
This is a modified version of a series of talks I have given with some extra & updated slides and many notes that I verbally explained in the talks.

# Introduction

Current thinking is that “cool roofs” are not appropriate in southern Australia because they increase energy useage.

Our work proves this is wrong because nobody considers electricity usage of reverse cycle airconditioners at different ambient temperatures.

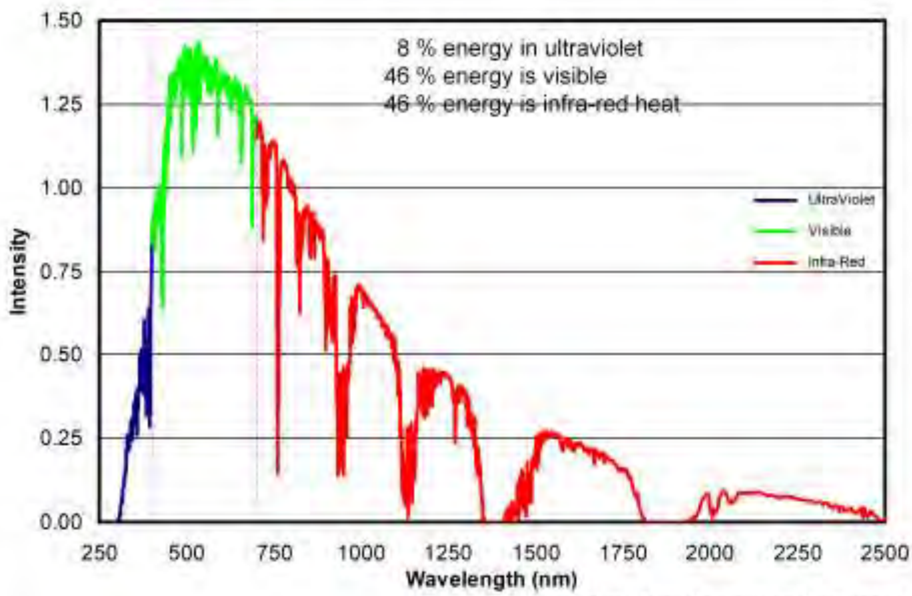
**Your** airconditioner is the main reason that electricity prices go up and up, not only because of peak demand costs but also because of the required infrastructure.

Our work at UniSA shows that R-values of *total roofs* are nowhere as high as that of the insulation batts used.

The results here show the importance of high Total Solar Reflectance, the percentage of the Sun’s energy reflected at a surface.

# Total Solar Reflectance (TSR)

TSR is the reflectance of a material for the total solar spectrum. Reflectance of infrared heat to 1100 nm is important in reducing total sunlight absorption




*derived from Renewable Resource Data Center spectral data*

The ability to reflect the Sun's energy at wavelengths greater than 1100 nm is not so important as there is only a relatively small amount of energy in total at those longer wavelengths.

# Cool Roofs

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- "Cool roofs" have high (or highish) reflectance of sunlight energy. The invisible ultraviolet and infrared components of sunlight are included in this. Cool Roofs do not necessarily have to be "heat reflective"
- It is generally preferable to opt for roof colours that absorb less of the Sun's radiation.
- That minimises roof surface temperature increases and means the roof insulation system becomes less critical.
- At UniSA, we have undertaken a study to understand surface reflectance effects whilst doing work for a National Climate Change Adaptation Research Facility report.

The final report can be found at https://www.nccarf.edu.au/sites/default/files/attached_files_publications/Saman_2013_Adapting_households_to_heat_waves.pdf

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# Roof colour fashion

It is currently “fashionable” to have roof colour as dark as possible, with a recent move to jet black.

Older white roofs

New black roofs

The fashion for darker roofs started just after 2000 but the last year or so there has been a slight shift back to lighter coloured roofs.

# Issues of interest

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Annual energy use for a resident's heating and cooling and the yearly total.

$CO_2$ emissions.

Both of these flow directly from house heating and cooling electricity (or gas use) in maintaining indoor temperatures at comfortable levels.

Peak electricity loads during hot spells where, in SA, about 23 hours per year contribute to 45 % of wholesale generation costs. It feeds through to SA residents paying the highest rates in Australia.

Additional to generation costs, more distribution and transmission capital expenditure has to be recouped over a number of years, increasing bills.

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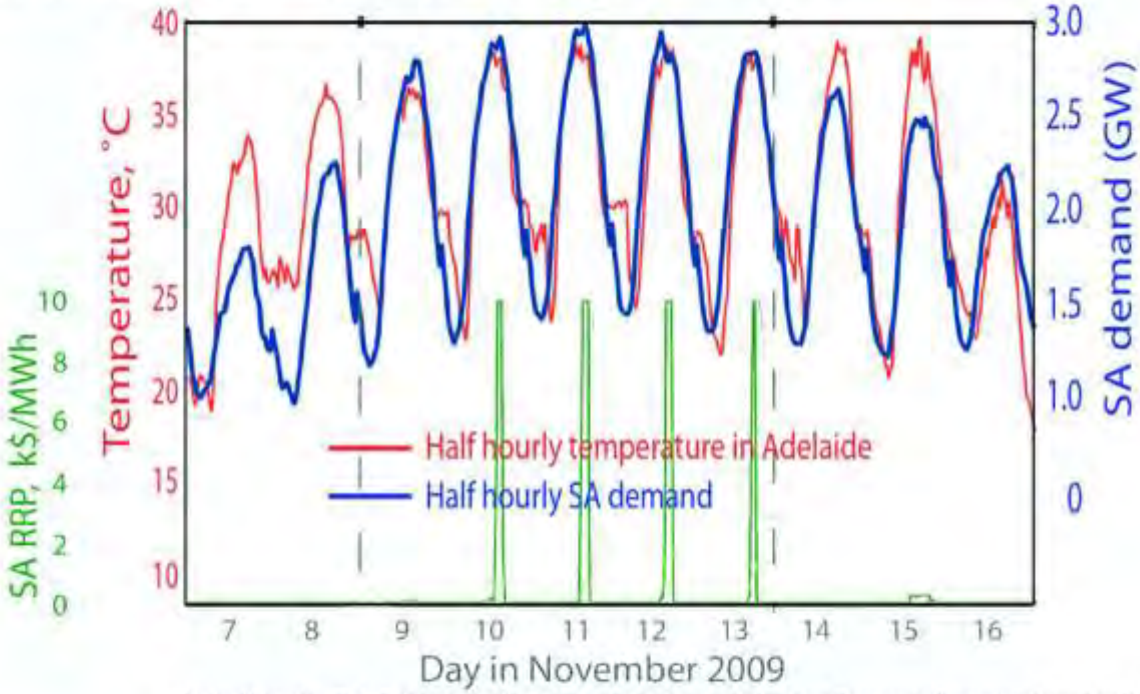
# Peak electricity in hot spells

Spikes are now allowed to go to $14,200/MWh under so-called "free market" conditions but the normal cost for over 99 % of the year is normally only about $30 to $40 per MWh.




*derived from Dr. Rob Dickinson's "Optimising Wind Power Production Economics" presentation, Aug 2012*

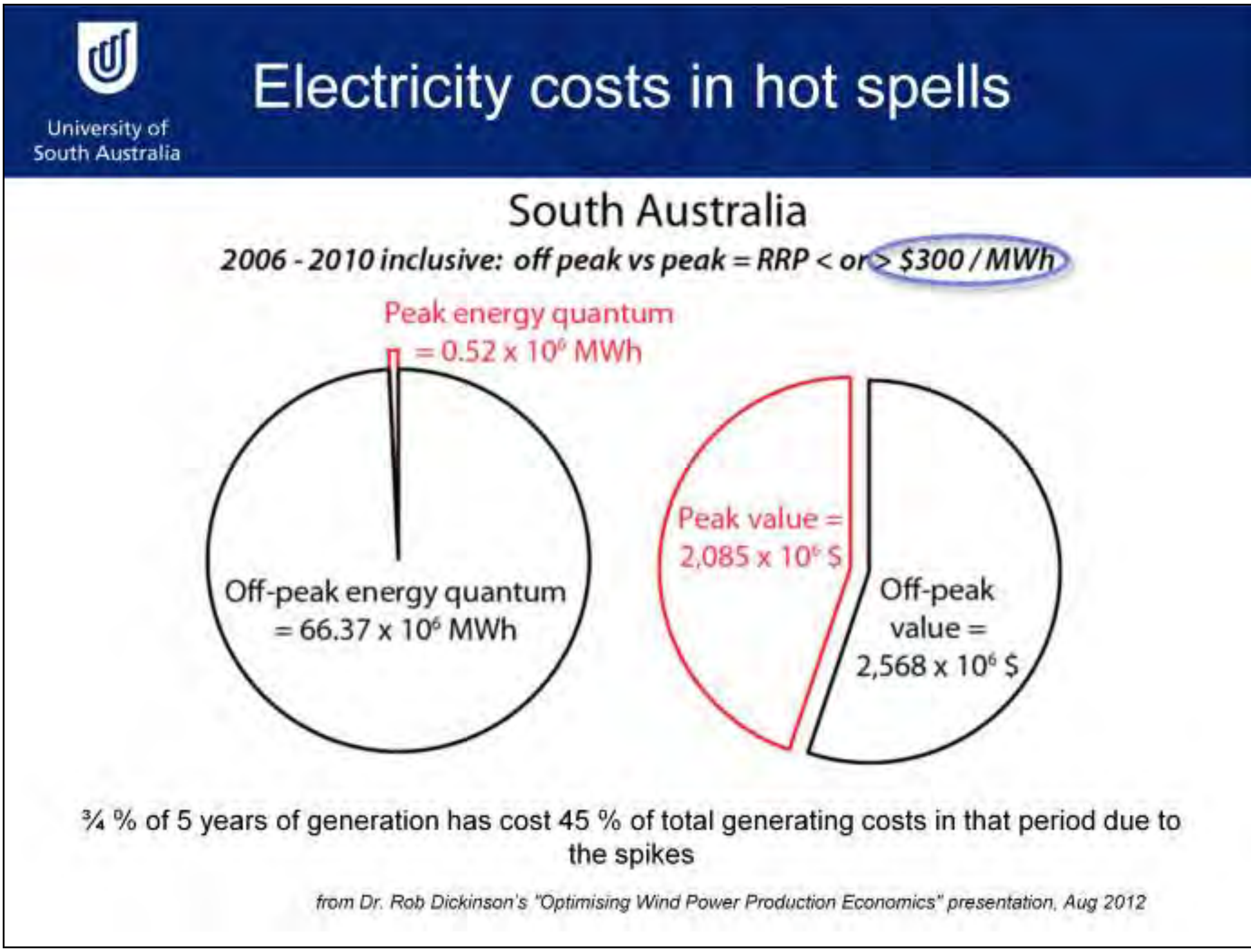
There is a close relationship between ambient temperature(red) and the state-wide demand (blue) for generating electricity.

The term "Base Load" is a term originally from the nuclear electricity because nuclear power plants run best at constant output but it can be seen here that the actual need is for highly varying output. Nuclear just doesn't cut it here.

The dips within a 24 hour period mean the daily minimum can be as low as 40 % of that day's peak. The need in power generation is for "Dispatchable Power". This is aside from where we get the electricity: coal, gas driven, photovoltaics, wind, hydro or batteries.

