Low and zero energy buildings - towards green cities in Australia

UNSW AUSTRALIA

Never Stand Still | Engineering | Photovoltaic and Renewable Energy Engineering

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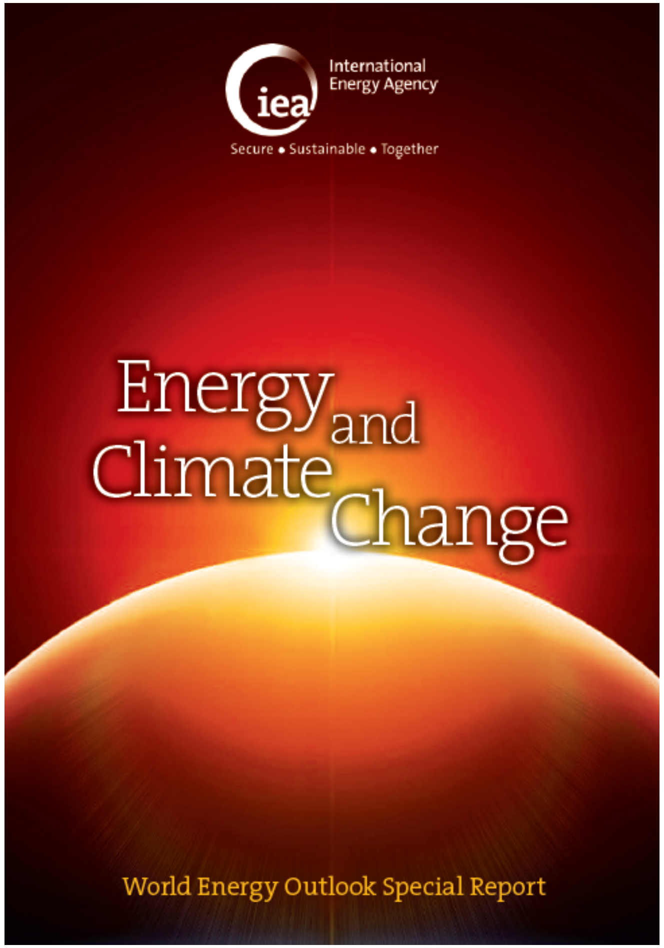
UNSW, Sydney, Australia

SPREE seminar series
17 December 2015

IEA 2015 WEO Report

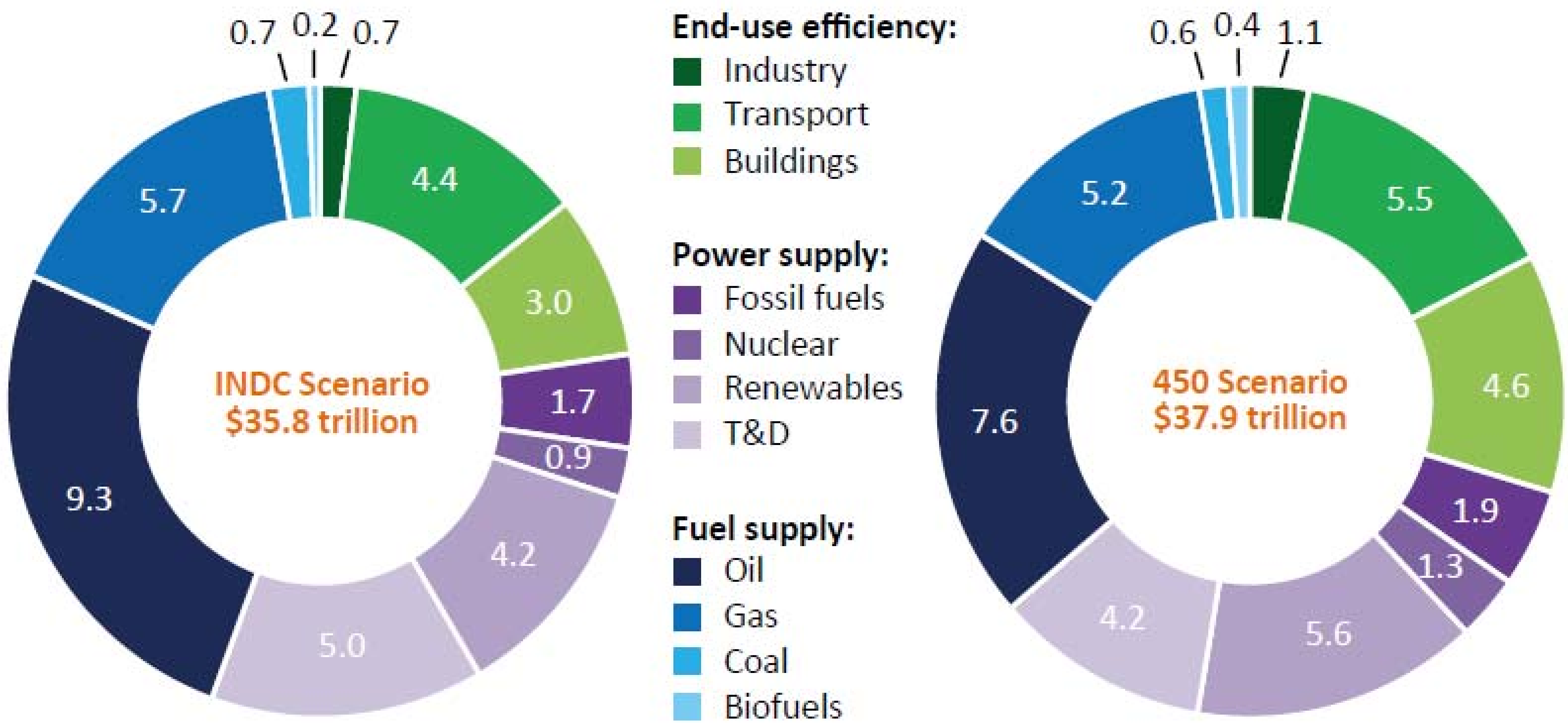


We face a moment of opportunity, but also of great risk. The world is counting on the UN climate talks in Paris later this year to achieve a global agreement that puts us on a more sustainable path. As IEA analysis has repeatedly shown that the cost and difficulty of mitigating greenhouse-gas emissions increases every year, time is of the essence. And it is clear that the energy sector must play a critical role if efforts to reduce emissions are to succeed. While we see growing consensus among countries that it is time to act, we must ensure that the steps taken are adequate and that the commitments made are kept.

https://www.iea.org/publications/freepublications/publication/WEO2015SpecialReportonEnergyandClimateChange.pdf

Investment required

Figure 2.4 ▷ Cumulative global energy sector investments by sector in the INDC and 450 Scenarios, 2015-2030 (trillion dollars, 2013)

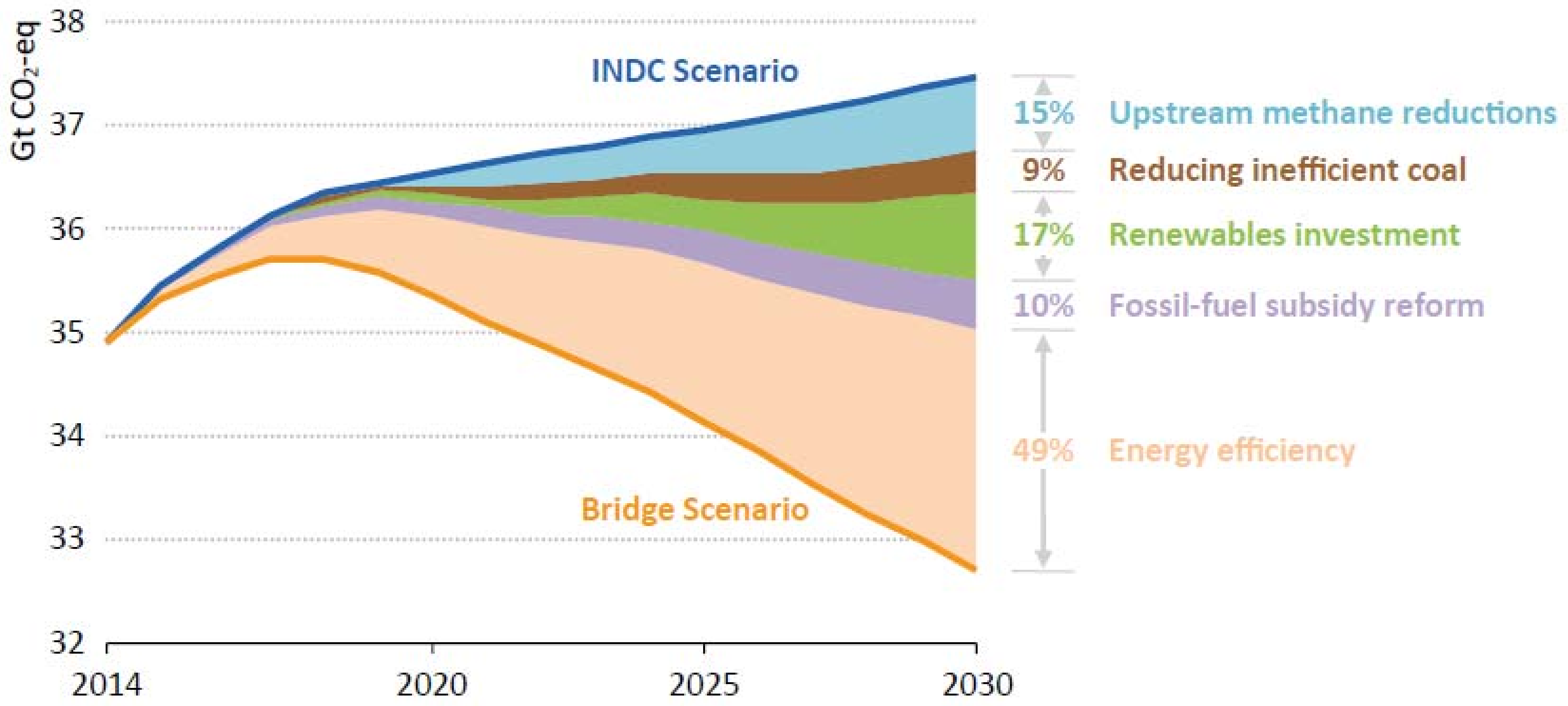


Note: T&D is transmission and distribution.

INDC – Intended Nationally Determined Contributions for COP21

Energy efficiency can reduce CO_2 even further

Figure 3.2 ▷ **Global energy-related GHG emissions reduction by policy measure in the Bridge Scenario relative to the INDC Scenario**



Evolution

Sydney University "Autonomous house" in the 1970s

http://larryspeck.com/2014/04/29/autonomous-house-university-of-sydney/

CSR house today – demonstration of how to "mainstream" an 8 star energy efficient design.

