The role of solar power and buildings to deliver low carbon living

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Building Integrated PV (BIPV) Workshop:
Piecing together the BIPV puzzle
June 7th, 2013
APVA BIPV Workshop, Bond University
• Energy, buildings and CO₂
• Low carbon, integrated design
• Response to climate
• BIPV, PV/T – multiple benefits (energy, materials)
• Low energy buildings – BIPV + energy efficiency
Figure 5.8 • World energy-related CO₂ emission savings by policy measure in the 450 Scenario

http://www.worldenergyoutlook.org/
Exhibit 5

**Australian 2030 carbon abatement cost curve**

- **Cost of abatement**
  - A$/t CO$_2$e

- **Reduction below 1990 levels, percent**

- **Break-even point**

- **Abatement below business as usual**
  - Mt CO$_2$e

- **Source:** McKinsey Australia Climate Change Initiative

Note: Abatement opportunities are not additive to those of previous years.
Figure 4: Percentage cost–effective energy consumption reduction potential across different sectors.

PV is growing fast and getting cheaper

Source: Professor Emanuel Sachs, Massachusetts Institute of Technology.
* Assumes annual production growth of 35% and an 18% learning curve. PV costs based on 18% capacity factor and 7% discount rate.
Most of the increase of electricity tariffs over the years has been in line with the CPI (average 4.4% p.a) except over the period 2007 – 2010, - electricity increases have been more like 14% p.a. (I have added a black dot to indicate the electricity price IF it had followed the CPI.

Time of Use Graphic

**Peak (Mon-Fri only)**

**Tariff 11**

**Off-peak**

**Shoulder**

**FIXED CHARGES:** Tariff 11 $26.20/quarter, Tariff 12 (Time of Use) $78.66/quarter

Electricity Production in Germany: May 2012

Actual production

- **Solar**: max. 22.4 GW; 4.1 TWh (Fr 25 May, 12:45)
- **Wind**: max. 14.1 GW; 2.9 TWh
- **Conventional**: max. 51.2 GW; 26.6 TWh

UNSW TYREE ENERGY TECHNOLOGY BUILDING - 150 kWp PV ARRAY
UNSW TETB Electricity
Mar 4 – 10, 2013

UNSW Kensington Electricity
Jan 7 – 13, 2013

Greensense View® - Kensington Campus

Electricity Demand - Mon Jan 7 2013

Weather Today
Wind: null @ 23km/h
Humidity: 65%
Sunrise: 6:50 AM
Sunset: 7:13 PM

On-site Generation Summary
Current generation: 0 kW
System Capacity: 0%

Right Now
Current Consumption: 7,476 kW
Benchmark: 7,063 kW
5.9% above average

Energy Generated Today: 22,632.0 kWh
Lifetime: 2,684,016.0 kWh

Emissions Avoided Today: 19,010.8 kg CO₂-e
Lifetime: 2,257.2 t CO₂-e
Low carbon design & integration
Low energy buildings need integrated low energy building systems

1 Bligh Street, Sydney
6 star office building
Solar cooling in Germany using adsorption air-cooling and solar heat.
TMY Temperatures for Melbourne

Consider average temperatures (light blue middle line)
Summer:  \( T_{av} < 25^\circ C \) - close to thermal comfort (green band) – hot days “spikes”
Winter:  \( T_{av} \sim 10^\circ C \) – \( \Delta T \) to thermal comfort = \( \sim -10^\circ C \)
TMY Temperatures for Brisbane

Consider average temperatures (light blue middle line)
Summer: $T_{av} \sim 25 \, ^\circ\text{C}$ - close to thermal comfort (green band)
Winter: $T_{av} \sim 15\, ^\circ\text{C} - \Delta T$ to thermal comfort $= -5 ^\circ\text{C}$
Integrated Design

Cost Transfer

Transfer costs from mechanical and electrical systems to building architecture

PV and Rooftops

PV and rooftops equals green electricity delivered to the customer offsetting electricity at retail prices.
PV modules can provide shading and lighting at no extra cost.