The spikes in generating costs (green) are caused by generators deciding to withhold from bidding in AEMO's "free market" knowing temperatures will be very high and waiting until the "market price" rises to the Market Price Cap. In 2009 that was $10,000 but, as of  July 2018, it is $14,500.

In particular, generators who are also retailers (gentailers) can game the system to maximise their profits. The Finkel Report "**Independent Review into the Future Security of the National Electricity Market - Blueprint for the Future**" also mentions this aspect but little is done in the recommendations to counter it..

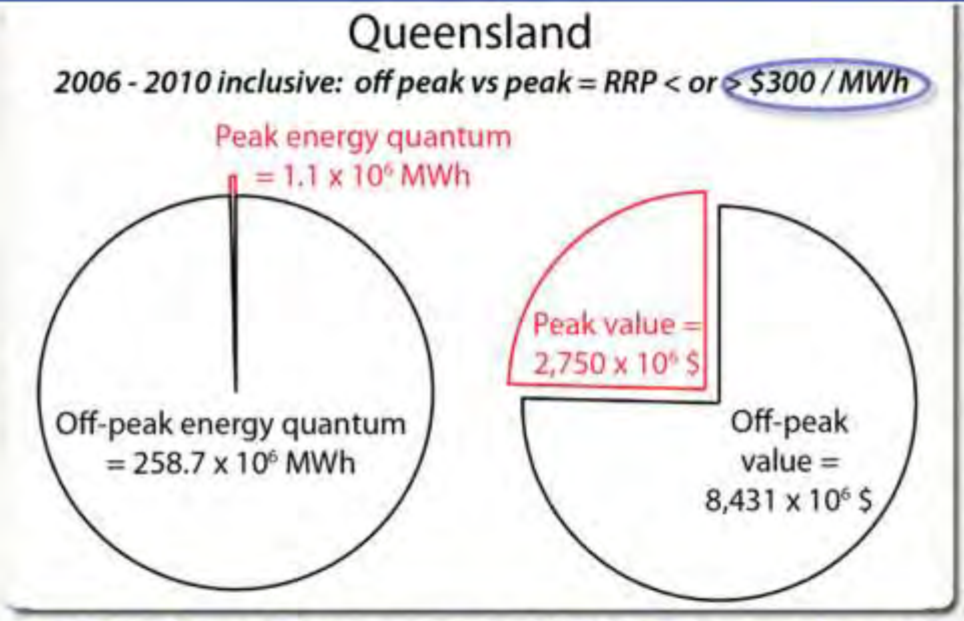



These are only the direct generation costs of about 7-8 cents/kWh. At retail level, distribution (poles, wires & transformers) is half of our bills and intrastate & interstate transmission costs are roughly 10 % with retail costs and profits making up the rest.

Distribution & transmission upgrades mean a normal split or ducted reverse cycle airconditioner costs the community about $7000 that everyone else has to pay over the lifetime of the unit. The unit itself may have cost you say $2,000 for a split system or $6,000 – 8,000 for a ducted system but the community has to bear the extra costs. The $7,000 comprises a mix of higher generating, distribution and transmission costs.

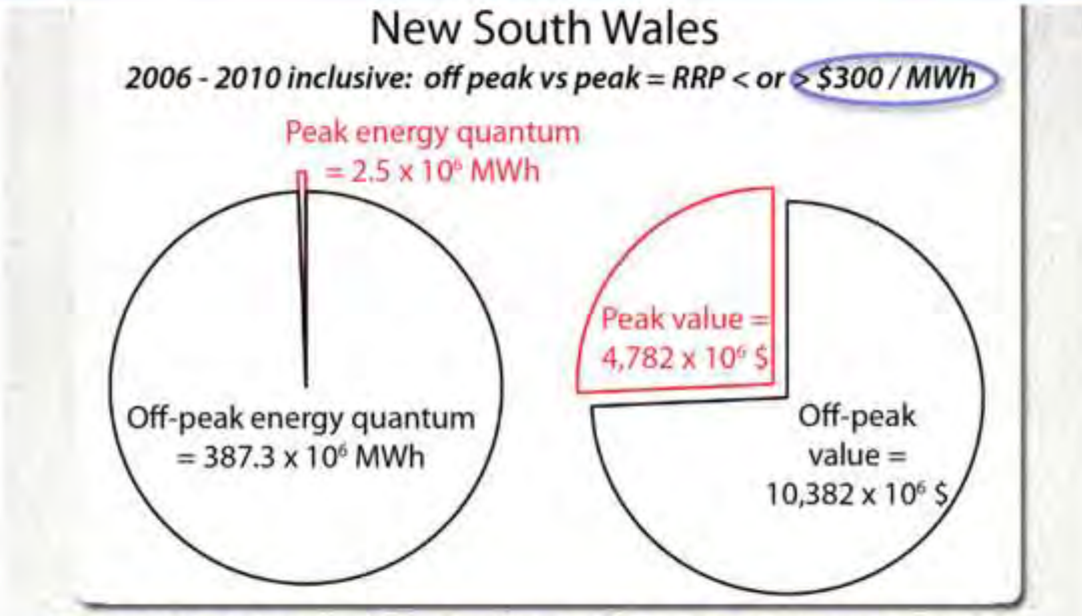
The reason this 45 % is much higher than other eastern States is because the heatwaves in SA (and WA too) tend to be of much longer duration, often up to a week.

# Peak costs in various States




"Optimising Wind Power Production Economics", SA IET Retired Engineers, August 2012

# Peak costs in various States

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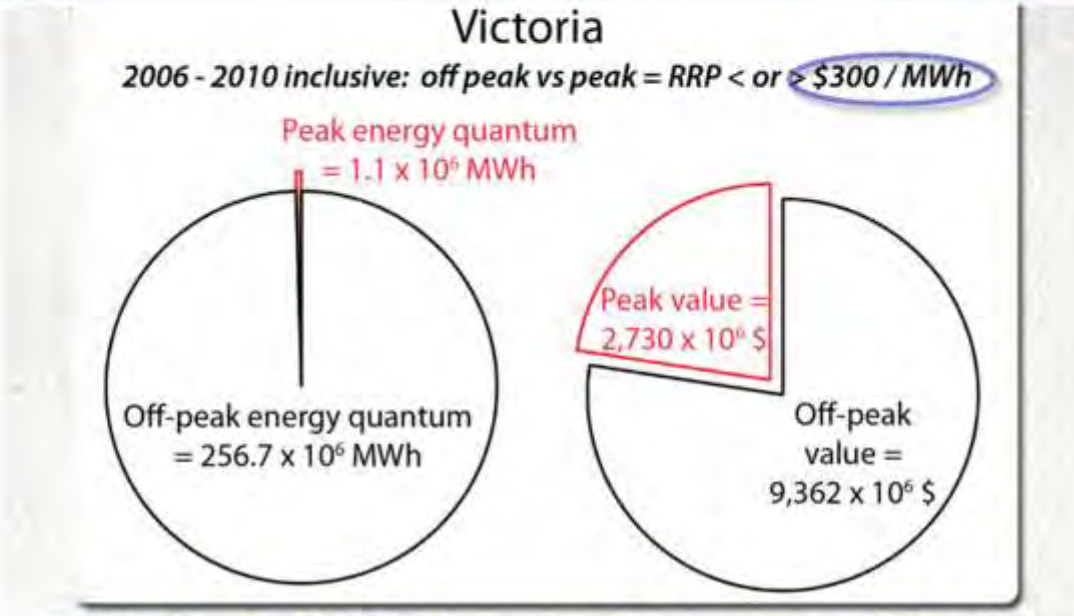
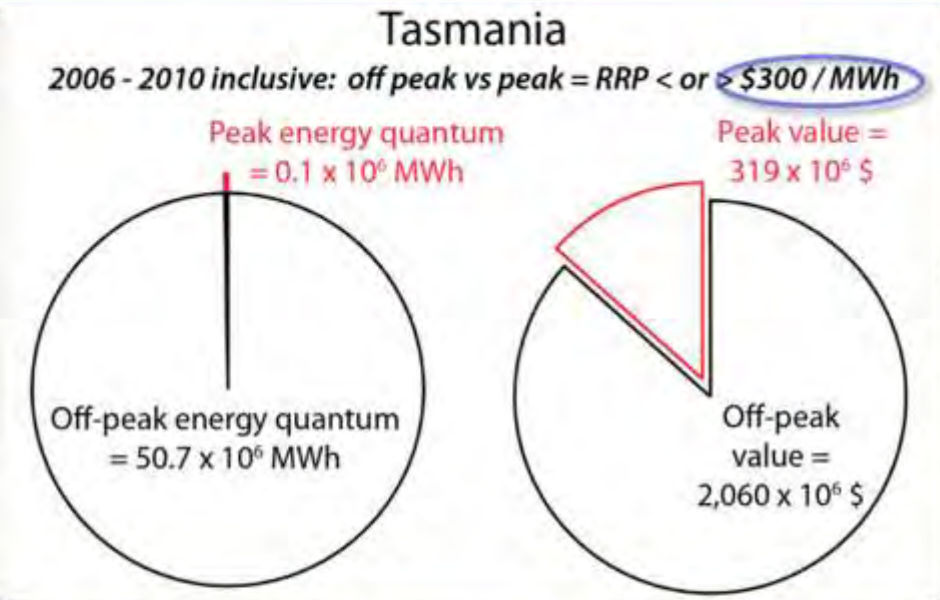
# Peak costs in various States




*"Optimising Wind Power Production Economics", SA IET Retired Engineers, August 2012*

# Peak costs in various States




"Optimising Wind Power Production Economics", SA IET Retired Engineers, August 2012