http://www.csr.com.au/Our-Products/Documents/CSR-House-A4.pdf

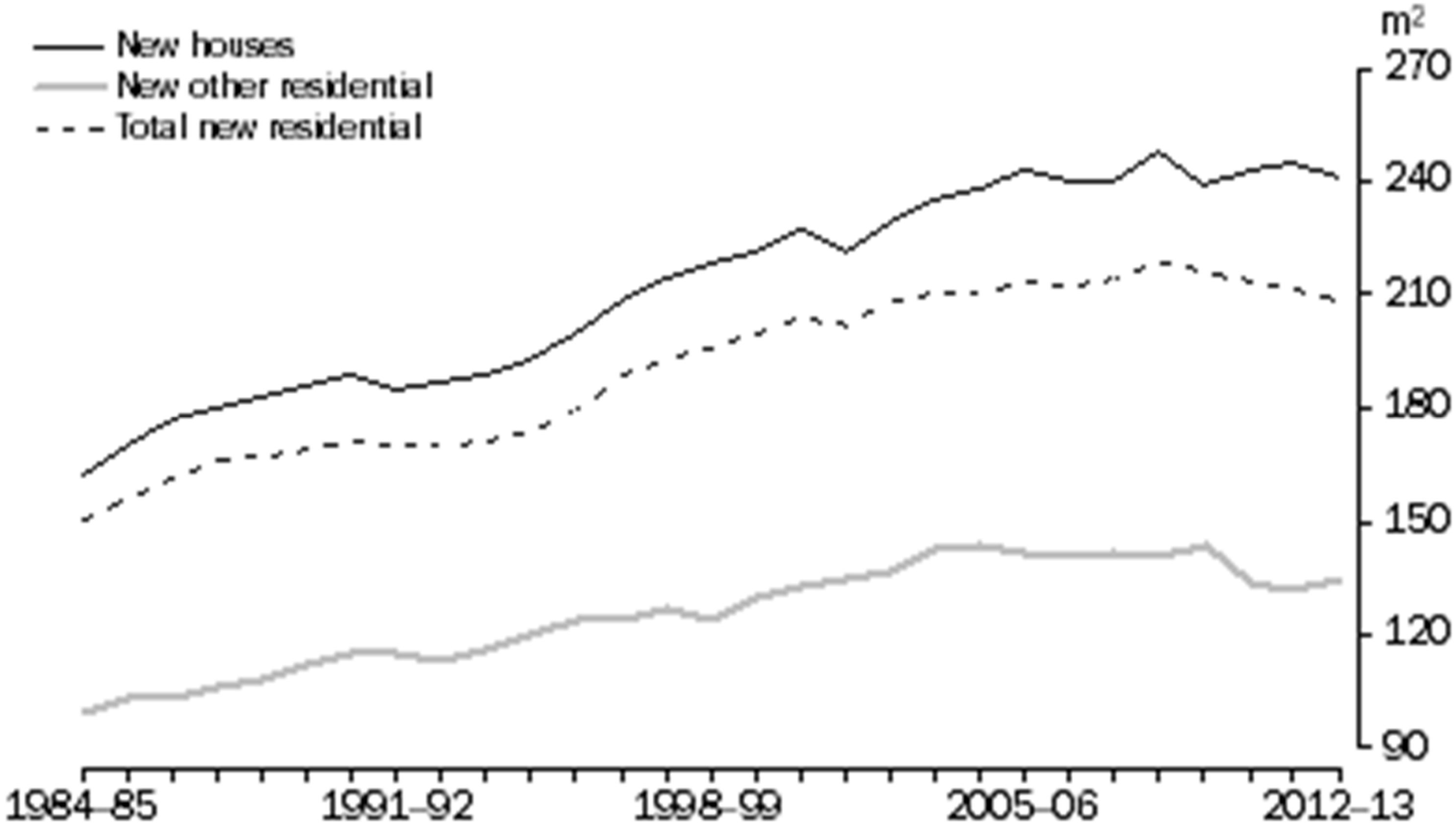
Poor thermal performance of buildings

Older style Australian home

Typical “modern” Australian home – largest in the world

If built before 2006 – no requirement in Building Code to address energy issues

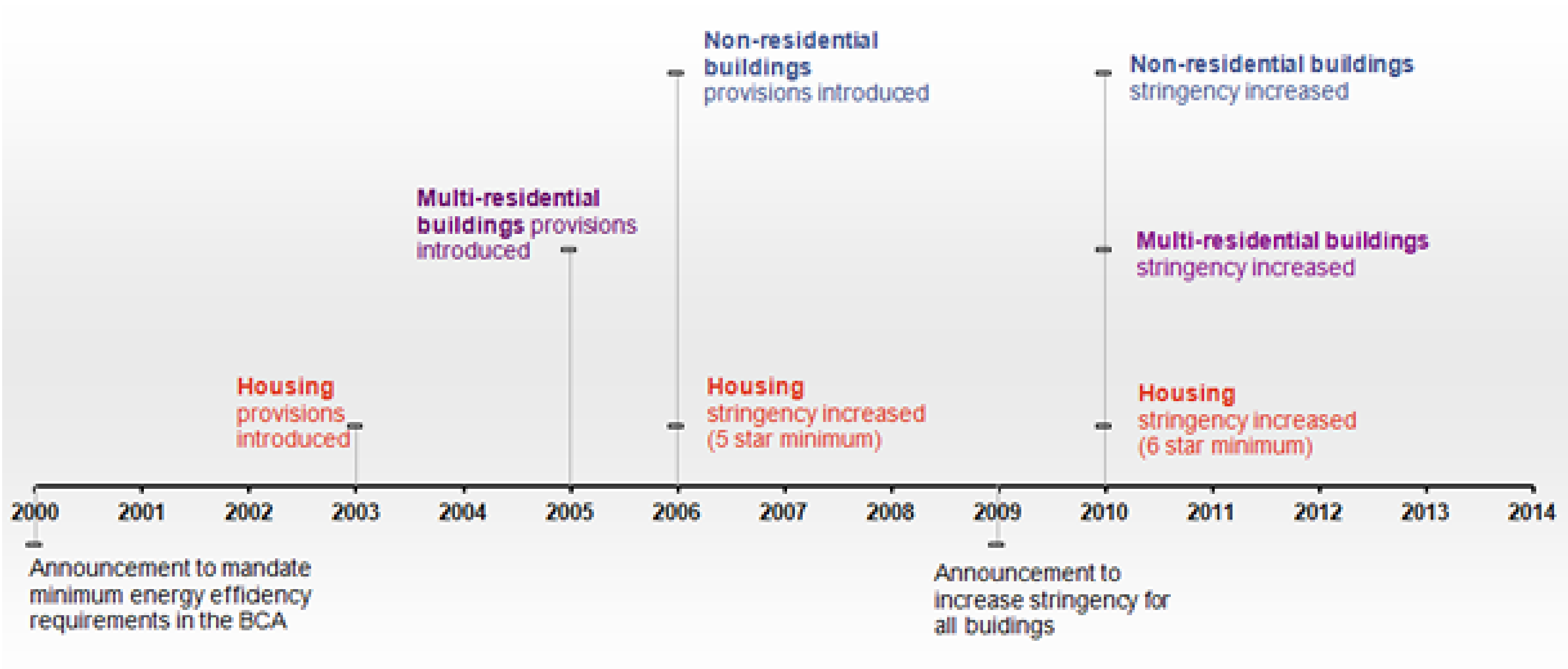
Australian homes – largest in the world



http://www.abs.gov.au/ausstats/abs@.nsf/featurearticlesbytitle/E9AC8D4A1A3D8D20CA257C61000CE8D7?OpenDocument

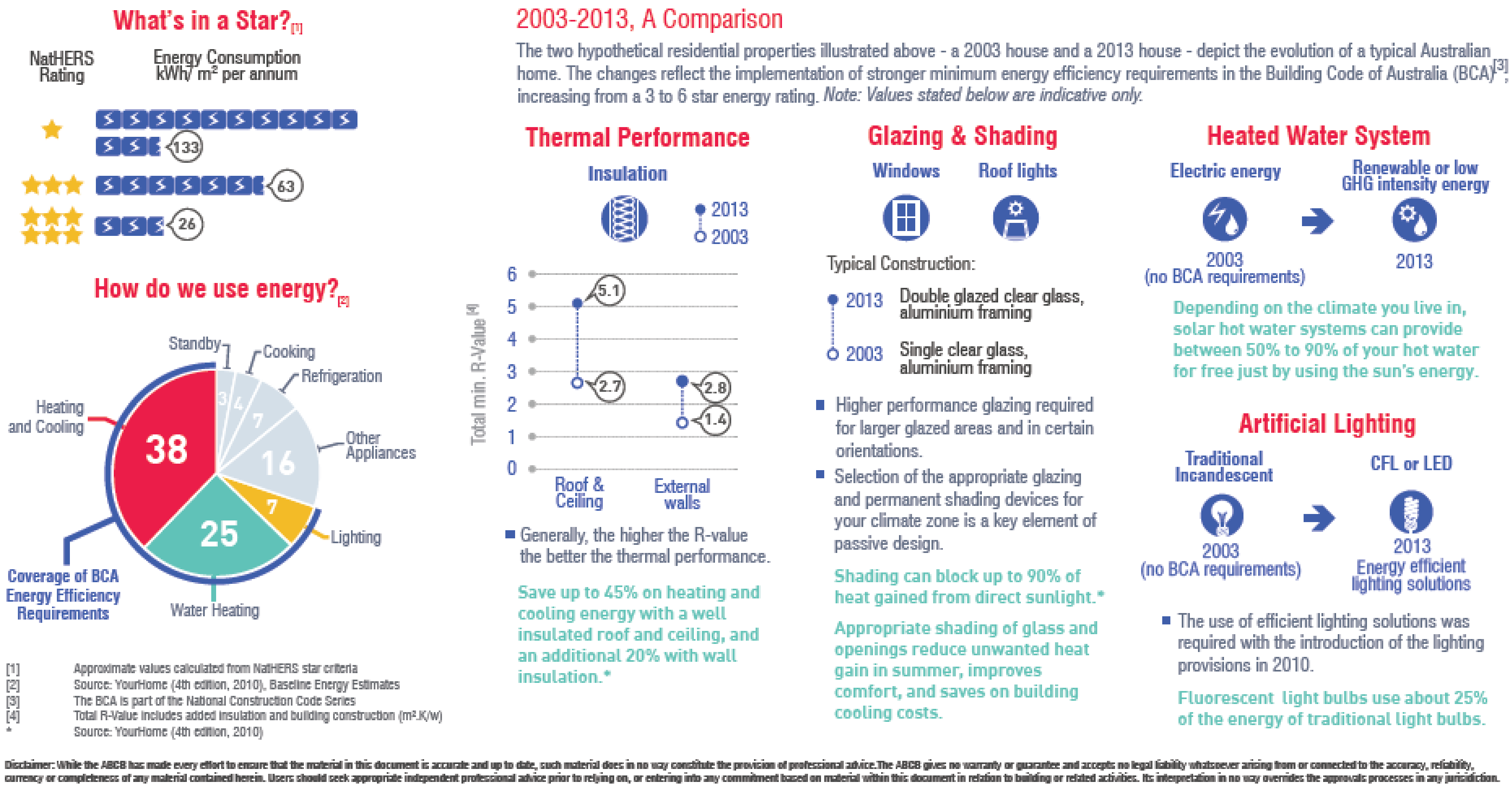
Green buildings in Australia

2003 – Australian Building Code – first introduces energy requirements for residential housing.



http://www.abcb.gov.au/en/work-program/energy-efficiency.aspx

BCA



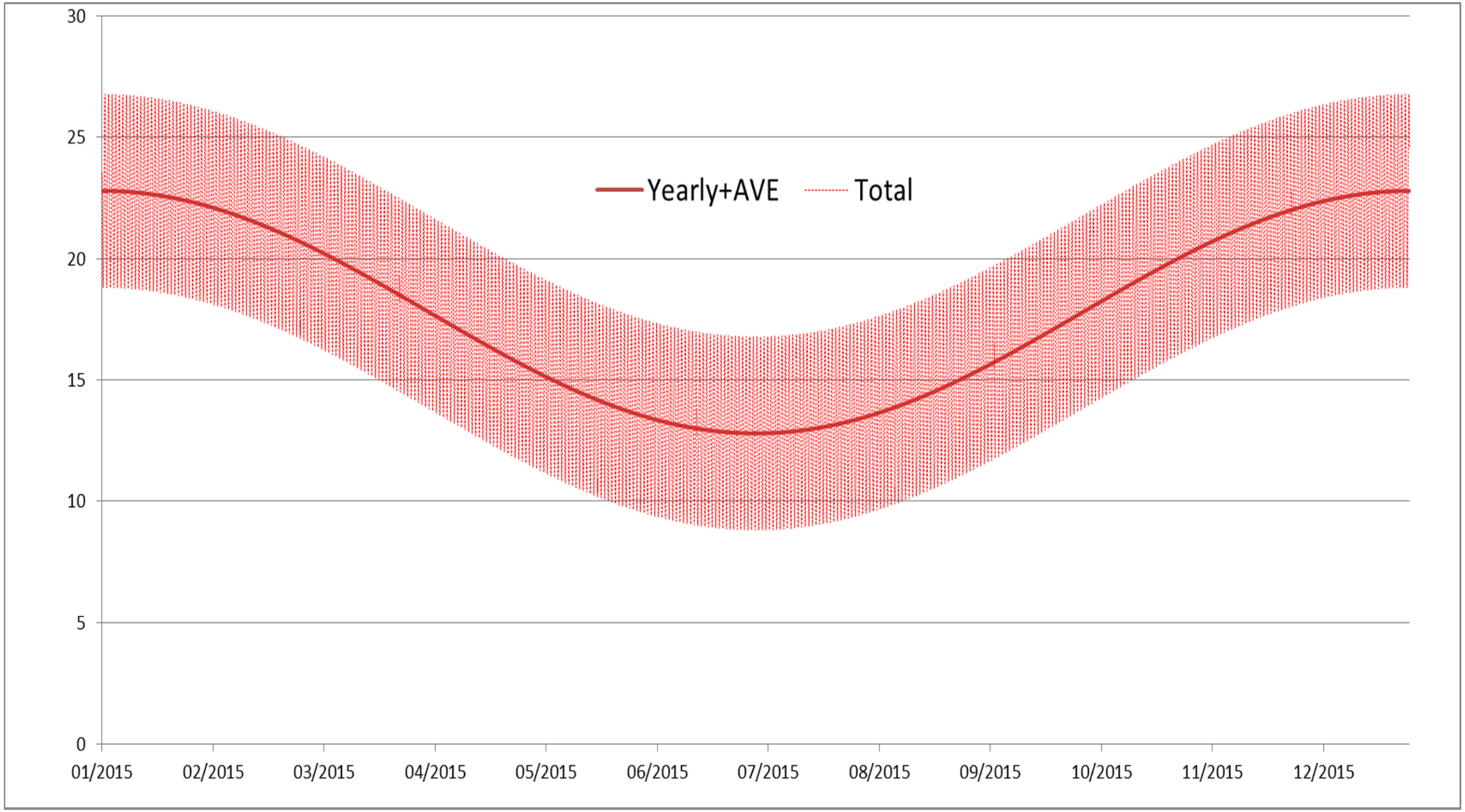
http://www.abcb.gov.au/en/work-program/energy-efficiency/residential-housing.aspx

