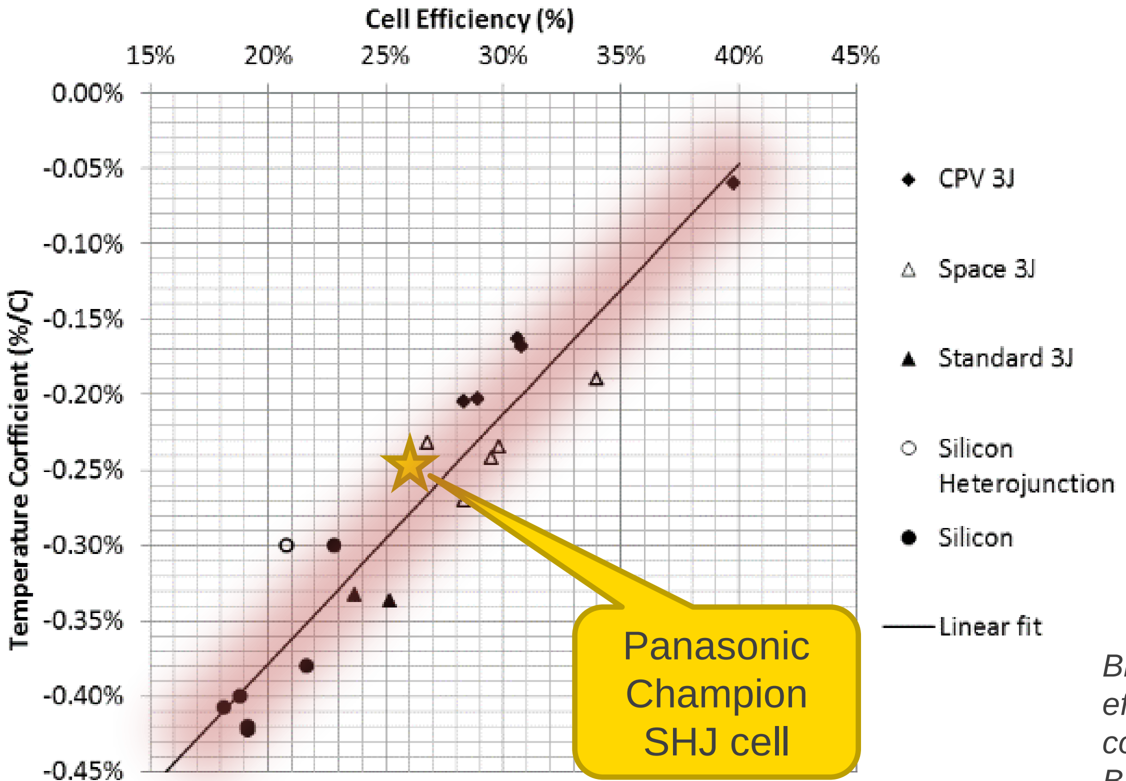
- High energy density per area
- High Thermal + PV efficiencies (potentially)
- Co-generation and even tri-generation possibilities

But…

- Complex (plumber + electrician + 2x standards)
- Needs to be tailored for each application – ‘right’ application
- Not great penetration or market (first panel in 70s)
- Hence, currently PTV systems are expensive and rare