# Solar reflectance & Emissivity

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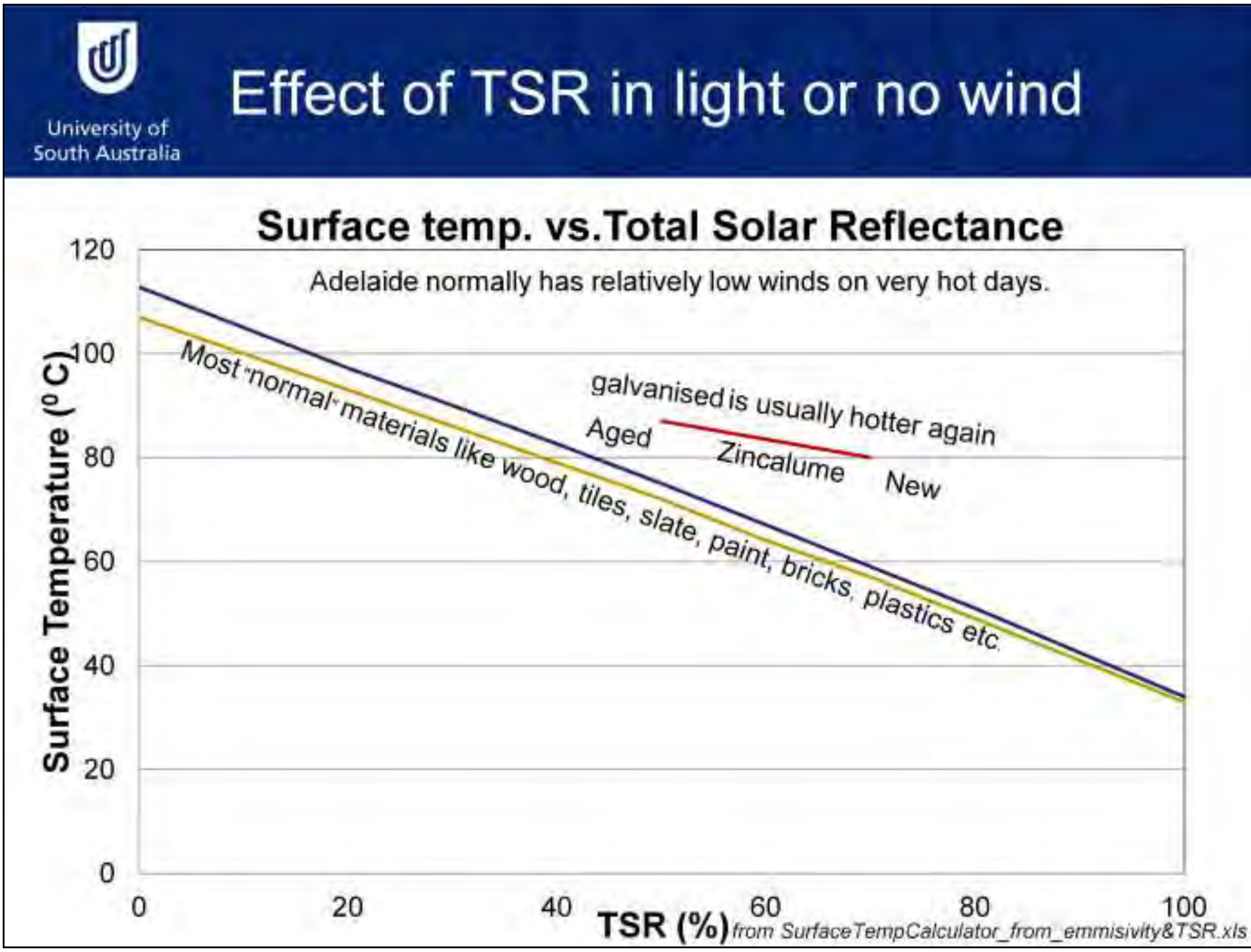
Sunlight radiation not reflected at a surface is absorbed giving a hot surface.

Visibly darker colours will *always* absorb more of the visible part of sunlight and contribute to a hot surface even if they are 'heat-reflective'.

Higher surface temperatures make the integrity of thermal insulation far more critical.

The ability for hot surfaces to give off heat at very long wavelengths is called Emissivity.

Exposed metals (Zincalume & galvanised) are poor at giving off heat so they become hotter than most other materials having the same TSR.




Exposed metals (zincalume & galvanised) are poor at giving off heat (low Emissivity) so they become hotter than most other materials having the same TSR. This is between 12 and 20 degrees Celsius hotter than materials having the same TSR.

As Zincalume ages, the TSR decreases but there is an increase in emissivity due to the oxide layer on the surface so the excess temperature over normal materials becomes less.

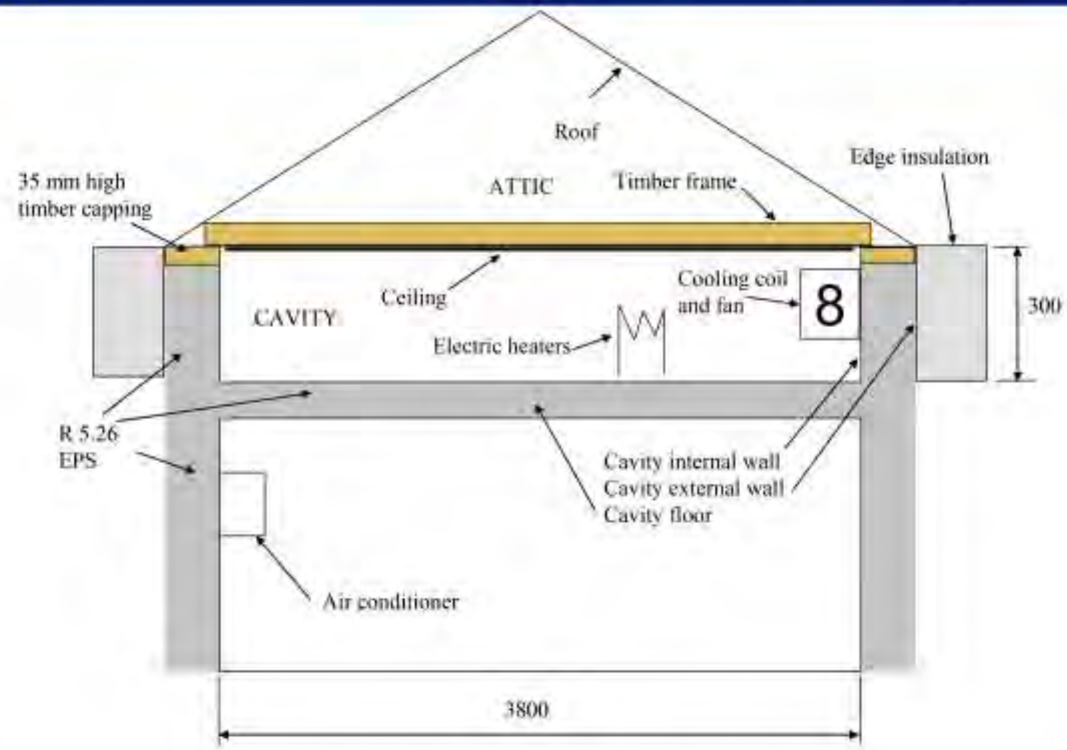
# Roof insulation effectiveness

UniSA huts have measured total-roof R-values about half that of the bulk insulation due to thermal bridging by roof and ceiling timbers.

Additionally, a 5 % gap between batts themselves or batts and joists gives a further 50 % reduction.

This is the reason we have practical results and the theoretical ones.

# UniSA test cabin setup




from "Summer Thermal Resistance Measurements of Timber Framed Roofing Systems and Benefits of Reflective Paints" Belusko, Pockett, Bruno, Saman, Solar2010

This setup very accurately measures the heat flow into the 300 mm high "living space" from the roof alone.

We are specialised in roof thermal flows, in Tasmania their specialisation is in floor heat flow/insulation and a NSW regional university is specialised in wall heat flows.

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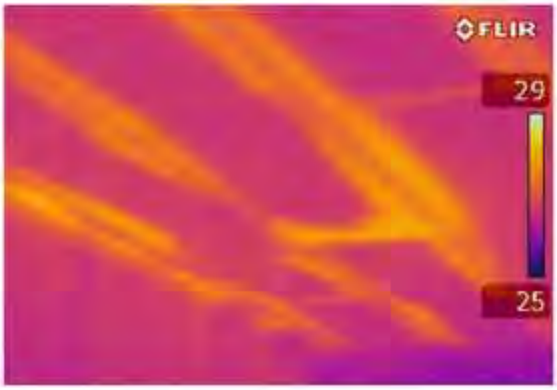
# Insulation quality assurance




Current insulation is 50% lower than expected

Installation defects magnify weaknesses during heat waves because of the thermal short-circuits

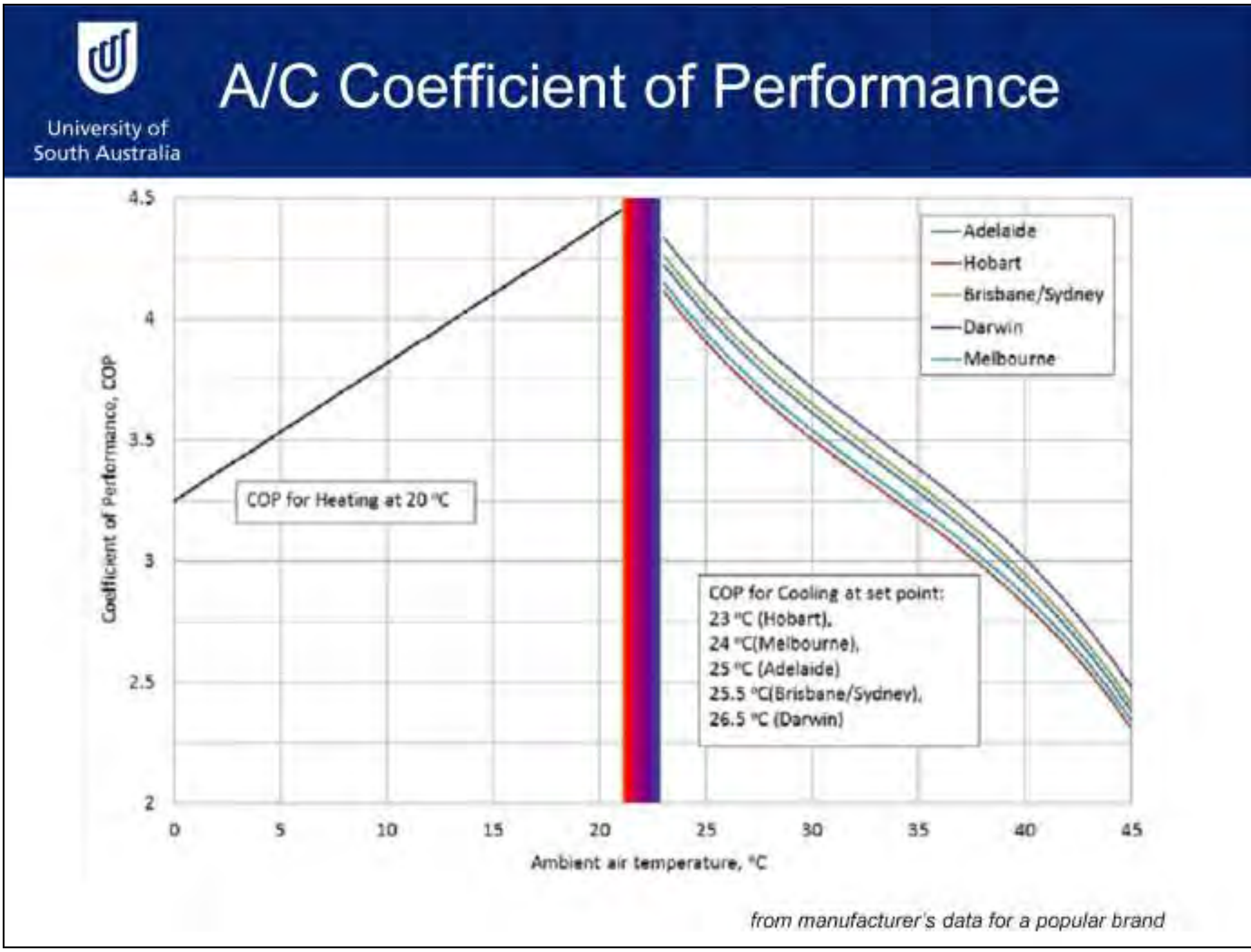
We must bring standards in line with OECD

Introduce quality assurance such as thermography

It is very common in Australia for insulation to be extremely poorly installed.

Additionally, electricians have advised me that quite often insulation extends for only 4-5 metres from the manhole with the rest of the stocks for the job being tucked away out of site and not installed.

The gaps between bulk insulation and the ceiling joists can be clearly seen in the thermal images.




**Cooling efficiency** is much less than heating and falls off *very* quickly as the ambient temperature increases, being **about half its maximum when we have a very hot day**.  This requires much more electricity to get the same cooling effect and is one of the reasons why our modelling shows more effect for light rather than dark roofs compared with modelling based only on the first step, heat flow into conditioned spaces.