Insulation requirements for homes: BCA

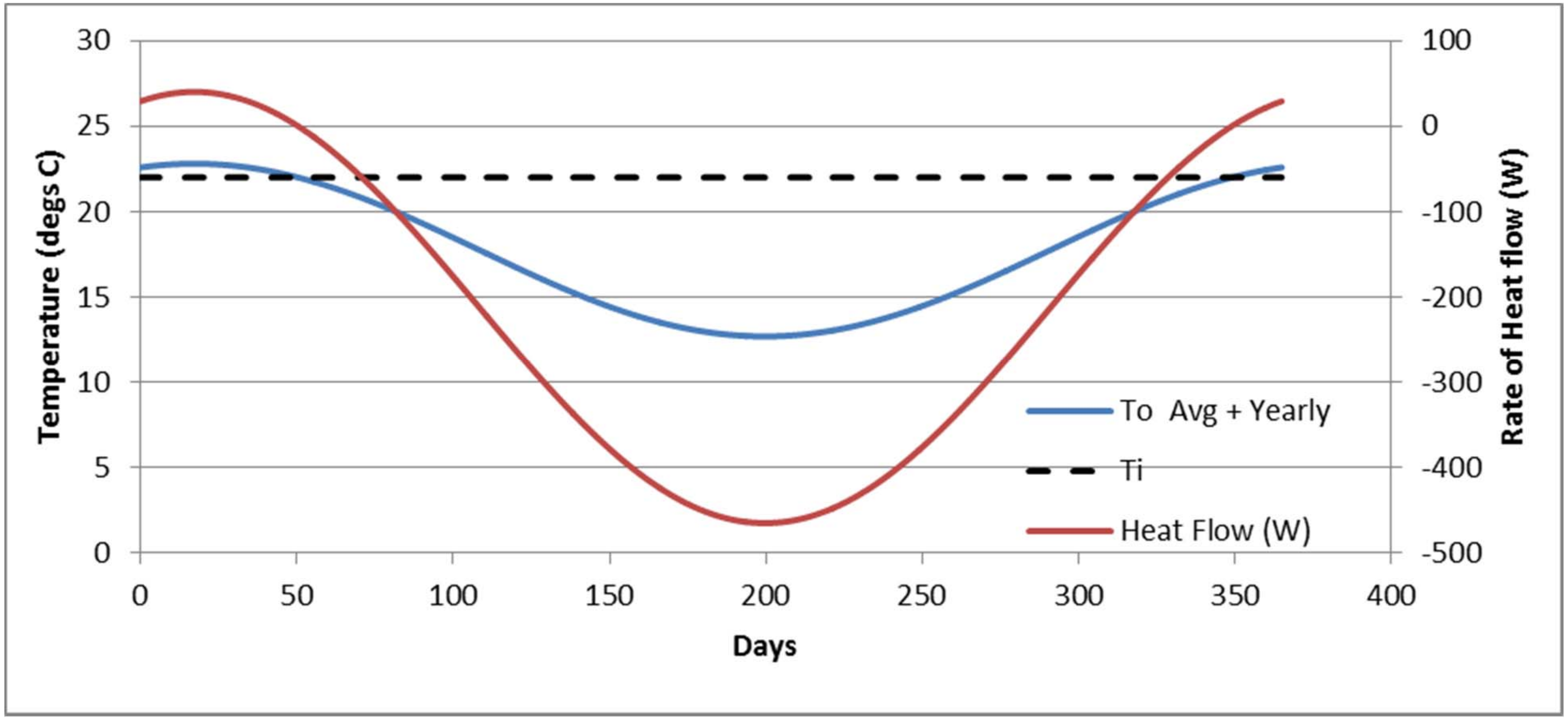
Climate zone:	1	2		3	4	5	6	7	8
Roof / Ceilings									
Direction of heat flow	**Inwards**		**Inwards/Outwards**		**Outwards**				
Very light coloured roofs (Absorptance ≤ 0.4)	R4.1	R4.1	R4.1	R4.1	R4.1	R4.1	R4.1	R4.1	R6.3
Light coloured roofs (0.4 < Absorptance ≤ 0.6)	R4.6	R4.6	R4.6	R4.6	R4.6	R4.6	R4.6	R4.6	R6.3
Dark coloured roofs (Absorptance ≥ 0.6)	R5.1	R5.1	R5.1	R5.1	R5.1	R5.1	R5.1	R5.1	R6.3
Walls									
Direction of heat flow	**Inwards**				**Outwards**				
	R2.8	R2.8		R2.8	R2.8	R2.8	R2.8	R2.8	R3.8
Floors									
Direction of heat flow	**Inwards**				**Outwards**				
	R1.5	R1.0	R1.5	R2.25	R1.0	R2.25	R2.25	R2.75	R3.25

http://www.build.com.au/bca-requirements-insulation

Idealized average outside temperature - Sydney



Results



Graph shows heat flow due to average and yearly outside temperature components. U = 0.25 W/m^{2}K. Predominantly heat is LOST through the wall throughout the year.

Daily heat flow =

$$AY_{td}T_d \cos(\omega_d t + \Phi_d)$$

Maximum DAILY heat flow = $AY_{td}T_d$ = 200 x 0.05 x **4 = 40 W** - fairly small !

True in this case as the wall is INSULATED and has mass.

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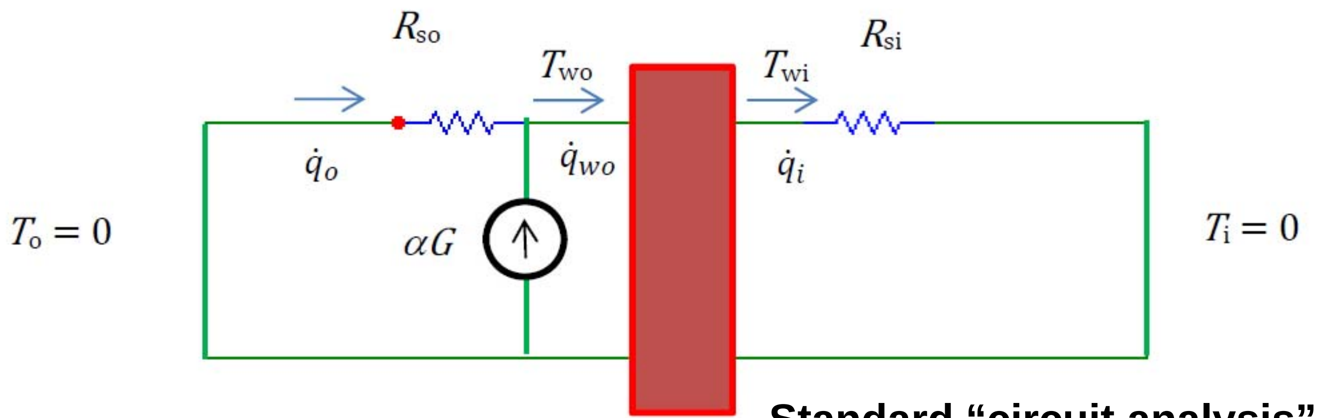
Solar radiation incident on external wall



Standard "circuit analysis".

$$T_{wo} = \alpha G\left(\frac{R_{so}Z_{wi}}{R_{so}+Z_{wi}}\right)$$

Examine impact of one source (αG) – set all other sources to zero (superposition).

$$\dot{q}_{wo} = \alpha G\left(\frac{R_{so}}{R_{so}+Z_{wi}}\right)$$

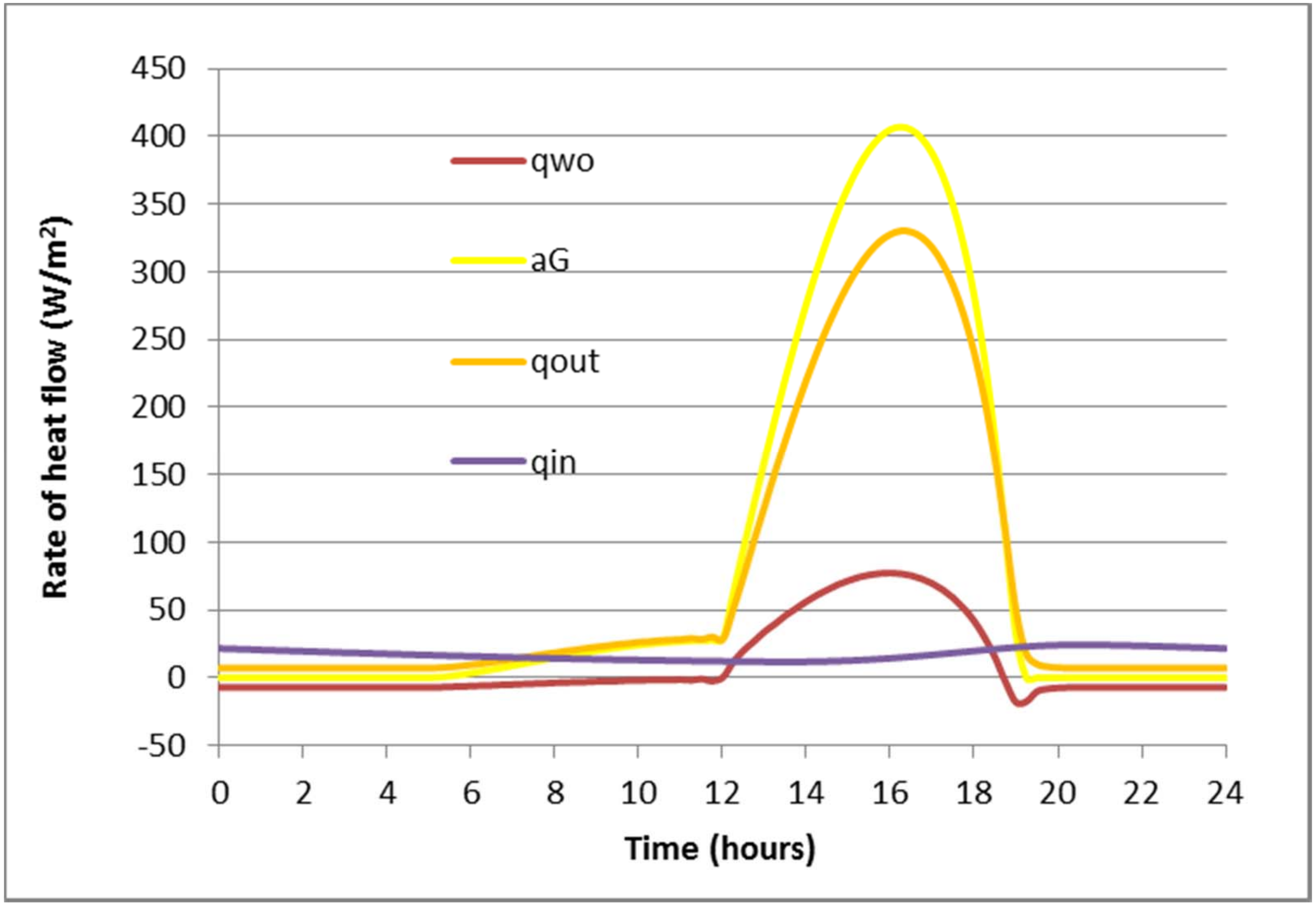
αG – acts as a "heat/current source"