Yet, BIPVT and high efficiency cells might change this

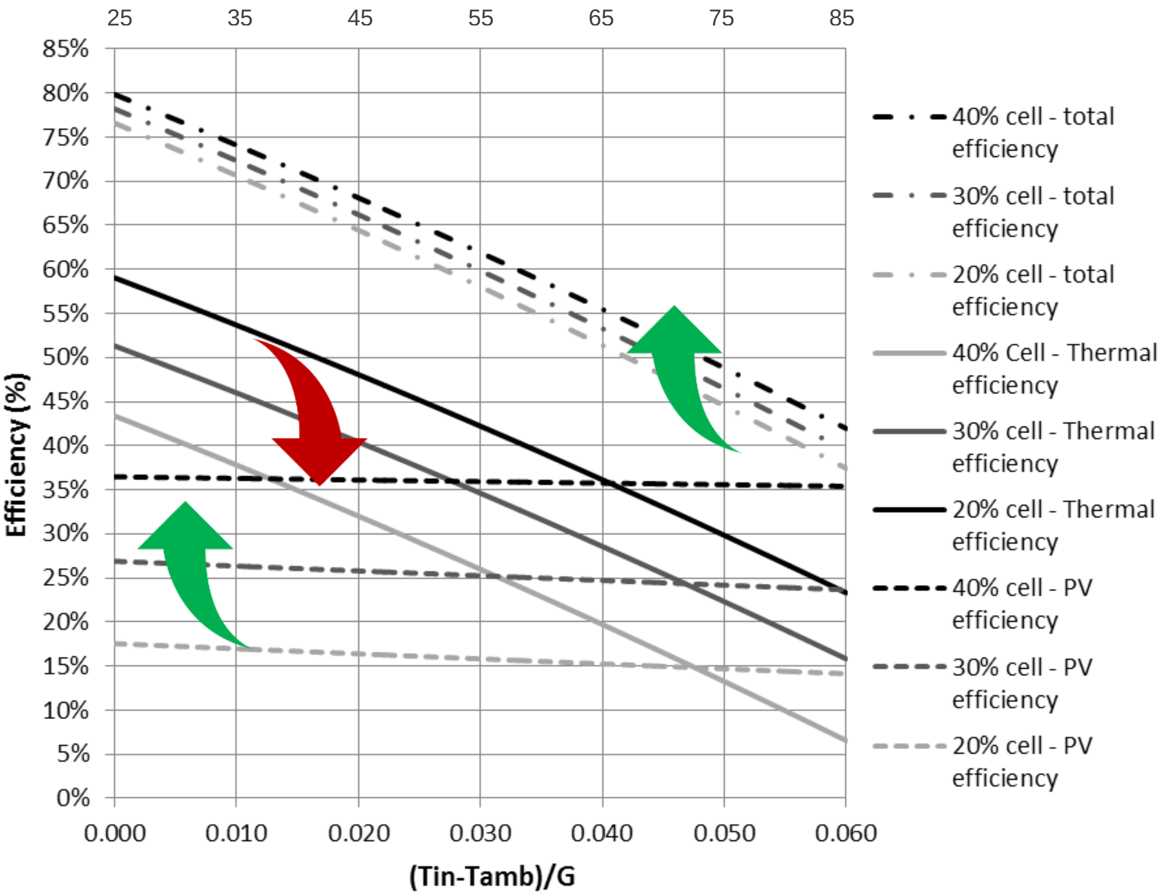
Cell efficiency vs Temperature coefficient



Bilbao, Dupre, Johnson. On the effects of high efficiency solar cells and their temperature coefficients on PVT systems. PVSEC-25, Busan, November 2015

Three cell ‘efficiency’ candidates

	Cell Efficiency (%)	Module (% / Wp)	Temperature Coefficient (P_{mpp} %/K)
Medium	20%	17.6% / 290W	-0.38%
High	30%	26.4% / 435W	-0.22%
Higher	40%	35.2% / 580W	-0.05%