This is for fixed speed aircontitioners. Inverter systems are thermally less efficient.

Research done at UniSA has shown that even very conservatively sized airconditioning should not need any more that a peak rating of 90 W/m$^2$. My 20 m$^2$ extension would have been more than adequately cooled with a 1800 W unit but the smallest in the brand I was buying was 2400 W.

It is better not to have the airconditioner idling as the Coefficient of Performance (CoP) falls markedly. It is a bit like idling the engine of a car at traffic lights  in that a lot of petrol is used but you aren't  travelling far

# AccuRate modelling

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This study looks at roof reflectance as a factor with variations in house design, insulation configuration, and location to give annual energy usage for heating and cooling plus peak electrical load.

Individual house constructions are modelled by CSIRO's Chenath engine to predict heat flows into and out of living zones based on Typical Meteorological Year (TMY) data for a location.

TMY data covers ambient temperature, humidity, wind speed, cloud cover and Sun angle taken into account at hourly intervals through a year for a particular location and is representative of a large number of years.

# Roof insulation combinations

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Two six-star rated designs were also modified to take account of the realities of insulation.

House A rated 6 star with R-3 batts was also modelled with R-1.4 and House B rated 6 star with R-4 also modelled with R-1.6, the practical R-values of roofs.

Options were modelled with (according to the 6 star rating) and without (older houses) internal double sided reflective sarking under roof joists.

All were modelled with roof surfaces having TSRs of 90 % (super-white), 50 % and 10 %(charcoal) to indicate the magnitude of effects.

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# House A

*from anonymised building drawings for House A*

House A and House B (on the next slide) are very typical Australian designs, one being bigger and with a different layout to the other. A percentage of Australian houses nowadays are two storey but if there are several close by each other then the main influence on sun energy input will still be via the roofs.

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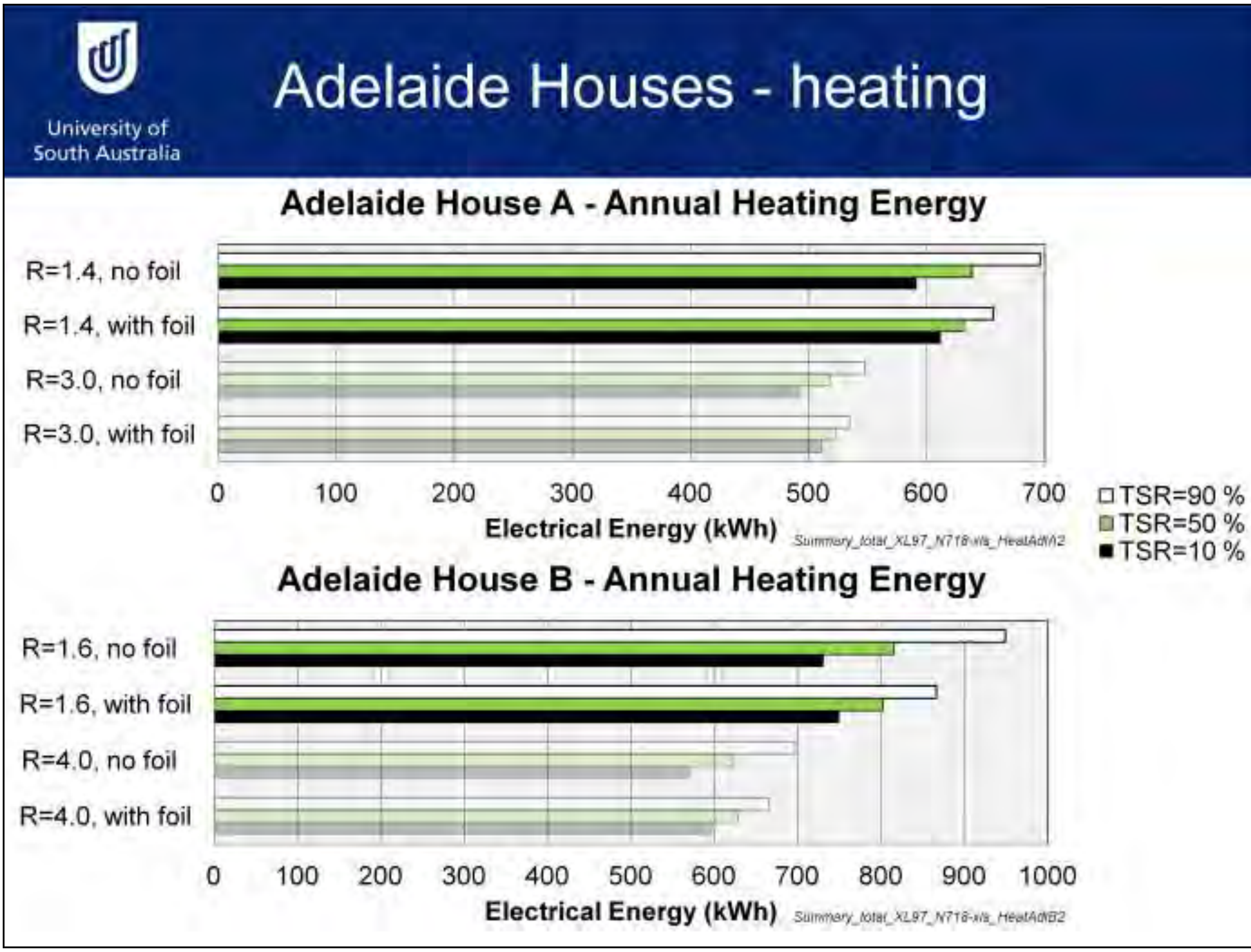
# House B


*from anonymised building drawings for House B*

A larger house with a greater area/volume that is air conditioned. The house layout is quite different to House A and the window areas, usage etc. are also different.




White bars are for white roofs, green for mid solar reflectance colours and black is for charcoal darkness in all graphs for the whole series of slides.

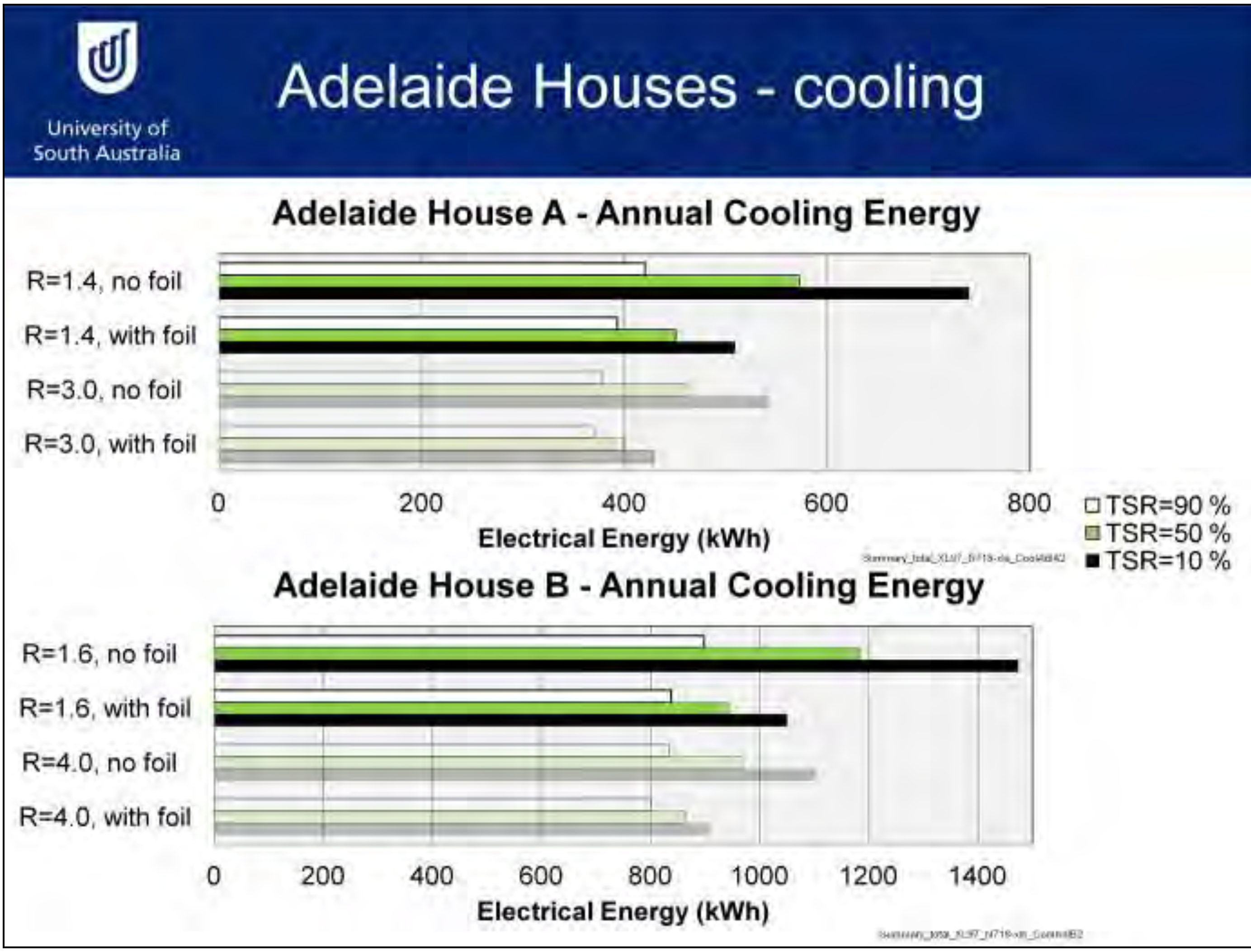
In all graphs, the first two reflect real-world performance and the greyed out are the theoretical if we weren't getting thermal bridging through roof and ceiling joists plus less-than-perfect batt installation. In most cases older houses won't have reflective sarking (foil) and will be the first one of the four.

Most, but not all, newer houses will have reflective sarking and the second of the four will be relevant.

House A uses much less electricity for heating and cooling than House B because it has a much smaller conditioned volume with less ingress/egress of heat from outside.