Conservatory ECN Building, Holland
PV roof at De Kleine Aarde
Shading of windows

Sydney, March 21\textsuperscript{st}, midday
Sydney, June 21st, midday
Sydney, Sep 21\textsuperscript{st}, midday
Sydney, Dec 21st, midday
March 13, 10:15 am, 2013 TETB Northern window. Sydney DBT = 28°C max.
Opportunity to improve external shading to exclude direct solar gain
(Sep 21\textsuperscript{st} – Mar 21\textsuperscript{st})? PV panels - which currently have an installed system cost of
~ $250/m\textsuperscript{2} may be the best option?
Conserval Engineering - SolarDuct PV/T, generates electricity and heat.
PVT – air system

S.M. Bambrook, A.B. Sproul, Maximising the energy output of a PVT air system, Solar Energy, Volume 86, Issue 6, June 2012, Pages 1857-1871
PVT System design

- 660 Wp PV array
- Air flow 400 - 2000 m$^3$/h
Thermal results

- Time
- Temperature (°C)
- Irradiance (W/m²)

- Inlet
- PVT Duct 1
- PVT Duct 2
- PVT Duct 3
- Outlet
- Ambient air
- Irradiance
Thermal results

- Temperature rise (To - Ti)
- Fan power

Temperature (°C) vs. Air flow rate (kg/s.m²)

- Fit to Temperature rise
- Fit to Fan Power

Power (W)
Efficiency

![Graph showing efficiency vs. air flow rate](image)

- **Electrical Efficiency**
- **Thermal Efficiency**
- **Fit to Electrical Efficiency**
- **Fit to Thermal Efficiency**

The graph illustrates the relationship between electrical efficiency and thermal efficiency with respect to air flow rate (kg/s.m²). The data points and fitted curves provide insights into how efficiency changes with varying air flow rates.
### Whole system result

<table>
<thead>
<tr>
<th></th>
<th>0 kg/s.m²</th>
<th>0.06 kg/s.m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal output</td>
<td>0 kWh</td>
<td>11.6 kWh</td>
</tr>
<tr>
<td>Electrical output</td>
<td>2.9 kWh</td>
<td>3.2 kWh</td>
</tr>
<tr>
<td>Fan energy</td>
<td>0 kWh</td>
<td>0.1 kWh</td>
</tr>
<tr>
<td>Net electrical output</td>
<td>2.9 kWh</td>
<td>3.1 kWh</td>
</tr>
</tbody>
</table>

- 0.2 kWh electrical GAIN + 11.6 kWh thermal output
PV/T air systems

• Outlet temp suitable for space heating
• Sky cooling at night > purging of thermal mass in the building overnight
• Array ventilation increases PV output
• Additional PV elec output > fan energy
• Good potential for residential application – retrofit and new build

S.M. Bambrook, A.B. Sproul, Maximising the energy output of a PVT air system, Solar Energy, Volume 86, Issue 6, June 2012, Pages 1857-1871
Optimised low energy home for Sydney

Fig. 10. Annual plot of the outside air temperature compared with the indoor temperature for a well insulated optimisation case.

Optimised low energy home for Sydney – floor area 200 m².

Structurally insulated panels: \( R \)-value = 5.2 m²K/W (walls), 6.5 m²K/W (ceiling)
Thermal mass – concrete slab 0.15 m (insulated - 6.5 m²K/W ), internal wall = 0.2 m
Windows : DG low-e, wooden frames: U value = 1.6 W/m²K, SHGC = 0.60
Night purging in summer: 4 ACH

- Reduced the space heating and cooling energy requirement of a new house in Sydney by up to 94% compared with the legislated BASIX requirements.
- Infiltration was reduced and ventilation air flows were controlled and utilised an air/air heat exchanger.
- An internal thermal mass wall and an insulated concrete slab were included in the optimised models and summer night ventilation was used to purge the heat from the thermal mass.
- The optimised house model has a lower net present cost compared with a house that meets the current BASIX building standard, taking into account the cost of construction, the HVAC cost and the electricity cost over a period of 20 years.
- Assuming energy efficient appliances and energy conscious user behaviour, a daily household energy load of 9.4kWh could be supplied by a 2.4 kWp photovoltaic system.
Fig. 9. Frequency of free running indoor temperatures.
Termites don’t burn coal yet they have a low carbon built environment.

“High rise” termite mound

Indoor climate control

Solar driven ventilation

Air-earth heat exchange

10 m high, maintains 31±1°C in 3–42°C for termites’ fungus-farming