$$\dot{q}_o = -\alpha G\left(\frac{Z_{wi}}{R_{so}+Z_{wi}}\right)$$

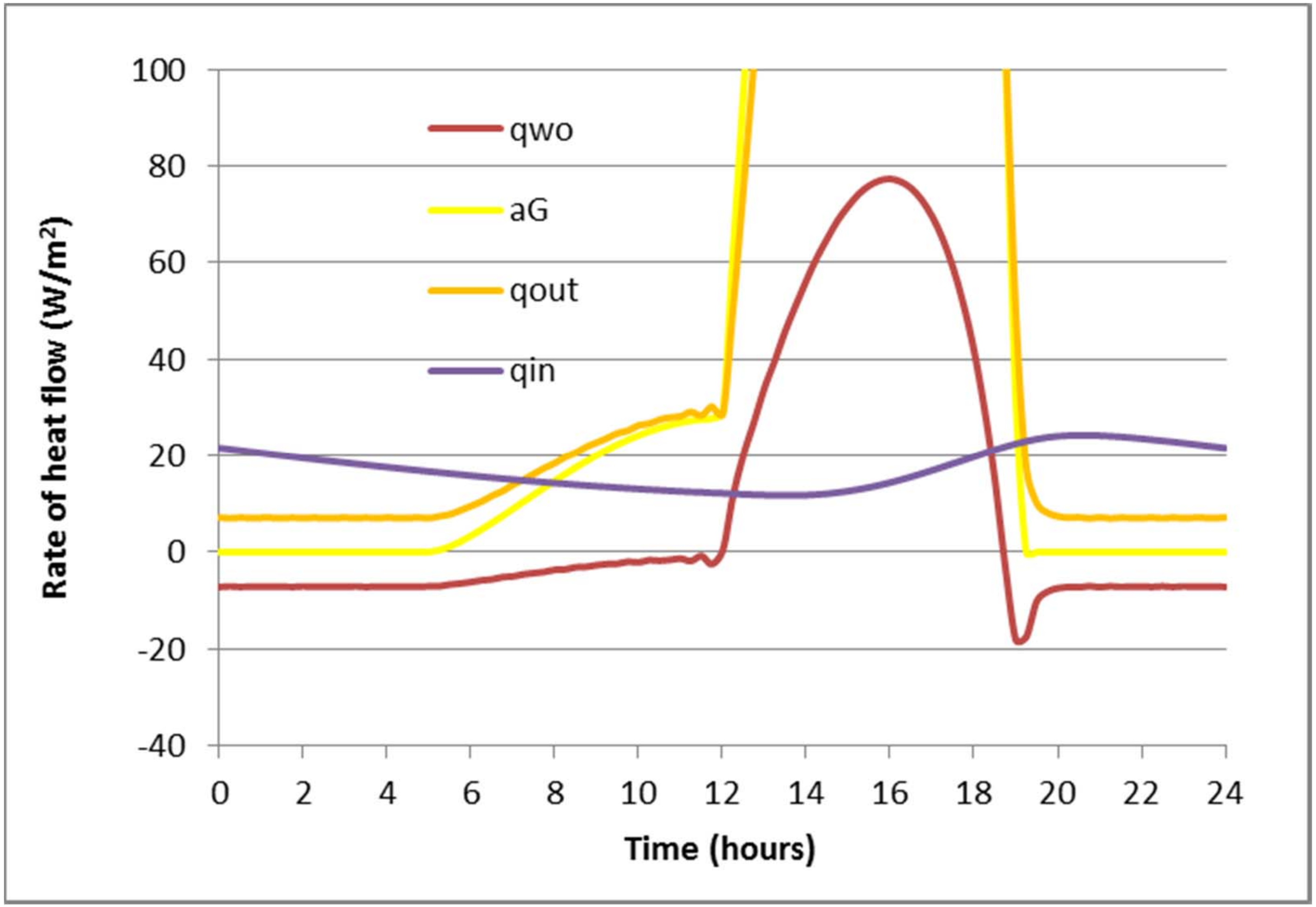
The thermal impedance from the outside surface of the wall to the inside is Z_{wi} (i.e. $1/Y_t$). This is in parallel with R_{so}.

Current divider. (Literature common nomenclature used - "surface factor".

Solar radiation incident on a western wall – concrete 200 mm Summer conditions



Solar radiation incident on a western wall – concrete 200 mm
Summer conditions



Heat flow into building

Average

17.4 W/m^2

Wall area: 200 m^2

Heat load per day:

83 kWh

Add external R value = 2 m^{2}K/W

Average

2.5 W/m^2

Heat load per day:

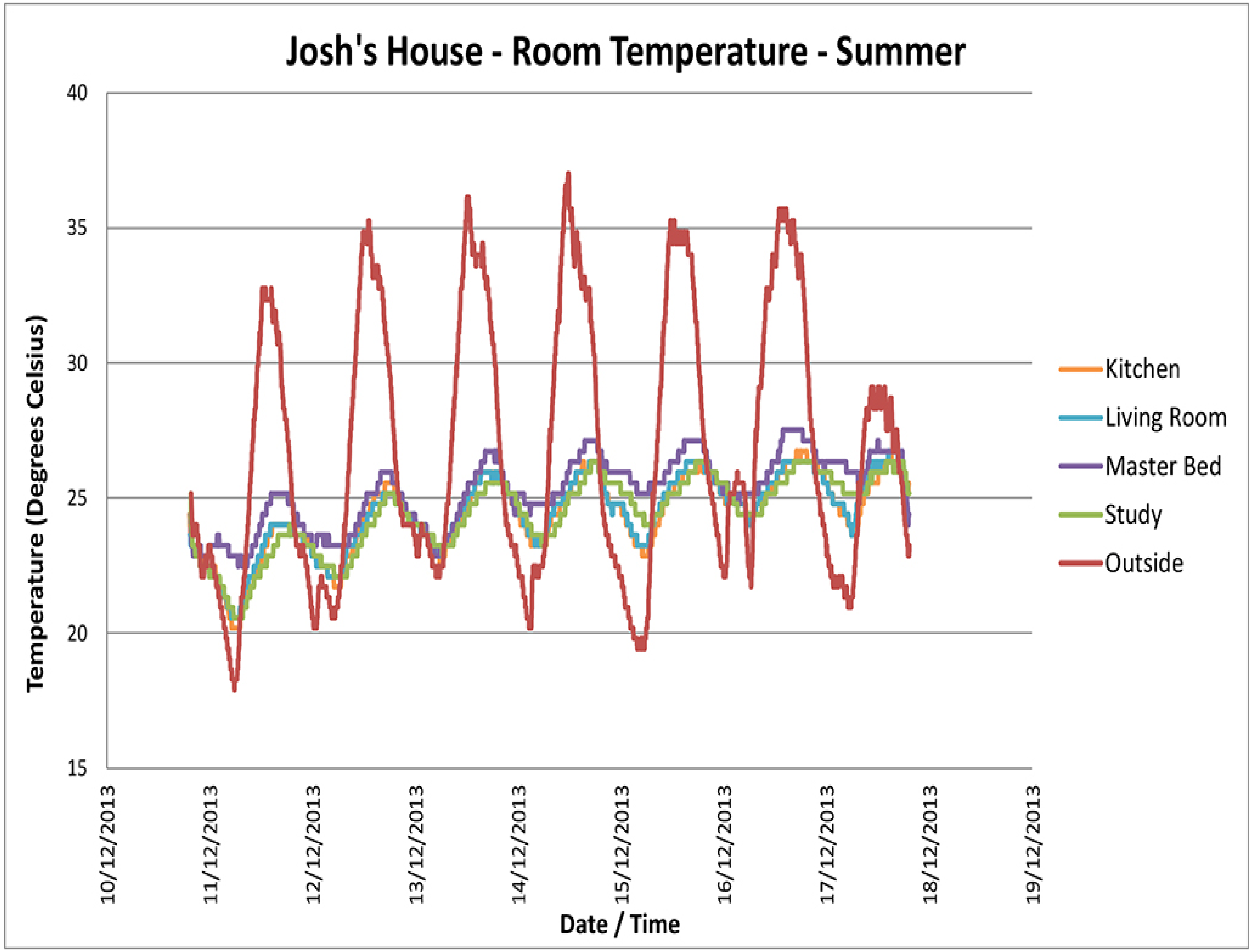
12 kWh

CRC Living Laboratory

- Award winning 10 Star Josh's House in Fremantle
- How well does the house perform?
- How best we can engage people in low carbon & energy efficient living?

http://joshshouse.com.au/

Monitoring - summer



Energy Use Breakdown

The breakdown of energy uses in the house compared to energy uses in a standard Perth residence[1] is presented in Table 3, and shown graphically in Figure 10. The proportionate breakdowns are very different, due to the presence of the various pumped water systems at Josh's House (rainwater, greywater and bore water), and the absence of mechanical heating and cooling.

Recently, the monitoring system was modified to allow the appliances to be divided into four separate circuits, which will allow for more detailed analysis of future data. This is important, because the appliances account for 50% of the energy consumption in the house. It will be beneficial to break this down further to obtain a more detailed energy use.

	Josh's House (kWh/day)	Perth Average (kWh/day)
Appliances	5.62	9.18
Lights	1.62	1.98
Cooking	0.85	0.54
Bore Pump	2.04	N/A
Rainwater System	0.67	N/A
Greywater System	0.35	N/A
Heating & Cooling	N/A	3.24
Water Heating	N/A	3.06

Table 3: Electricity end uses at Josh's House compared to Perth average

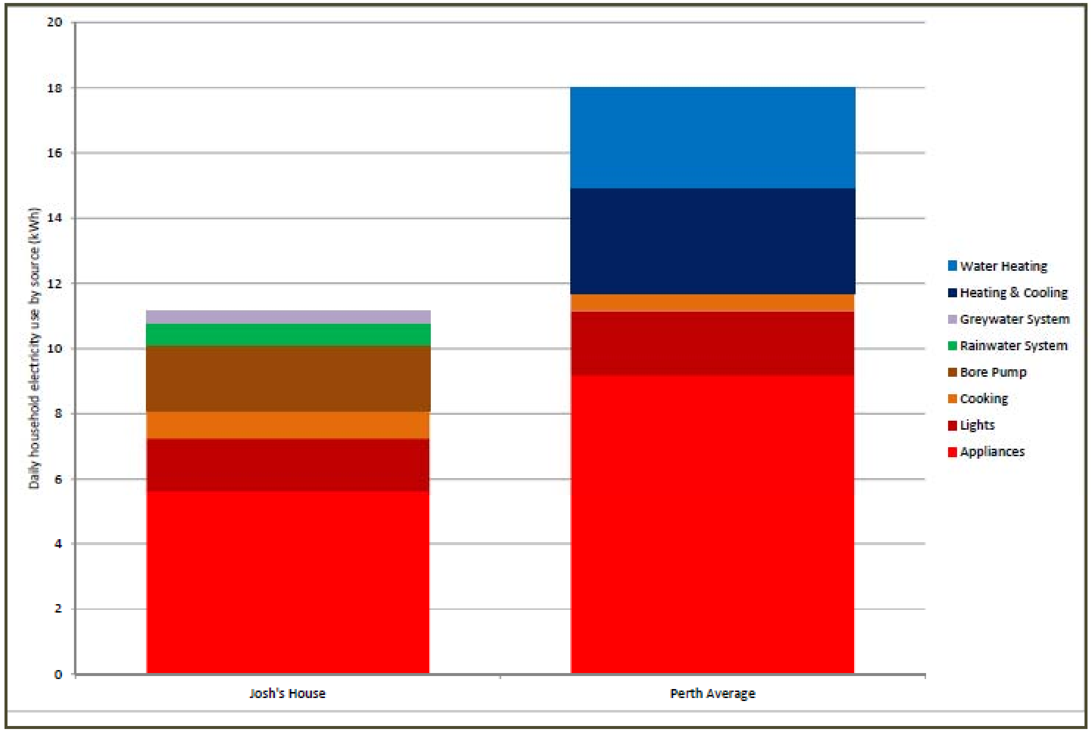
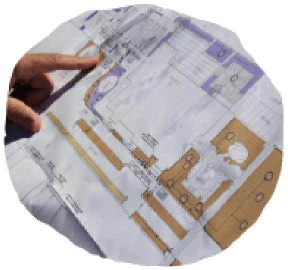


Figure 10: Proportionate energy use at Josh's House compared to the Perth Average

1 Source: Synergy: https://www.synergy.net.au/atôhome/deliveryôinôyourôhome.xhtml.



http://joshshouse.com.au/wp-content/uploads/2014/11/141121-JH-Year-1-Performance-Report-Design-Version.pdf

Cost Saving

On average the house consumes 11.15kWh per day. 5.48kWh of this is provided from grid electricity, with the rest (5.67kWh per day) being generated on-site. With an average daily PV generation of 15.4kWh per day, this means that 9.73kWh are exported to the grid each day, on average. The rebate for exported electricity to the Perth grid (Synergy) is $0.088529/kWh. This results in a daily rebate of $0.86, or an annual rebate of $314.41, which reduces the annual cost of electricity further, to $203.75, which is 88% lower than the average Perth household pays each year. This is shown in Figure 9.

The feed-in tariff for electricity exported to the grid is 8.8529c/kWh, whilst electricity imported from the grid is charged at 25.9052c/kWh. It is due to this unequal pricing that the house still pays for some electricity consumption, even though it is a net exporter of electricity.