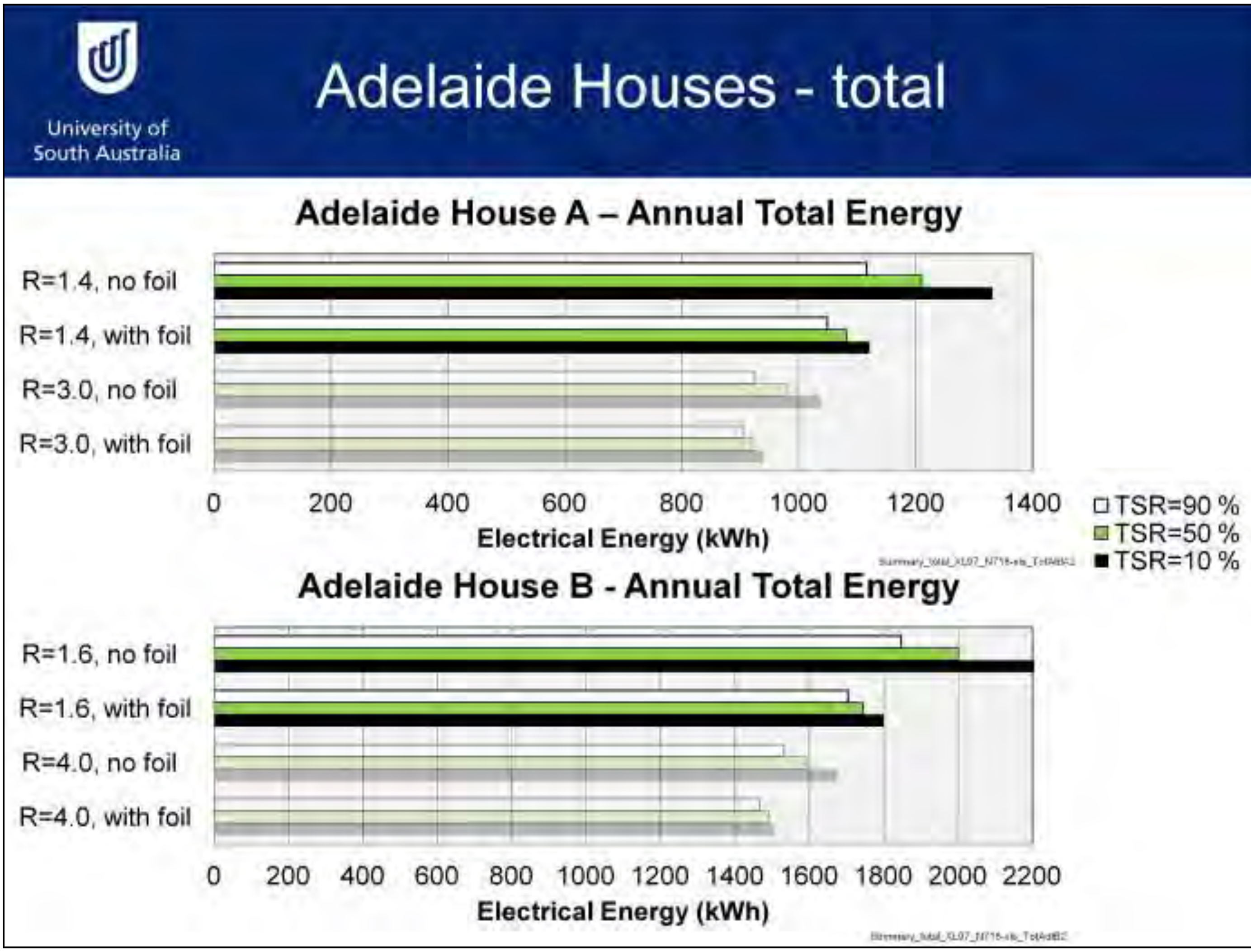
The dark roofs do absorb some heat that gets into the living space and it is better if there is no reflective sarking but that would be worse for cooling.

The *difference* between green and black bars in this and the following graphs is close to the *difference* between Surfmist and Monument in Colorbond colours.

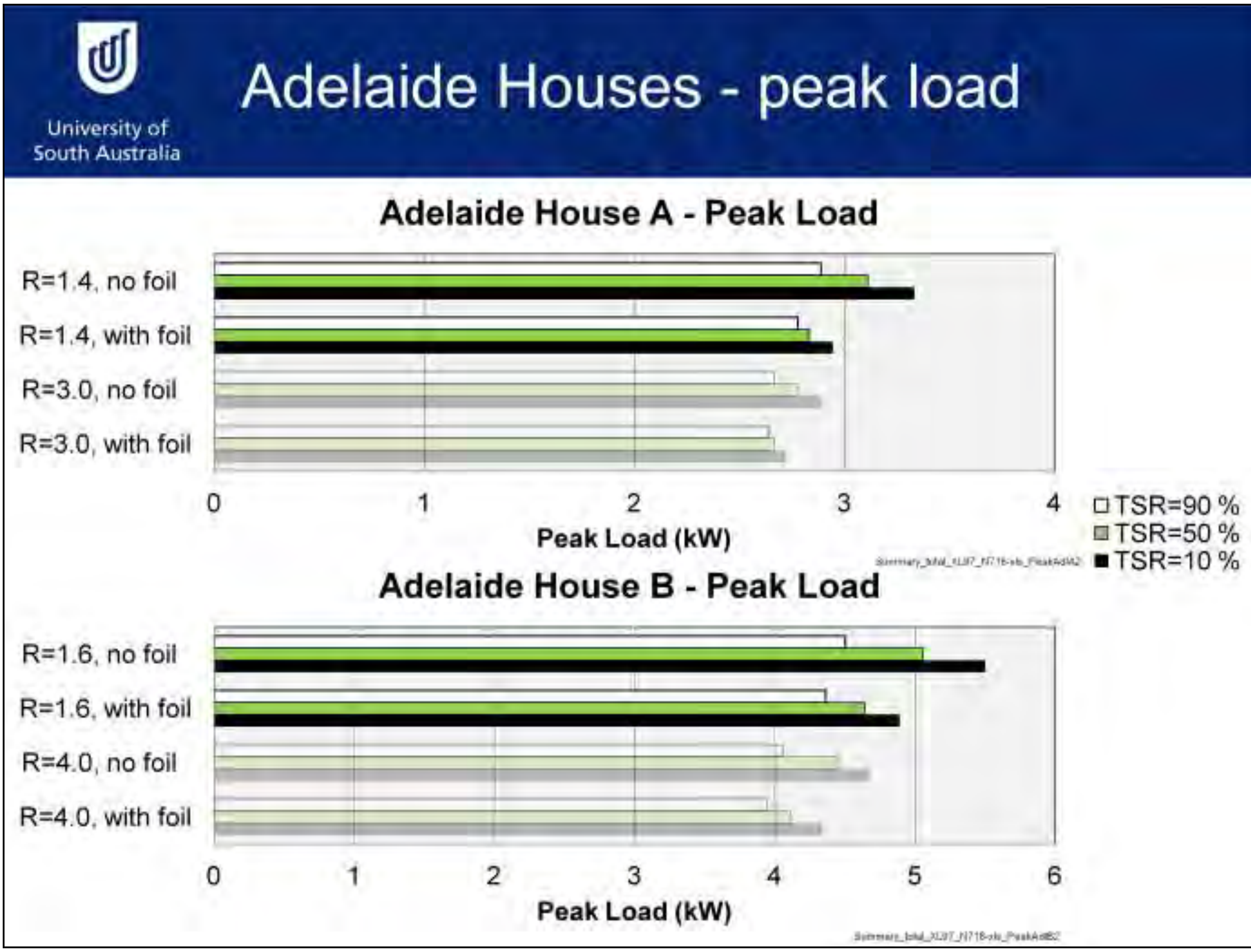



Lighter coloured roofs along with foil and better insulation all help massively cut back on cooling electricity usage.

The “flatter” steps between lower and higher insulation for white than for dark roofs means that the white has the same thermal effect in reducing heat flow into living spaces *in strong sunlight* as having massive insulation in the roof.

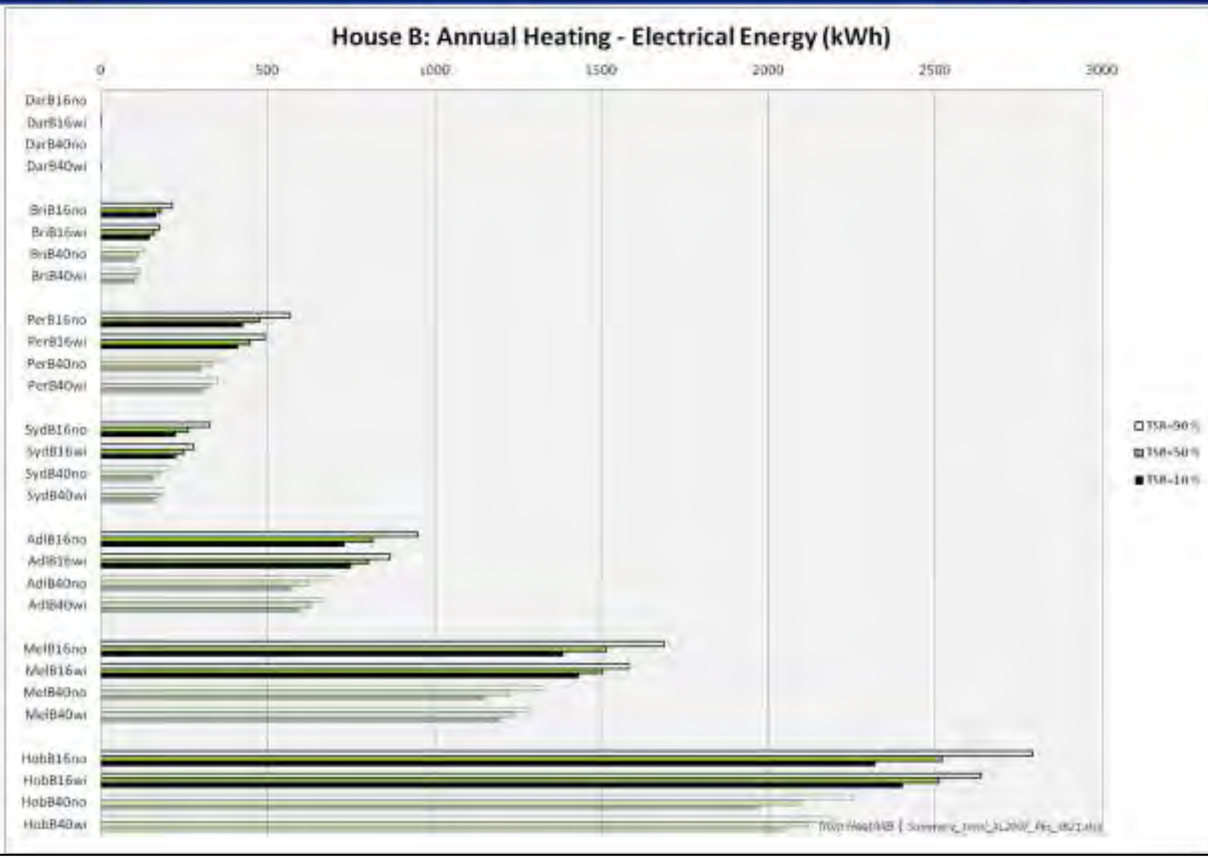



The total electricity usage per year for heating and cooling combined in real-world houses is much better (= lower cost for residents and $CO_2$ emissions) for lighter rather than “fashionable” very dark roofs.




The peak load during hot spells has a major influence on generation costs (see earlier slides) but also on distribution and transmission infrastructure that has to be upgraded. That leads, longer term, to big increases in electricity tariffs. My neighbour's black roof contributes to my electricity bill.

# All cities House B - heating




Cities Darwin, Brisbane, Perth, Sydney, Adelaide, Melbourne and Hobart arranged North to South (Perth is 220 km more northerly than Sydney).

The order within each city is the same as previously.

The further south, generally the more heating, as would be expected.