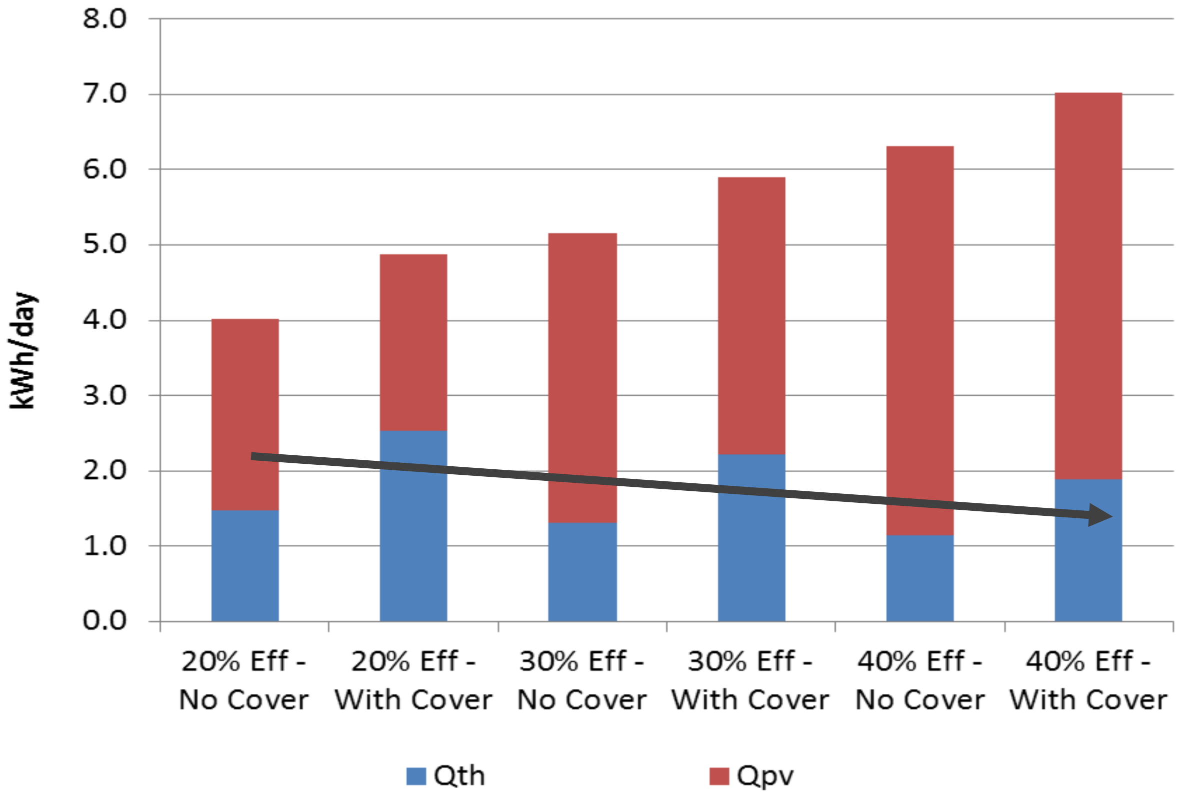


Electrical efficiency increases with cell efficiency

Thermal efficiency decreases

But, total efficiency increases (slightly)

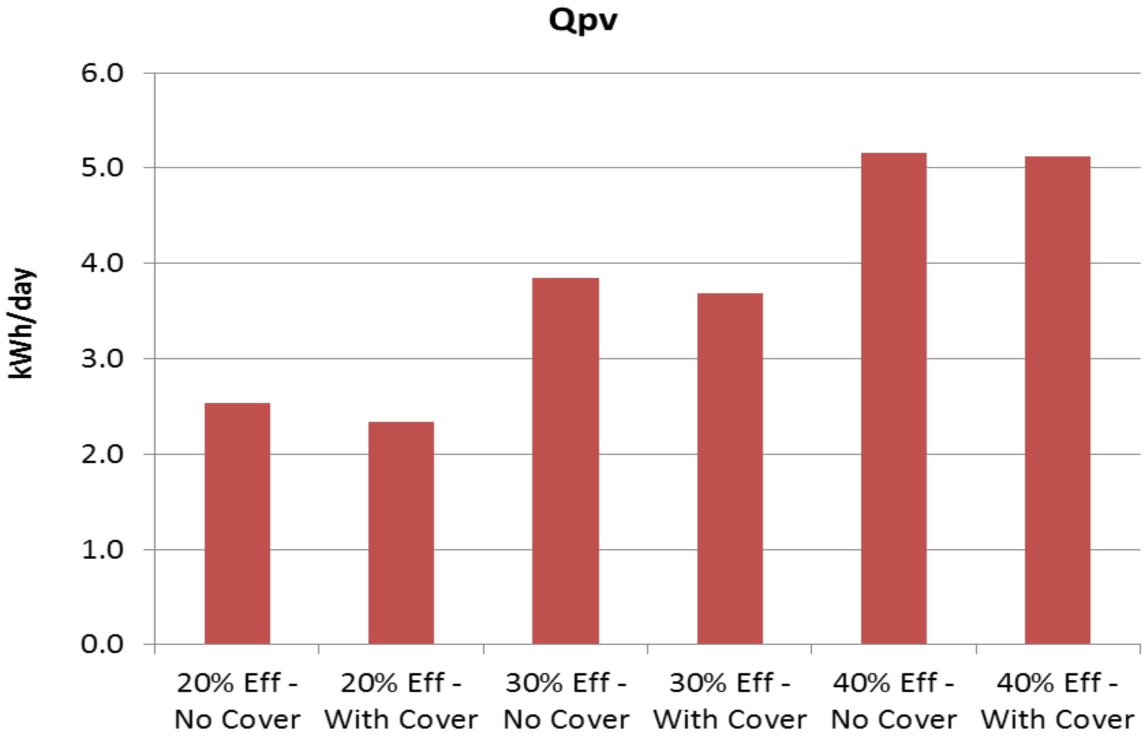
Simulation example – DWH in Sydney (1yr data)



Similar trend between cover and uncovered systems (compared with previous results)

Amount of thermal energy output could be 'tuned' depending on the application

Simulation example – DWH in Sydney (1yr data)



PV performance does not ‘suffer’ as much, because of low temperature coefficients

PVT future summary

- Increase in cell efficiency results in lower temperature coefficients (P_{mpp})
- Hence, there is less efficiency gains by cooling PV modules
- However, this also means less penalty by running the modules ‘warmer’
- Balance between ratio of electrical and thermal output (e.g. better for DHW) → better suited to meet load profiles
- Low cost of PV could open the door for using PVT modules in higher temp systems like BIPVT

- IEA SHC is working on defining a new PVT task https://www.iea-shc.org/event?EventID=1554

Q&A

Thank You!

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