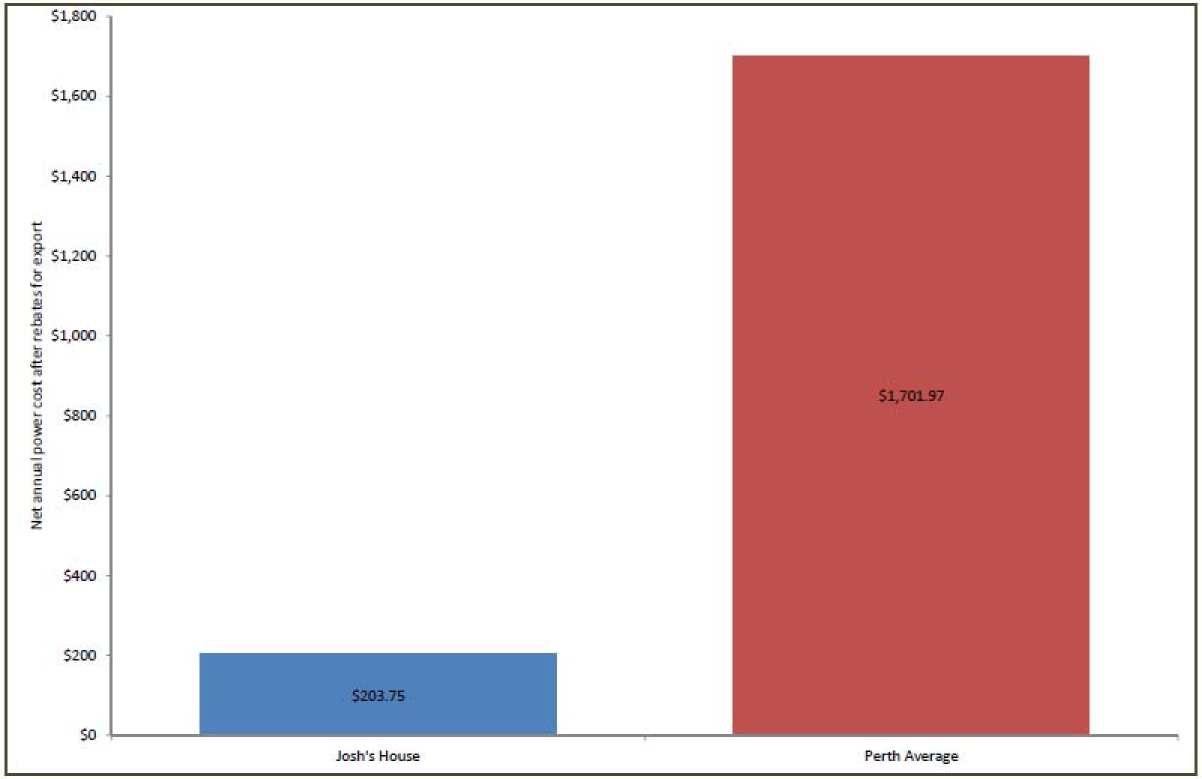


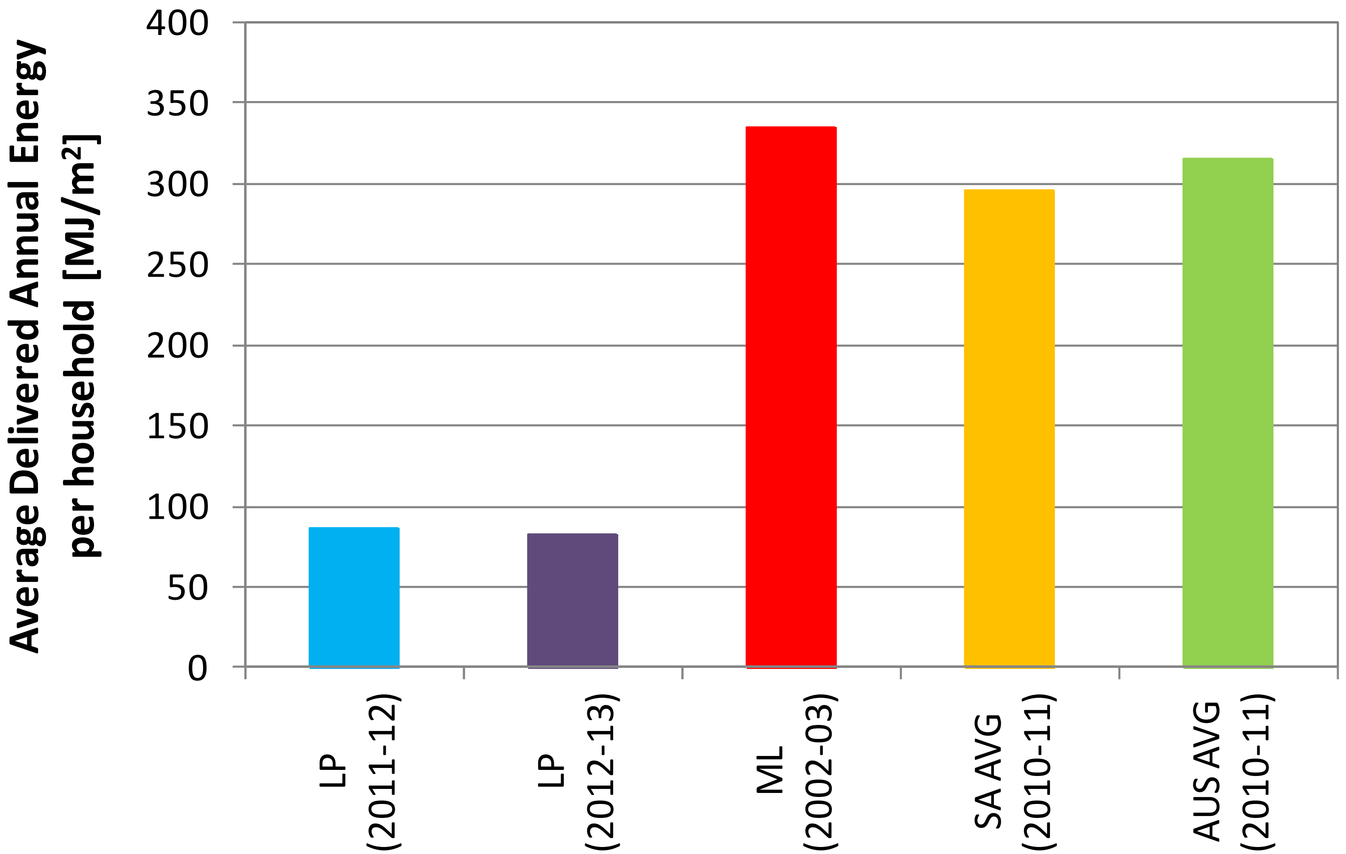
Figure 9: Annual cost of electricity (usage charges only), after rebates from exporting to grid

Lochiel Park – Adelaide, South Australia

Aim is to reduce non-renewable energy consumption by 66% and GHG emissions by 74% (measured against Adelaide average).

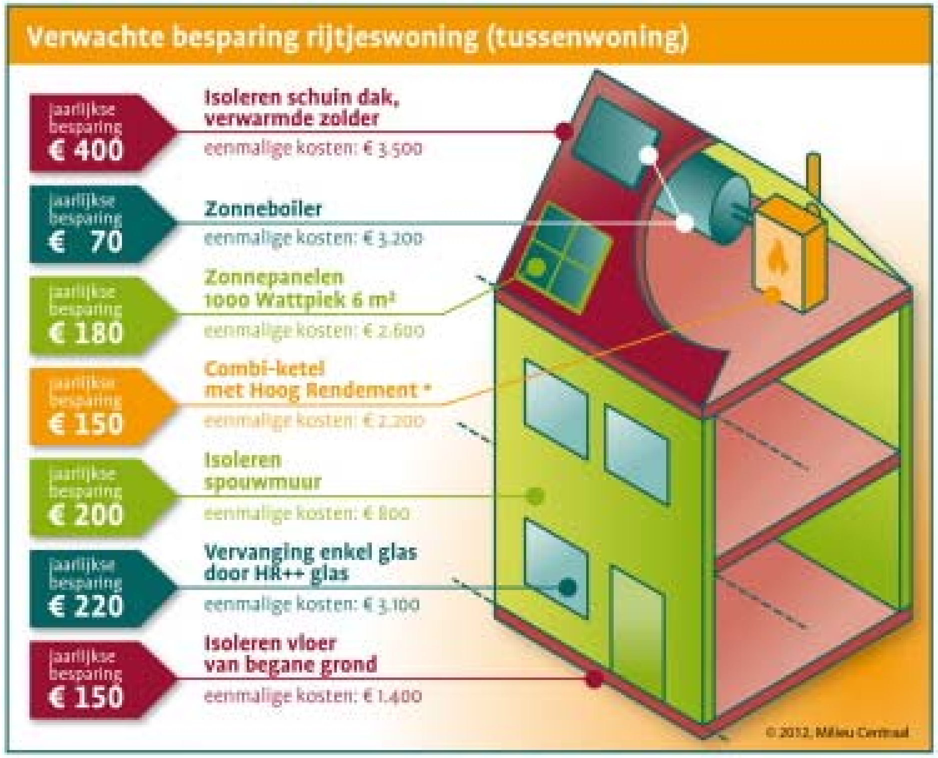
http://www.greenwayarchitects.com.au/lochiel-park-affordable-housing/

Lochiel Park



Comparisons of Lochiel Park (LP) house normalised total energy consumption against a sample of Mawson Lakes (ML) households, and both state (SAAVG) and national (AUSAVG) averages for delivered annual energy

Making Net Zero Energy refurbishments a market reality



De berekening is gebaseerd op een gemiddelde woning van dit type en gemiddeld huishouden (met 3 personen), bij een gasprijs van € 0,58 per m³ en een elektriciteitsprijs € 0,22 per kWh (2011-2012)
*) vervanging van een VR combi-ketel door een HR 107-combiketel.

http://energiesprong.nl/transitionzero/

- Energiesprong brokered a deal between housing associations and builders to refurbish 111,000 houses to Net Zero Energy (E=0) levels in the Netherlands. E=0 means, annually a house does not consume more energy for heating, hot water, lights and appliances than it produces. The refurbishments are financed by the energy cost savings; a refurbishment is executed within 10 days and comes with a 30-year energy performance warranty from the builder.

- Energiesprong's approach is based on organizing massive demand for a Net Zero Energy (E=0) refurbishment proposition, making financers and governments tune their financing offerings and regulations towards this product and challenging the construction sector to start an ambitious innovation process to deliver the proposition. The massive demand, the security that there will be financing and an enabling regulatory environment de-risks the innovation investment for the builders.

BEFORE & AFTER

- Public housing. Typical renovation costs about 50,000 to 60,000 Euros per dwelling, no cost to occupants, renovations completed in 10 days!
- Additional loan repayments covered by energy bills.

https://www.flickr.com/photos/111630915@N04/11419884295/in/set-72157638726631756

Residential electrical energy usage Sydney : SGSC data (2012 – 2013)

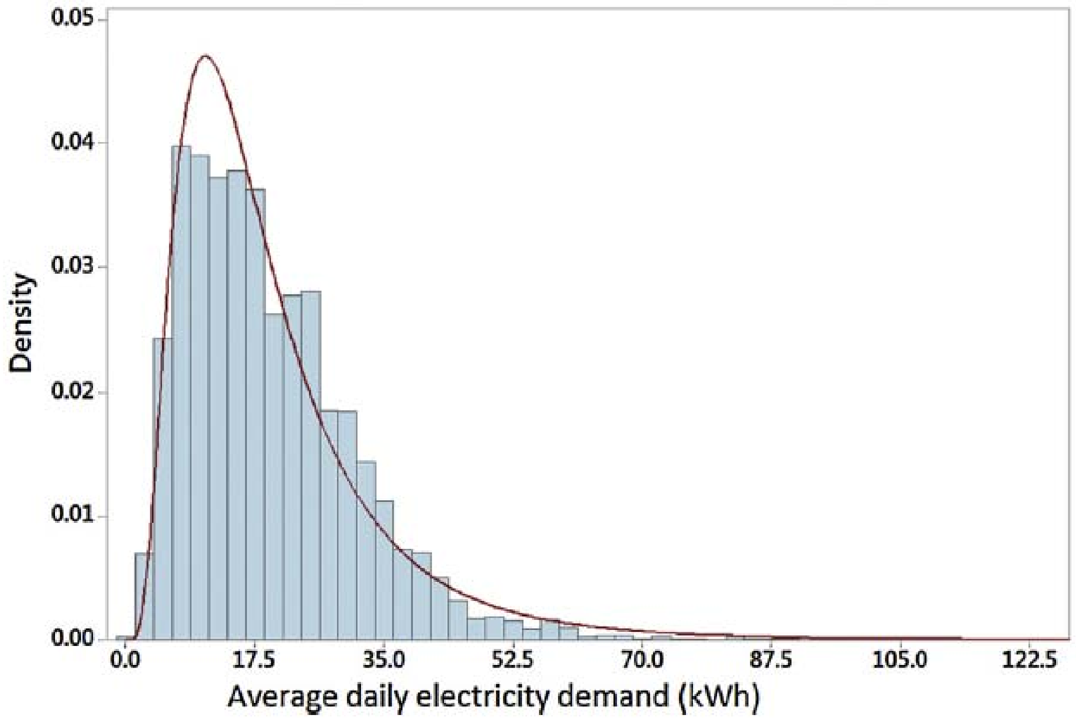


Fig. 2. Probability density distribution of the average annual daily electricity demand for the surveyed households.