Very slight rounding errors in the calculations mean that sometimes the steps white>green don’t exactly match the green>black ones

# All cities House B - cooling

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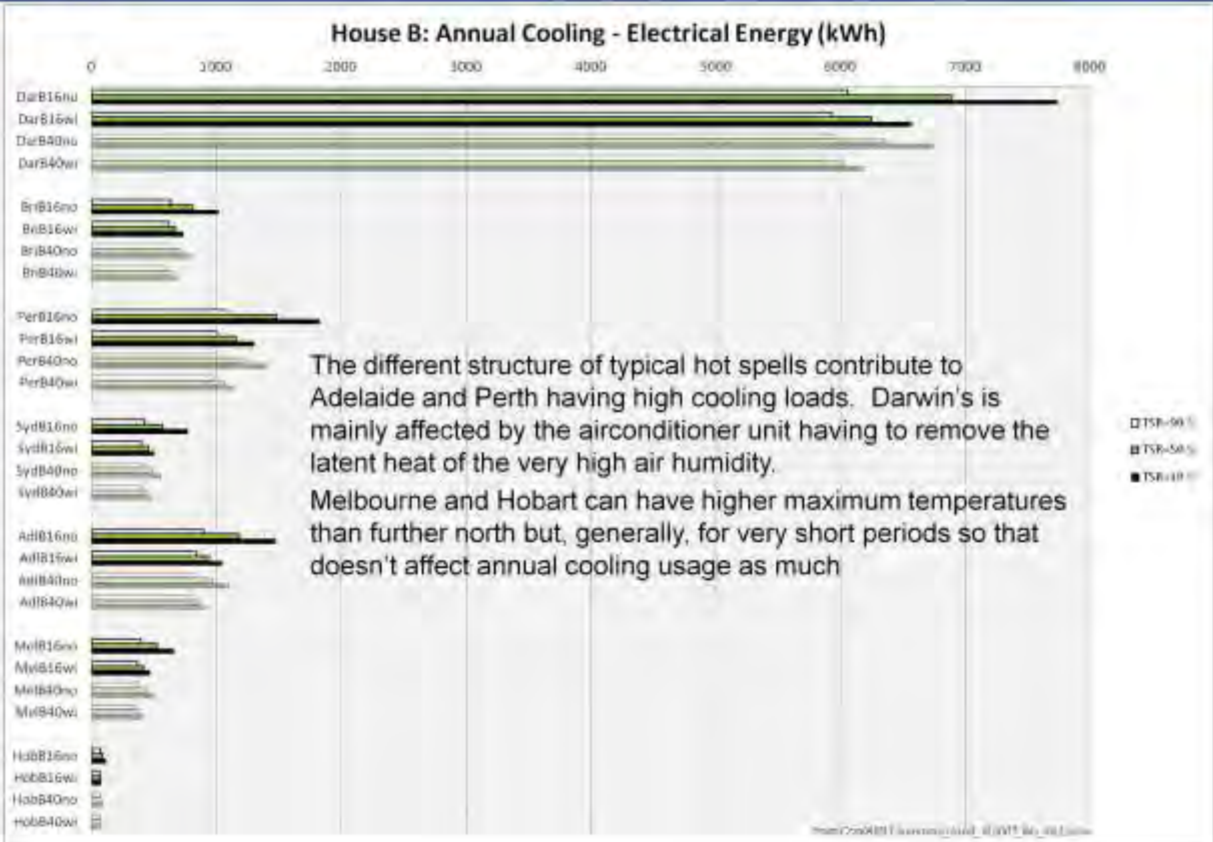
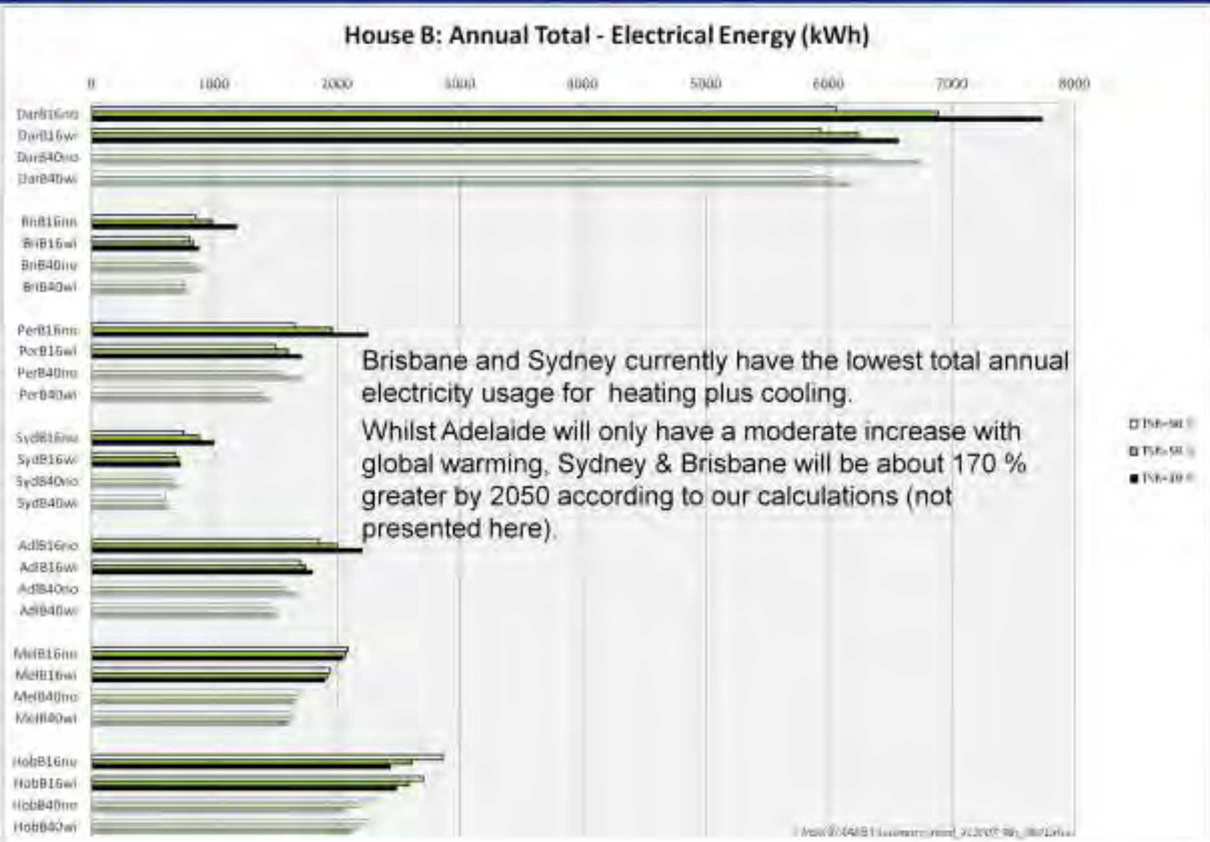



The different structure of typical hot spells contribute to Adelaide and Perth having high cooling loads. Darwin's is mainly affected by the airconditioner unit having to remove the latent heat of the very high air humidity.

Melbourne and Hobart can have higher maximum temperatures than further north but, generally, for very short periods so that doesn't affect annual cooling usage as much

# All cities House B - total




Brisbane and Sydney currently have the lowest total annual electricity usage for heating plus cooling.

Whilst Adelaide will only have a moderate increase with global warming, Sydney & Brisbane will be about 170 % greater by 2050 according to our calculations (not presented here).

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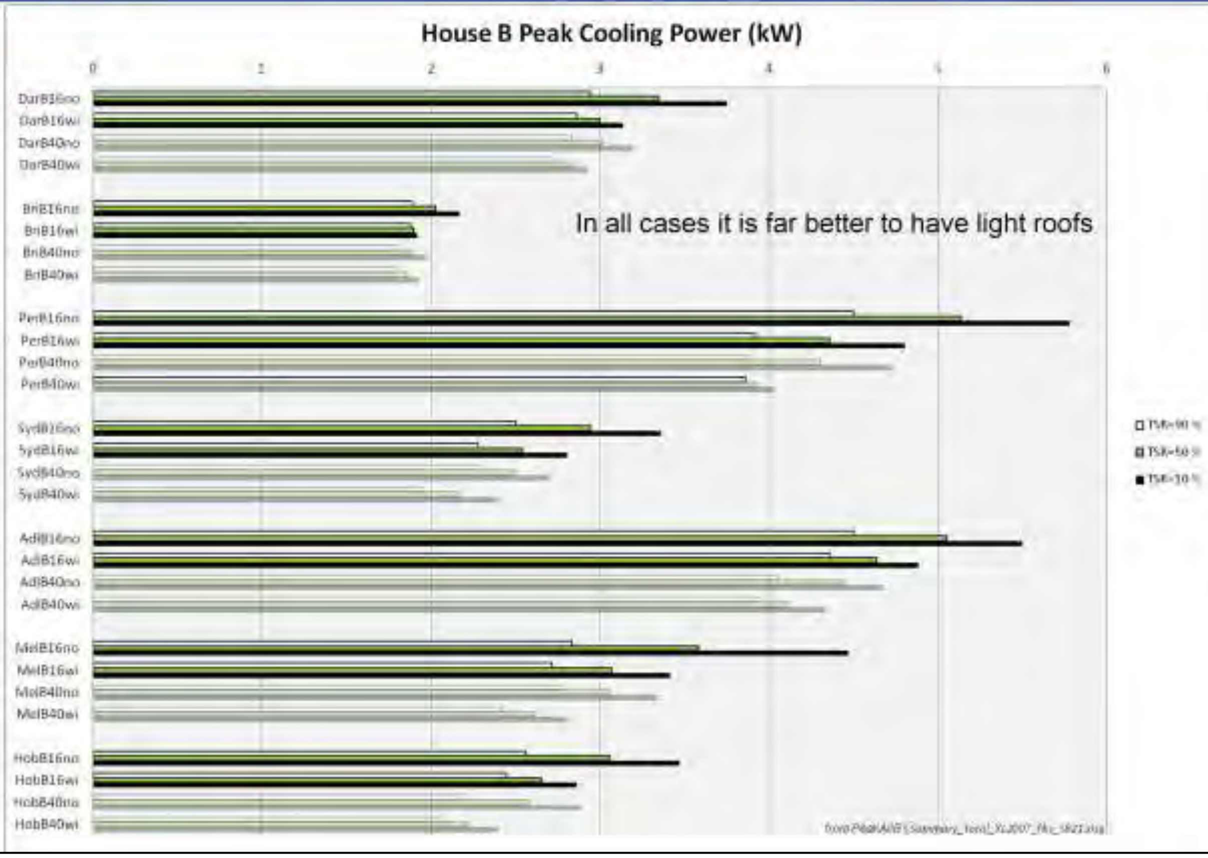
# All Cities House B - peaks




Hobart's lower total annual electricity usage for dark roofs (prev. slide) is counteracted by it having high peaks in electrically interconnected States where transmission/distribution infrastructure are also important.

# Cool Roof conclusions

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TSR is a critical factor in electricity usage

Reflective sarking plays a strong role in mitigating heat flow into & out of buildings

It is preferable with annual usage for most capital cities north of Melbourne to have lighter coloured roofs.

Exceptions could be areas with higher elevation or greater heating needs eg Stirling in SA and Canberra.

A low roof surface temperature makes the insulation system and its installation less critical.

Roof colour has a major impact on cooling, particularly for peak load expenses in hot spells.

Savings of 8 to 13 % in individual electricity bills can flow from using very light coloured roofs and it helps us all.

# Heat reflective paints

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How would you go about making a paint reflective for heat in sunlight without altering the perceived colour ?

What are the surface temperature benefits ?

What other factors need consideration ?

What are the cost implications ?