Survey and data for ~3000 houses/units.

Average usage ~ 19 kWh/day per household (~ 7 tonnes CO_2 per year/household)

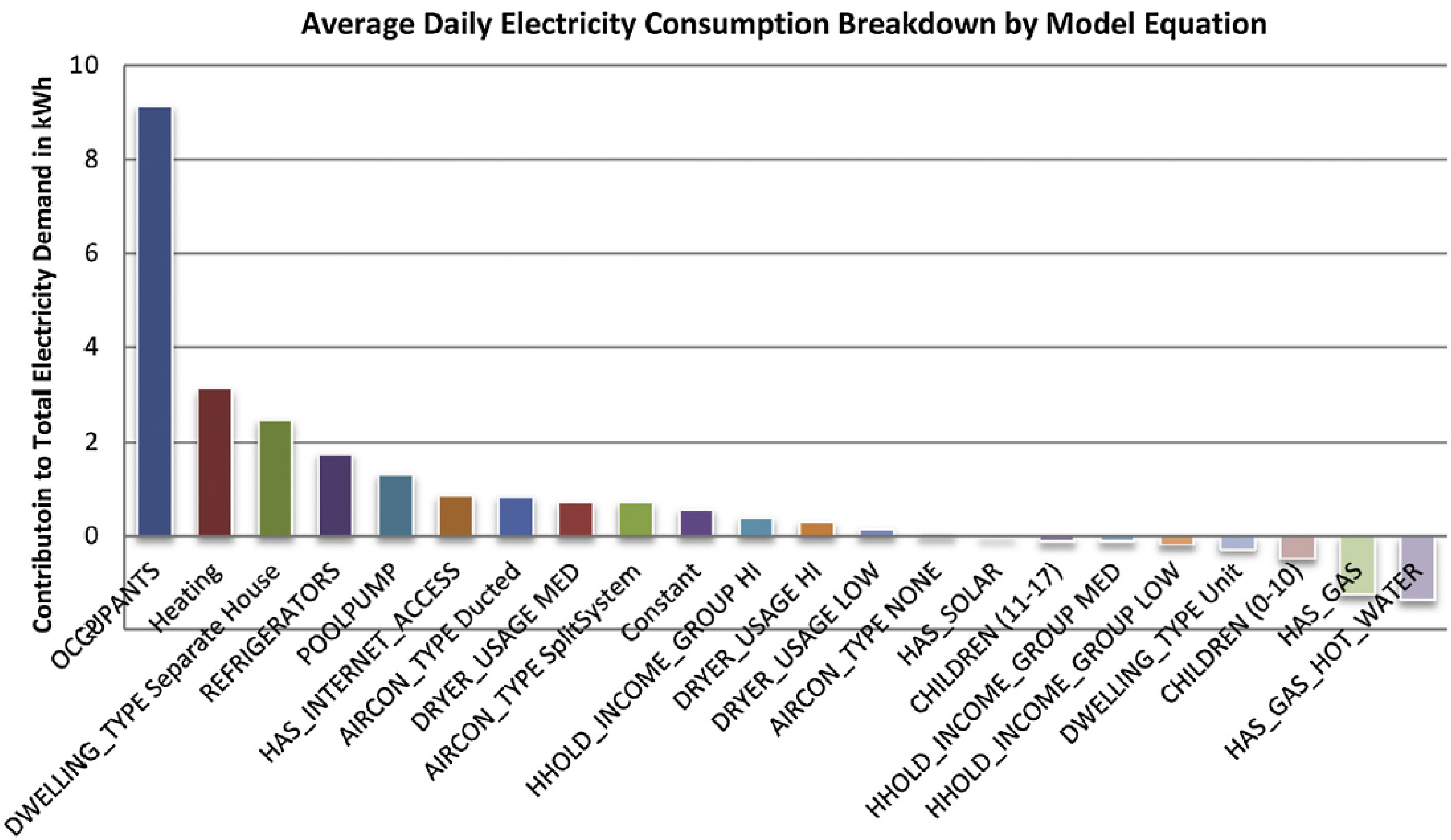
Maximum usage observed: 125 kWh/day

Statistical analysis of driving factors of residential energy demand in the greater Sydney region, Australia

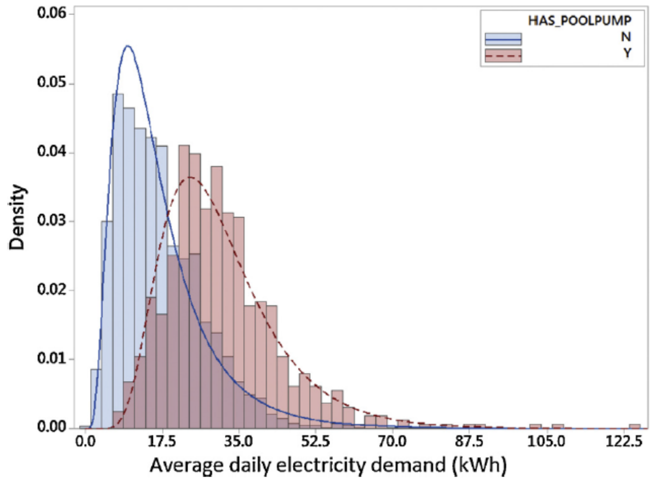
H. Fan[a], I.F. MacGill[b], A.B. Sproul[a,*]

Energy and Buildings 105 (2015) 9–25

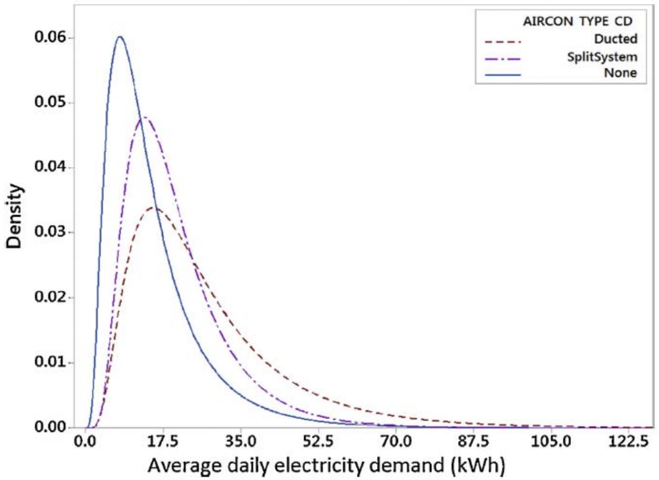
Modelled results



Pool & HVAC ownership



"Pool pump" ownership is a significant indicator of household electricity demand. About 15% of sampled households had a pool (and hence pool pump) and the annual average daily electricity demand of these households (31.2 kWh) was 93% higher than those without (16.9 kWh).



Almost three quarters of the surveyed households have "Air-conditioning" systems installed in their home, and primarily are smaller split systems (70%) or ducted systems (26%). There is a clear difference in daily electricity demand between households with and without air-conditioning systems, and, for those that do, by type of system: households with "Ducted" air conditioning (27.3 kWh) use on average 79% more electricity than households with no air-conditioning – "NONE"(15.2 kWh, σ = 10.1 kWh); while households with a "Split System"(20.4 kW h, σ = 10.4 kW h) on average consume 34% more electricity than households with no air-conditioning.

Correlation between HDD/CDD and electricity usage for Sydney (2012 – 2013)

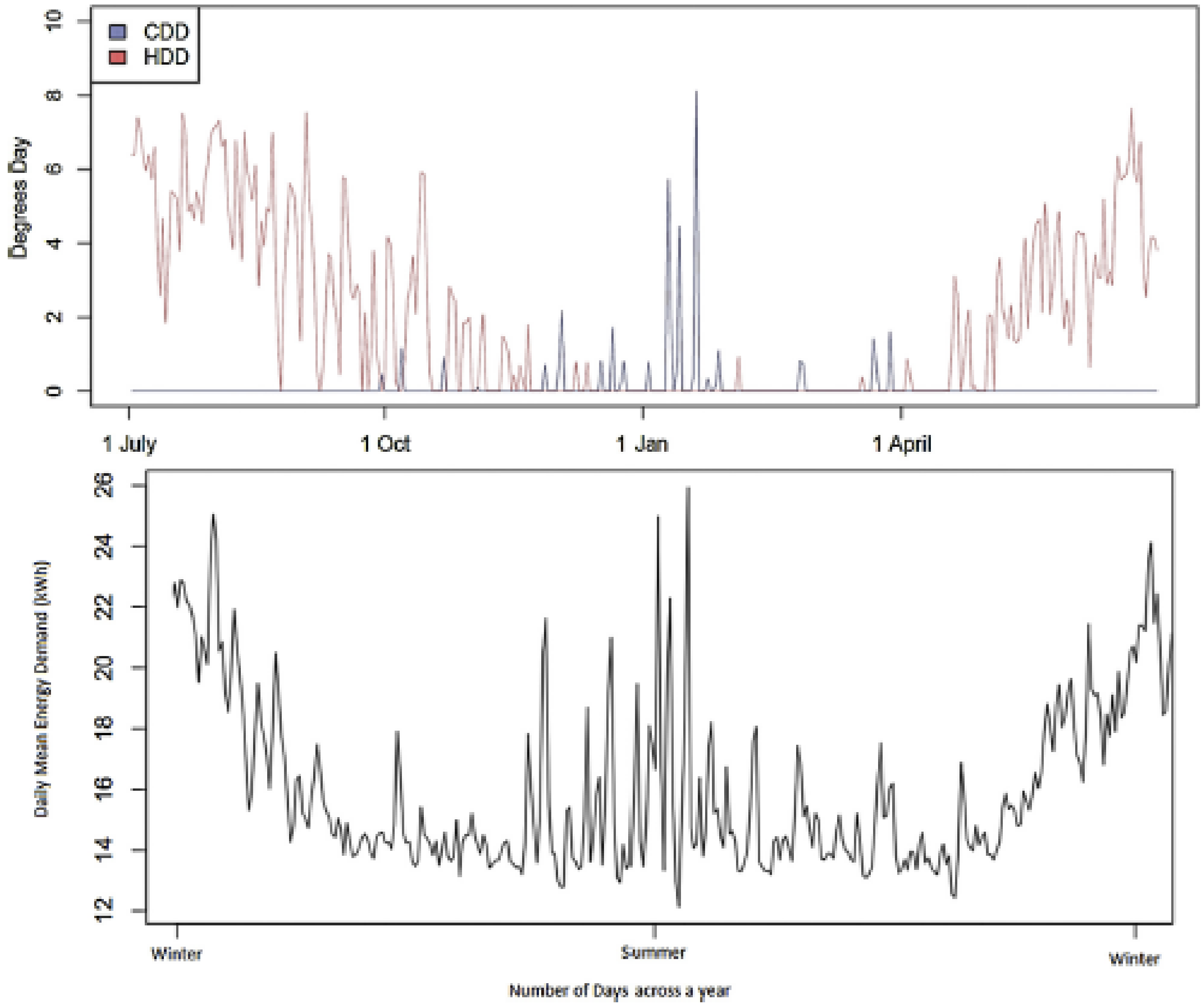
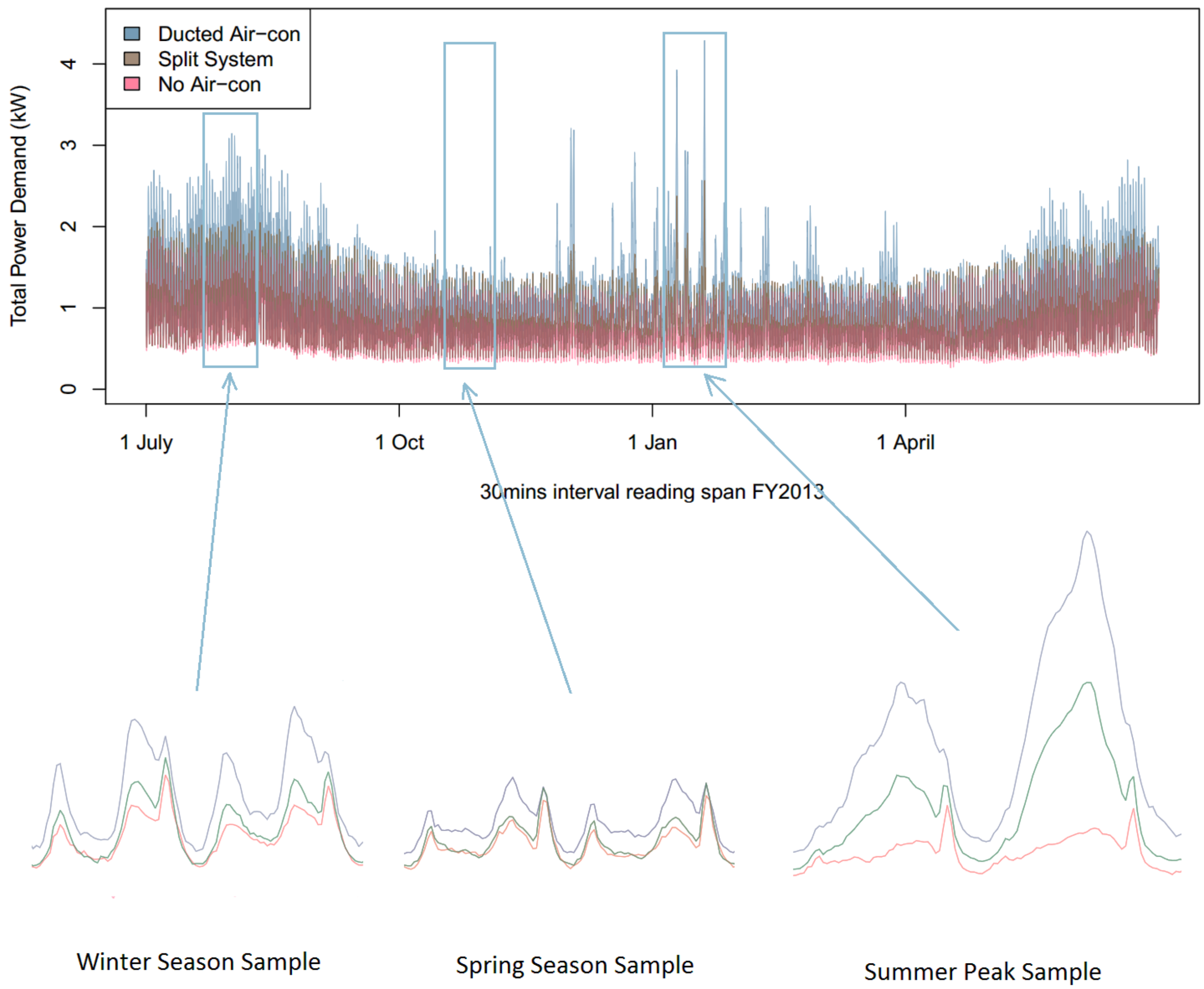


Fig. 4. Average daily CDD, HDD for sampled households in FY2013 (top) and daily average household electricity demand for all across the year of analysis (bottom).

Heating demand is a major driver of electricity usage over the year

Cooling demand drives spikes in electricity usage in summer


Ducted Air−con
Split System
No Air−con
Total Power Demand (kW)
0
1
2
3
4
1 July
1 Oct
1 Jan
1 April
30mins interval reading span FY2013
Winter Season Sample
Spring Season Sample
Summer Peak Sample

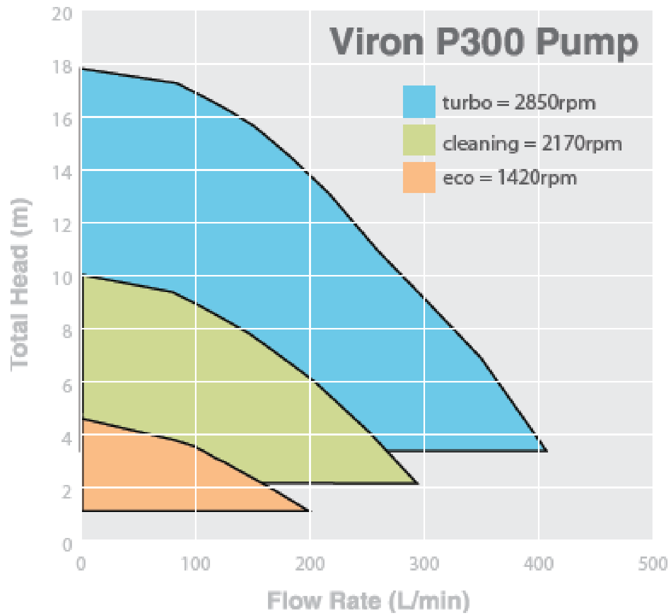
Most efficient reverse cycle AC currently available in Australia

INDOOR UNIT		FTXZ25NV1B	FTXZ35NV1B	FTXZ50NV1B
OUTDOOR UNIT		RXZ25NV1B	RXZ35NV1B	RXZ50NV1B
Rated Capacity	Cool (kW)	**2.5**	**3.5**	**5**
	Heat (kW)	**3.6**	**5**	**6.3**
Capacity Range	Cool (kW)	0.6-3.9	0.6-5.3	0.6-5.8
	Heat (kW)	0.6-7.5	0.6-9.0	0.6-9.4
Indoor Airflow Rate (Hi)	Cool (l/s)	177	203	250
	Heat (l/s)	195	221	240
Star Ratings	Cool	7	5.5	3.5
	Heat	7	5.5	4.5
Power Input (Rated)	Cool (kW)	0.42	0.68	1.18
	Heat (kW)	0.62	0.99	1.37
E.E.R./C.O.P.	Cool/Heat	5.95/5.81	5.15/5.05	4.24/4.60
A.E.E.R./A.C.O.P.	Cool/Heat	**5.90/5.77**	**5.12/5.03**	**4.23/4.59**

http://www.daikin.com.au/us7

http://reg.energyrating.gov.au/comparator/product_types/64/search/

Multispeed and variable speed pumps now in the Australian market
Up to 9 star efficiency!



Three speed pump – significant energy savings.
Reduce energy by more than 5 kWh/day

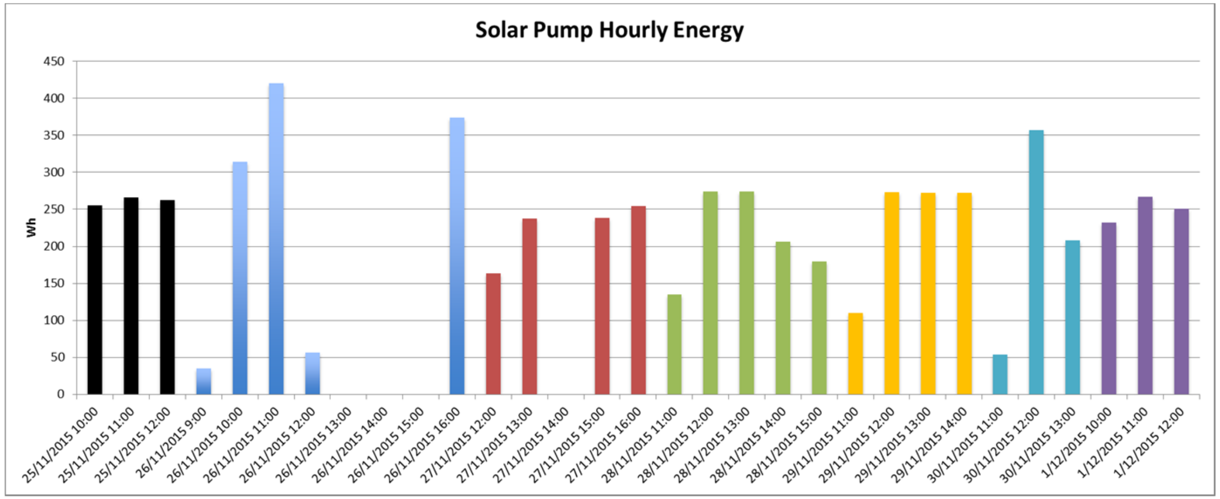
http://astralpool.com.au/products/viron-p300-pump-0

Pool heating – very energy

Heating types			
	Solar pool heating	Heat pump pool heating	Gas pool heating
Estimated daily energy usage[1]	6kWh	43kWh	786MJ
Estimated weekly energy cost[2]	$11 to $16 (Inclining Block Tariff) $5 (Time of Use – Off Peak) $9 (Time of Use – Shoulder) $22 (Time of Use – Peak)	$81 to $114 (Inclining Block Tariff) $40 (Time of Use – Off Peak) $65 (Time of Use – Shoulder) $159 (Time of Use – Peak)	$105 to $180
Greenhouse Gas Emissions (kg per week)[3]	45kg	321kg	360kg

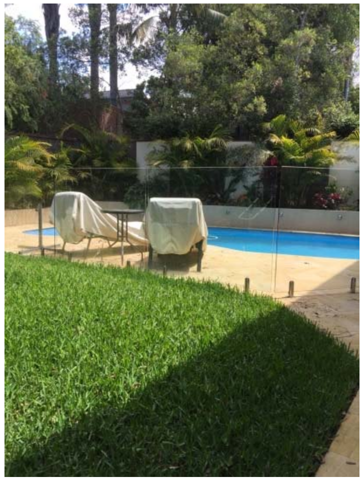
http://www.ausgrid.com.au/~/media/Files/Customer%20Services/Homes/Energy%20Efficiency/Ausgrid%20Swimming%20Pool%20brochure%202015.pdf

Solar pool heating: initial results



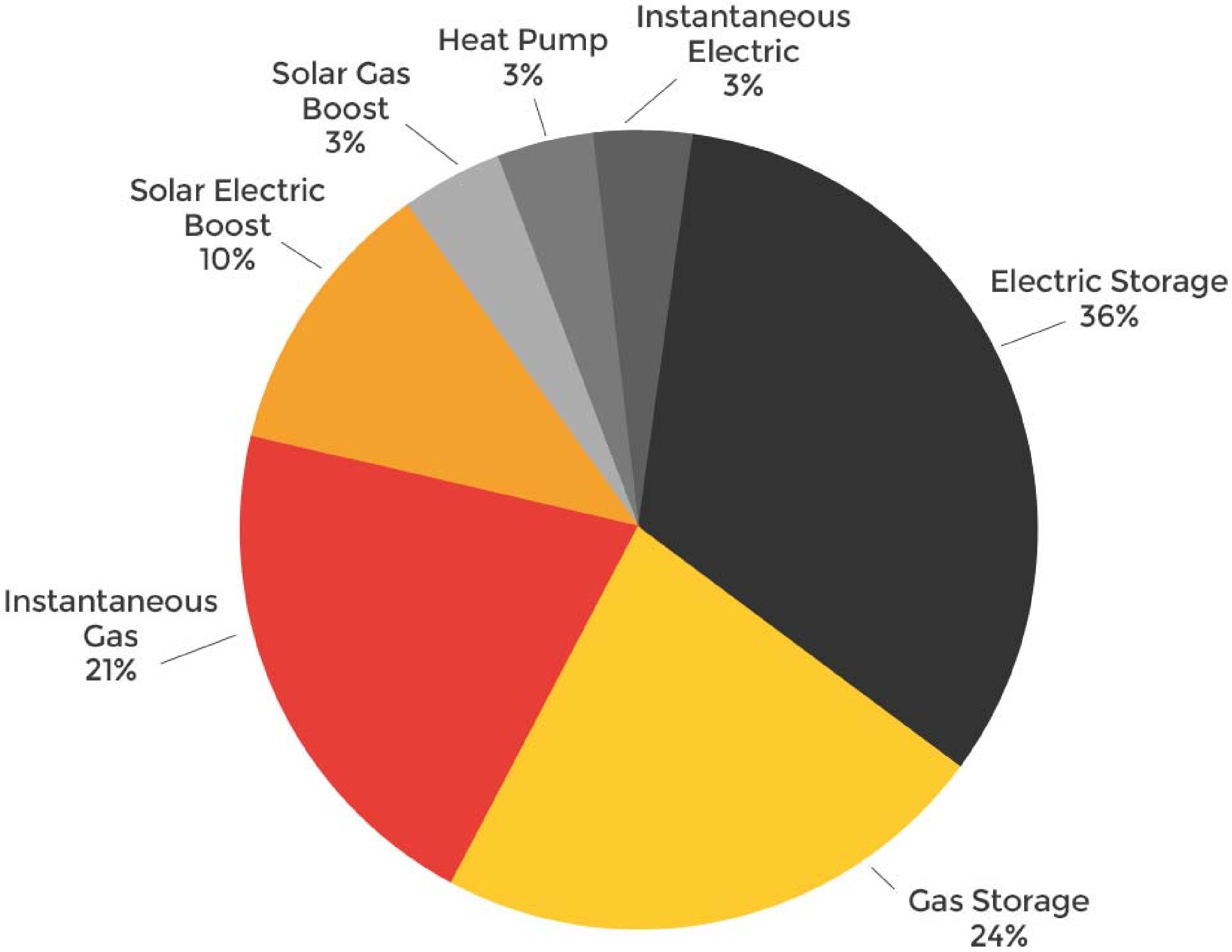
Average daily pump energy required:

0.9 kWh/day



Solar heating system using a Viron p280 – 3 speed pump

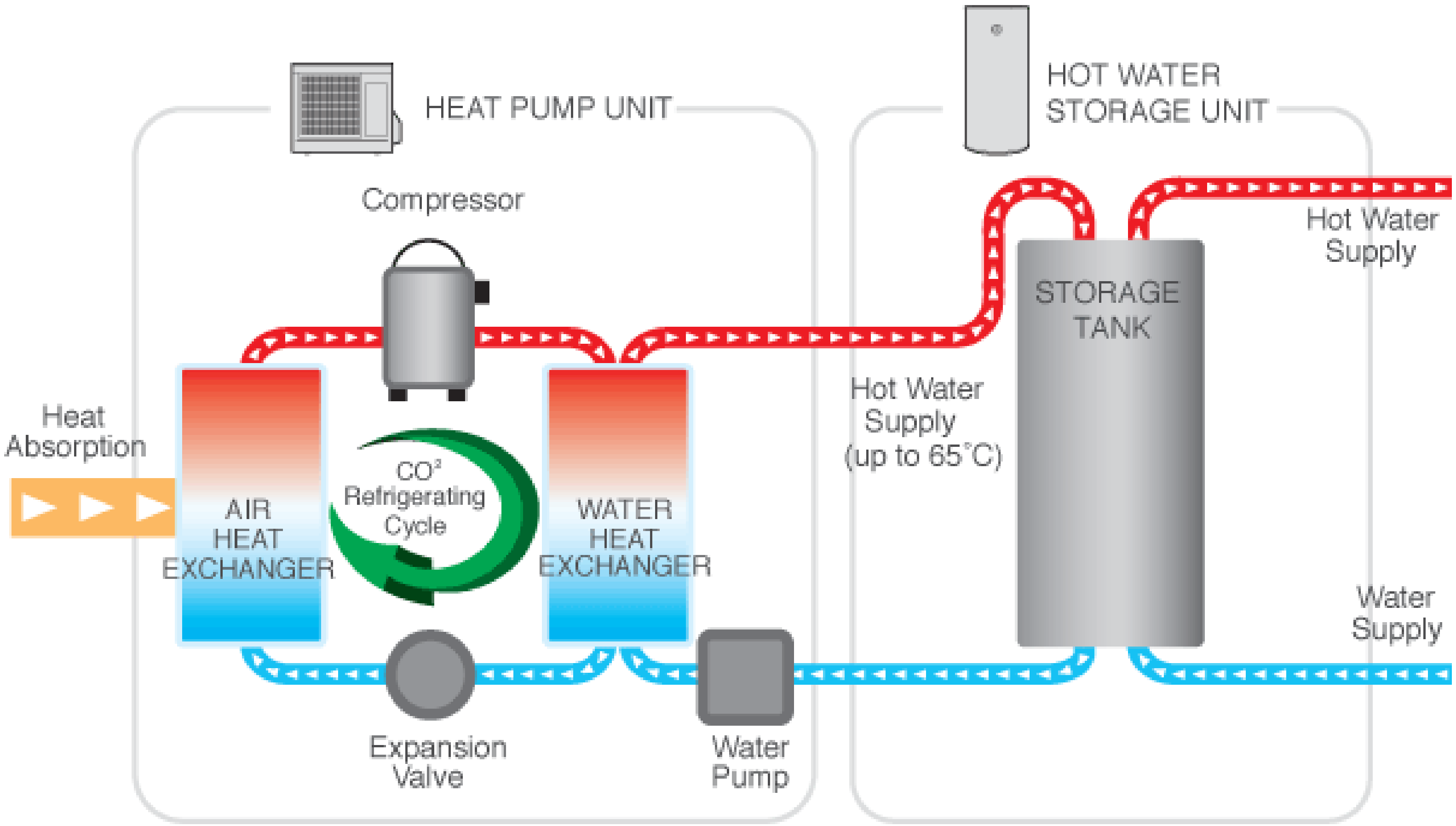
Penetration of hot water heaters, Australia, 2014



Source: BIS Shrapnel, The Household Appliances Market in Australia, 2014

Heat pump hot water

Sanden: They use a CO_2 refrigerant, COP = 4.5



https://www.sanden-hot-water.com.au/about-the-eco

Running costs for hot water systems in Sydney

Instantaneous gas

Pros: no storage losses, unlimited hot water!

Cons: Gas costs Sydney 3.5 c/MJ - 12.6 c/kWh. Efficiency 60% - condensing systems over 90%.

Solar Hot Water

Pros: ~80% solar fraction, can be backed up by off-peak.

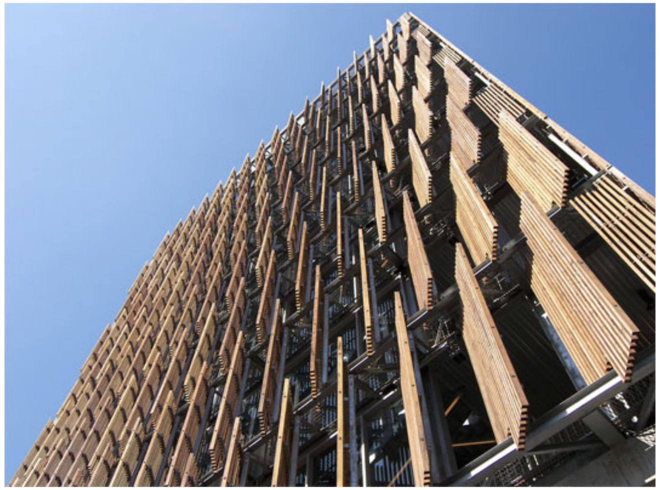
Cons: Back up required, better if forecasting is available. Capital costs higher than conventional

Heat pump

Pros: ~80% ambient fraction (COP = 4.5!), can be backed up by off-peak or PV (15 c/kWh) (thermal storage – delivered cost 3.3 c/kWh).

Cons: Back up required, better if forecasting is available. Capital costs higher than conventional

6 Star commercial and beyond



CH2 – 6 star Green Star - Melbourne

1 Bligh St – 6 star Green Star - Sydney

TETB UNSW – 6 star Green Star - Sydney

Pixel building. Highest LEED score world-wide. Melbourne

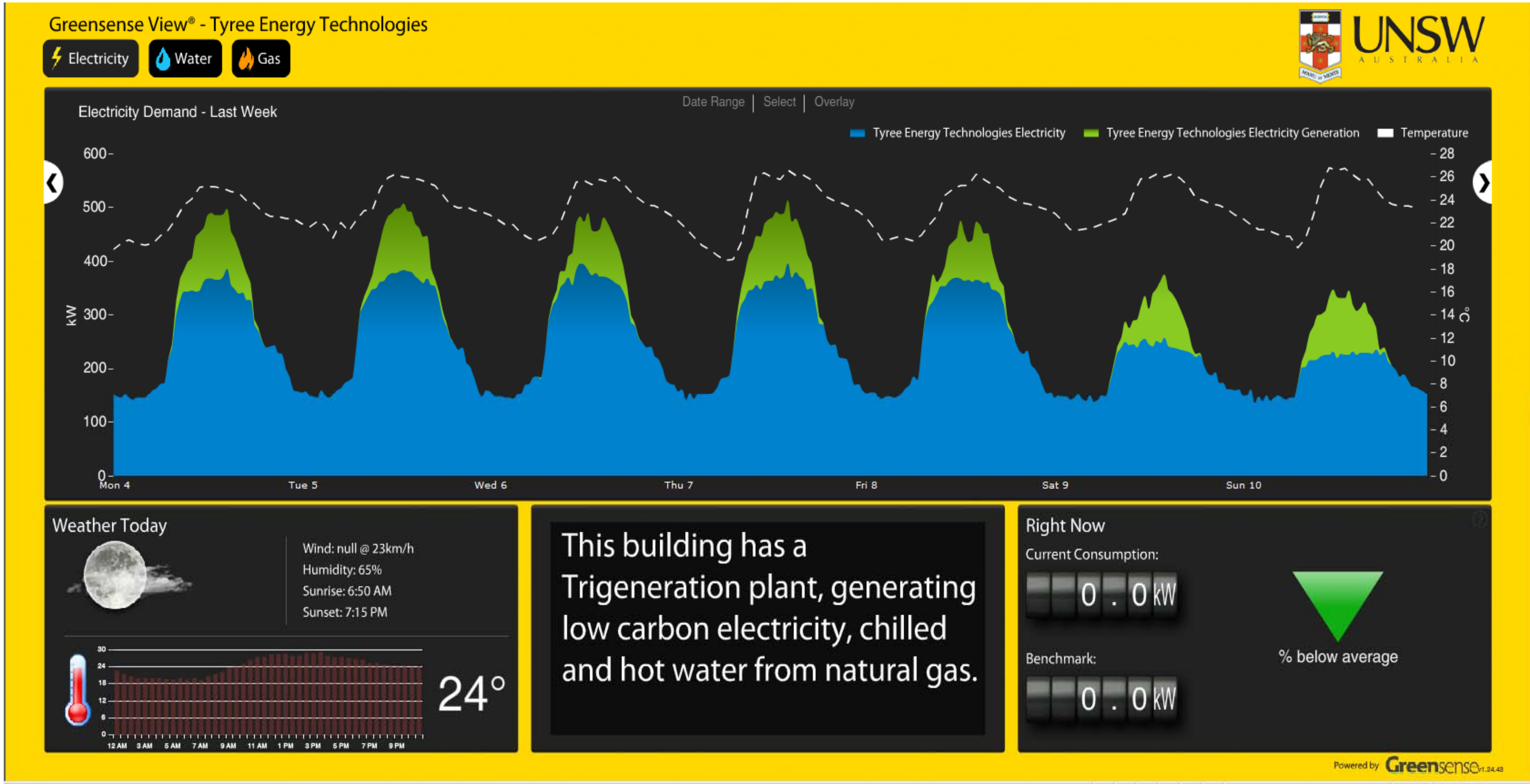
5 star residential

Central Park – 5 star NatHERS residential - Sydney

Haymarket Metro Plaza – 5 star NABERs and Green Star Multi-unit Residential & Retail - Sydney

UNSW Tyree Energy Technology Building - 6 star Green Star, 150 kWp PV array

UNSW TETB Electricity - Mar 4 – 10, 2013



http://www.facilities.unsw.edu.au/campus-development/sustainability-campus/greensense-live-energy-project

Conclusions

- Residential energy efficiency – significant resource that could be “mined” if we wanted to cost effectively reduce household electricity bills and reduce carbon emissions.
- 70% reductions have been modelled and demonstrated – typically ~8 year payback.
- Thermal performance of buildings is poor in Australia – can we retrofit better envelopes cost effectively – particularly insulate walls, improve glazing and shading?
- HVAC systems are improving all the time – COPs approaching 6 but we need more efficient homes OR large more efficient HVAC units.
- PV and high COP HVAC – precool buildings on hot days – ramp down demand and help reduce evening peak.
- Can we find ways to improve existing ducted systems? Zoning? Better insulation for ducting, minimizing heat gains into HVAC ducting particularly during peak.
- Pools – lets’ not avoid peak by simply shifting when pool pumps are running – variable speed or multiple speed pumps can lower energy significantly (and quietly!)
- PV – heat pump hot water- lower running costs than gas (but not off peak heat pump). Possibly lower life cycle costs than solar thermal hot water? Thermal storage for PV!

Acknowledgements

- This research was funded by the CRC for Low Carbon Living Ltd supported by the Cooperative Research Centres program, an Australian Government initiative.

- There are many more projects currently underway in this space - please see: http://www.lowcarbonlivingcrc.com.au/

- I would also like to acknowledge all of my colleagues and students who have been involved in various elements of the research described here particularly: Hua Fan, Iain MacGill, Jianzhou Zhang and Ted Spooner.

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