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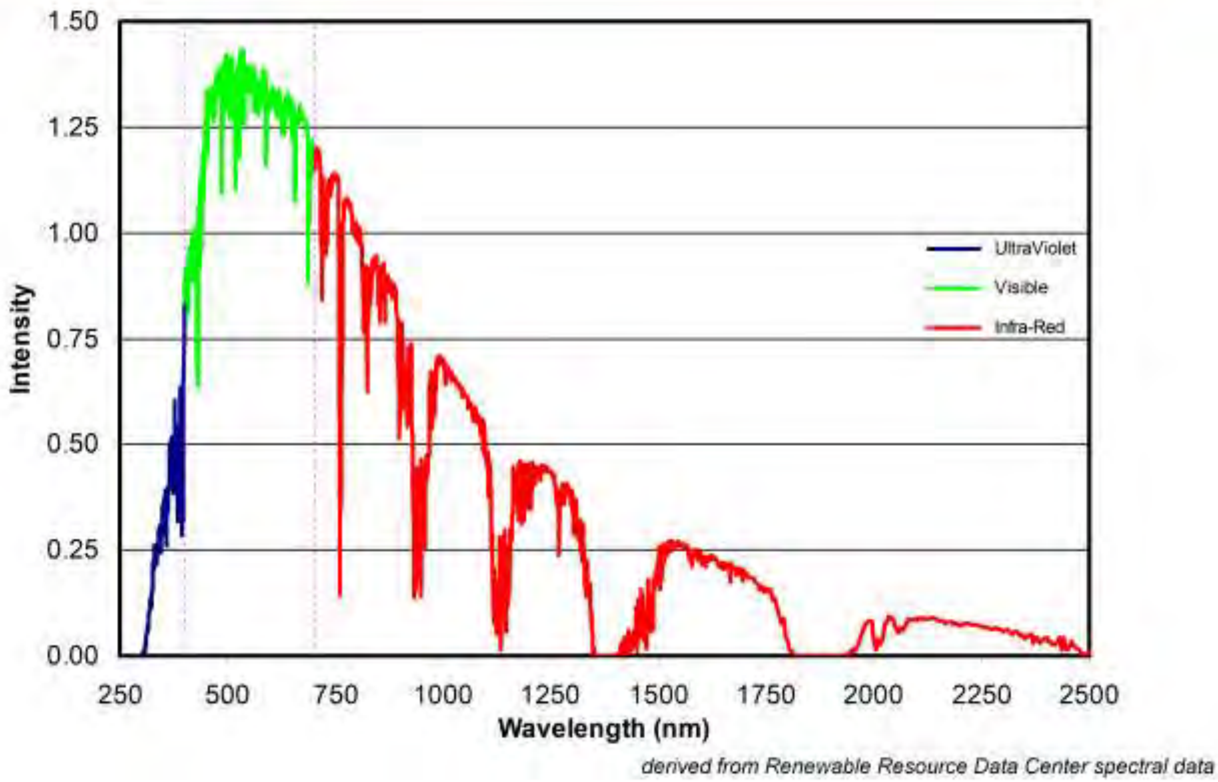
# Solar spectrum at Sea Level




Revisiting the solar spectrum at Sea Level graph shown earlier in order to focus in more on the Infra Red (IR) portion of the Sun's energy reaching us.  Nearly half the energy is in the Visible portion and nearly half is in the IR.

The TSR is the reflectance of a surface weighted for the relative intensities in incoming sunlight. You can't achieve good TSRs if you have a low reflectance in the visible (dark colour) no matter how good your IR reflectance is.

The critical part of the spectrum is  the region between 700 and 1100 nm where intensity is relatively high. If you can efficiently reflect IR in that range there is less absorbance causing the surface to heat up. With appropriate  scatterers by whatever means there can be a substantial lowering of absorbance and surface temperature. The eye's sensitivity in the 600 – 700 nm region is already falling off so it is possible to cheat a little with the visible colourmatch and already be boosting  reflectance slightly lower than the nominal 700 nm cutoff.

# Light scattering from spheres

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Mie scattering comes from Mie's solution to the Maxwell equations in scattering of electromagnetic radiation by spheres when Refractive Index (n) differences exist.

$n_{sphere} > n_{bulk}$ $n_{sphere} < n_{bulk}$

Reflectance of radiation can happen with metals or, alternatively, by exploiting changes in refractive index between two materials causing scattering of the radiation in all directions.

We see here two ways of achieving that with small "particles" having higher or lower refractive index than the bulk medium around them.

The size of the particles plays an important part in the scattering efficiency (and reflectance). For example $TiO_2$ pigment particles in a medium having a refractive index of 1.5 give optimal reflectance (and whiteness) when the particle size is roughly 1 micrometre.

# Creating heat reflective paints

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- Use pigments scattering well in the near IR but giving good colour matches in the visible region.
- Include hollow microspheres that scatter IR well but are not efficient scatterers in the visible.
- Formulate the paint to have suitable physical & chemical properties but have high emissivity to give lower surface temperatures.
- Use gloss finishes, preferably with surface modifications to reduce dirt and mould pickup that would increase sunlight absorption.
- Thick application because IR scattering is poor leading to low IR reflectance.

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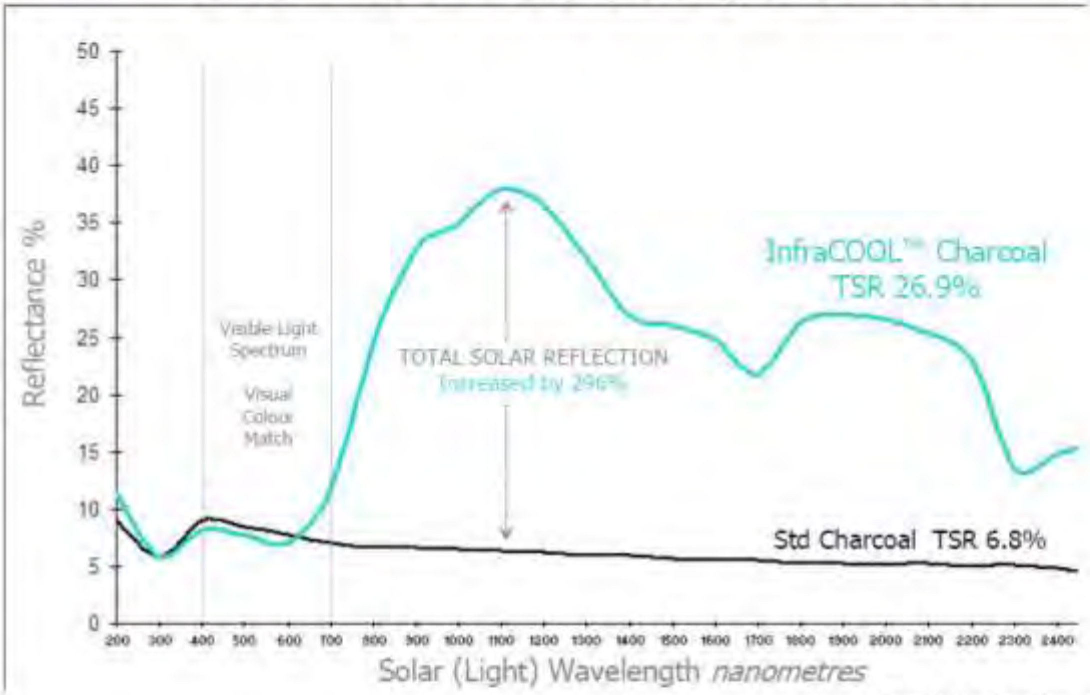
# Dulux-Acratex InfraCOOL

Charcoal with enhanced IR reflectance by careful pigment selection to maximise the TSR, avoiding carbon black.




*from Dulux AcraTex brochures*

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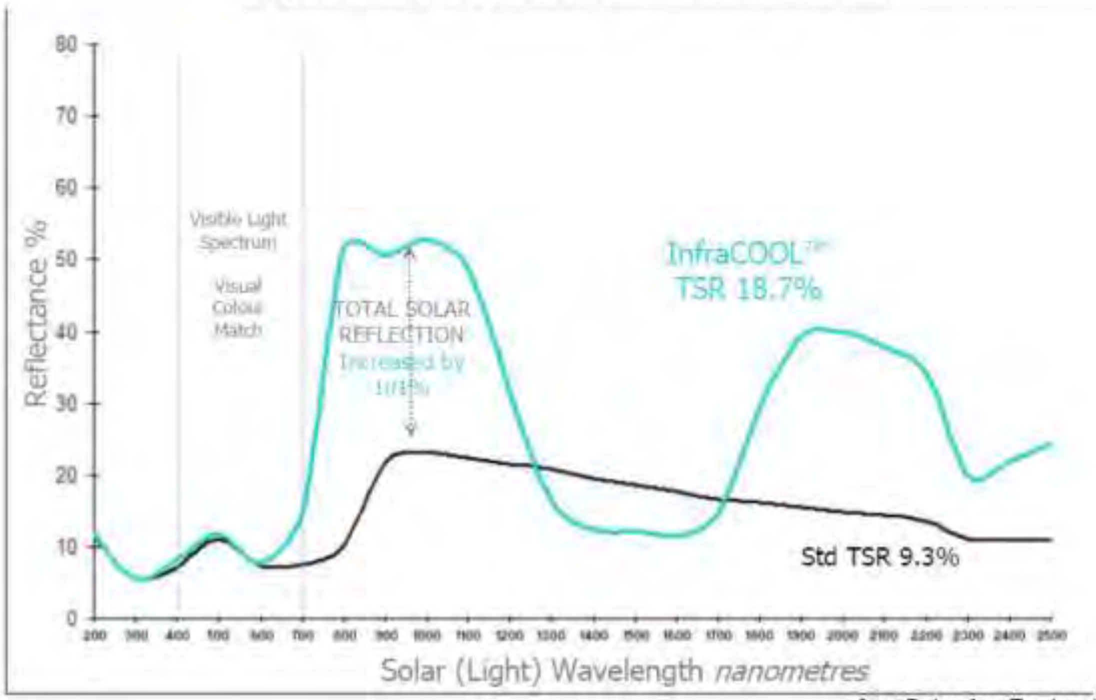
# Dulux-Acratex InfraCOOL

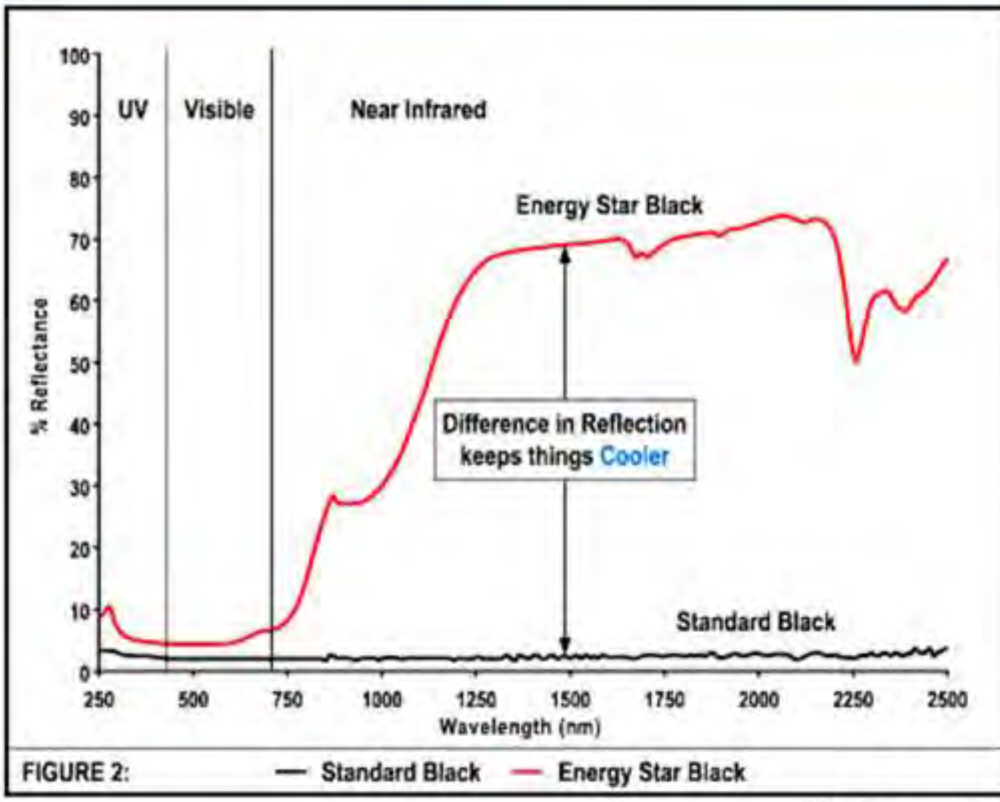
Mid Brunswick Green with enhanced IR reflectance by careful pigment selection to maximise TSR.




*from Dulux AcraTex brochures*

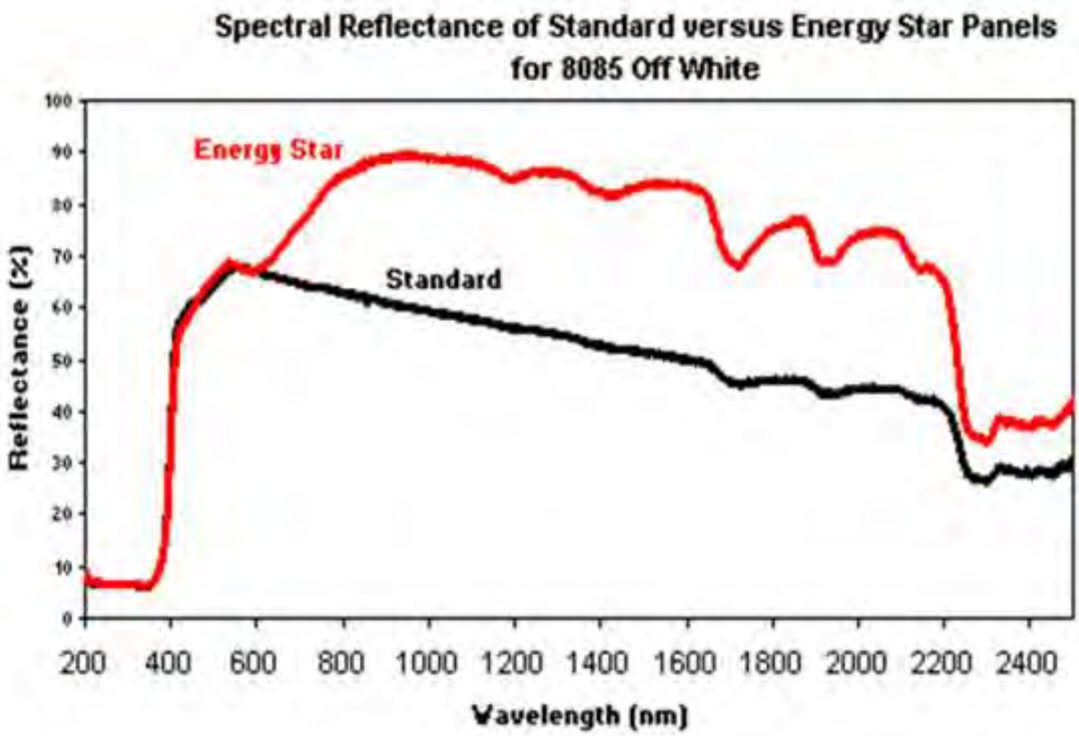
Despite the apparently large difference in reflectance between turquoise and black curves, eye sensitivity to the differences is weaker as the wavelength goes from 600 to 700 nm and the colour difference is unnoticeable to humans.

# ASTEC EnergyStar Black



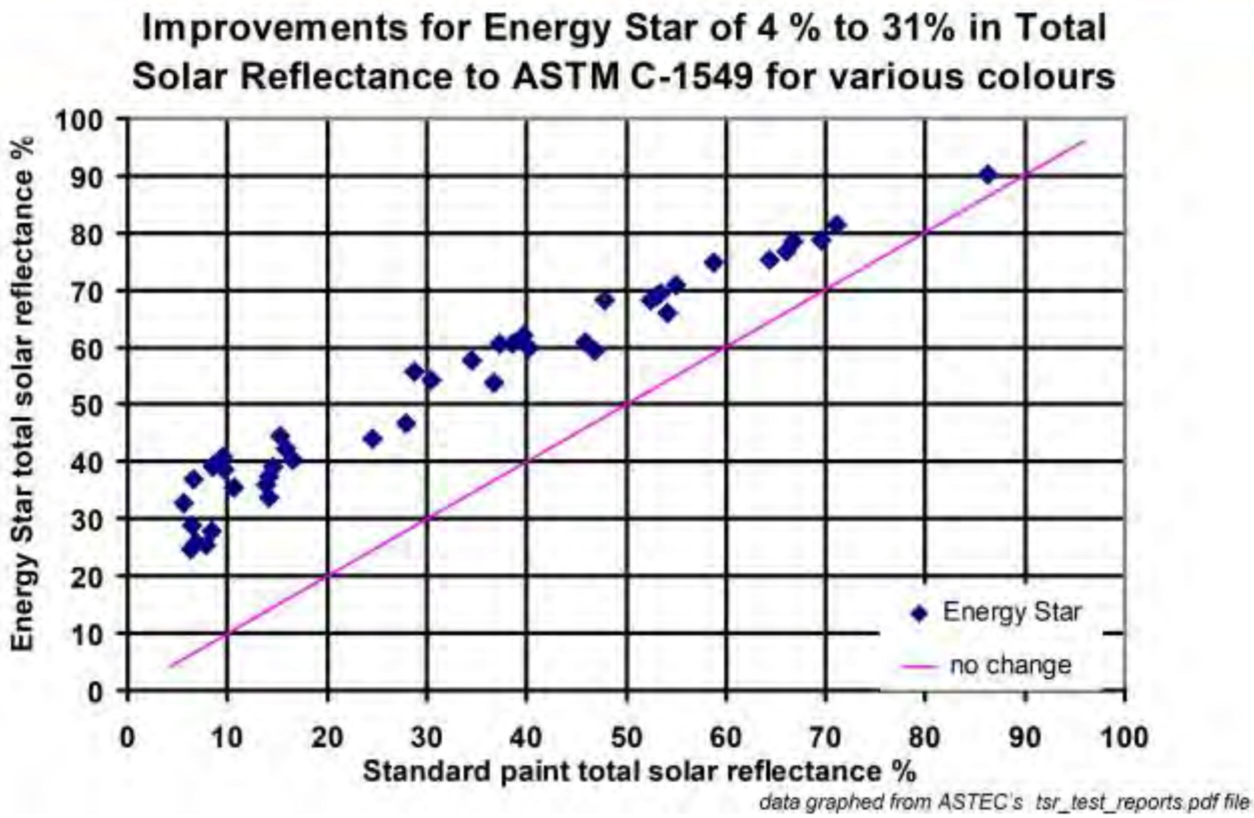

*from http://www.astecpaints.com.au*

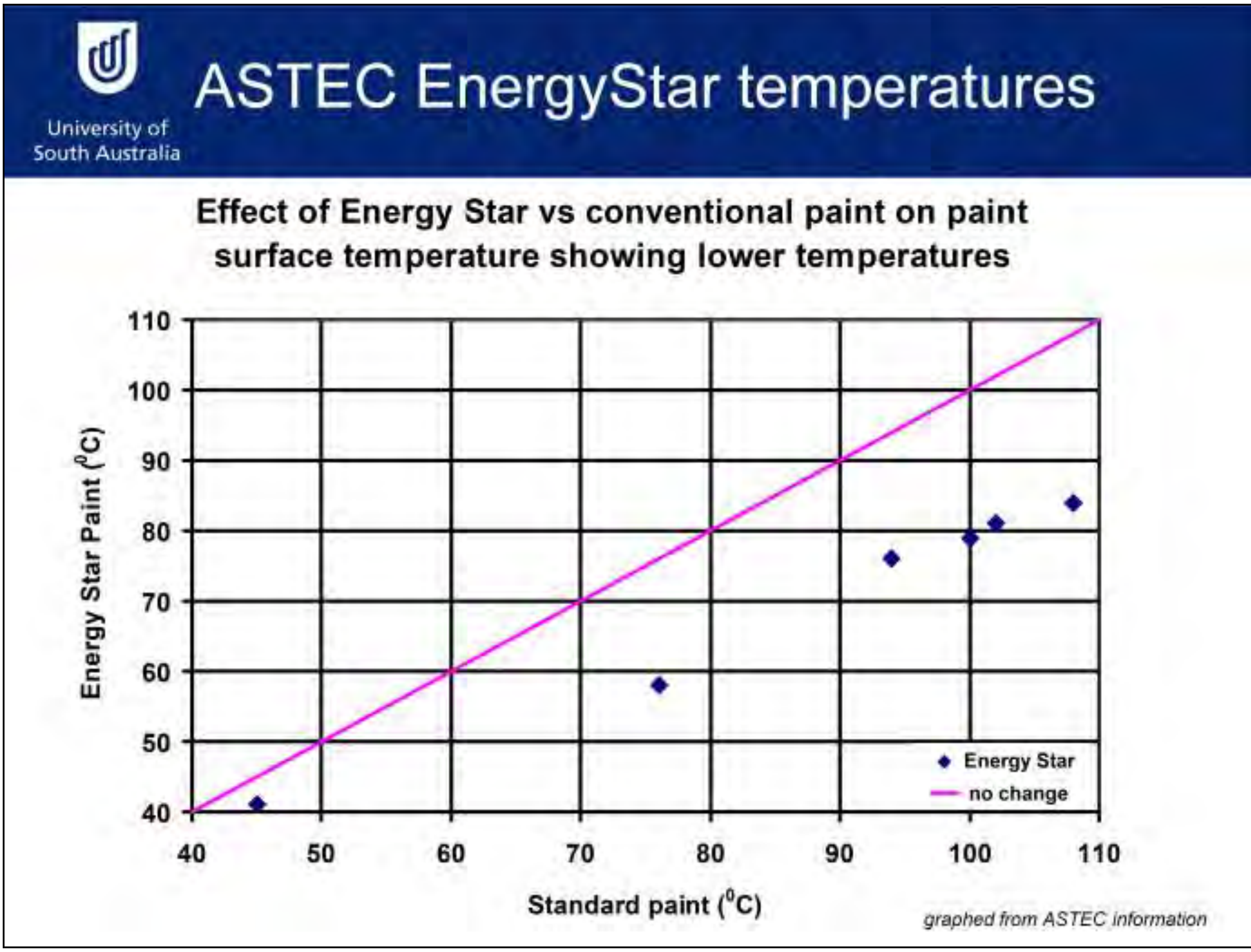
# ASTEC EnergyStar Off White




http://www.astecpaints.com.au/energystar/downloads/what_are_tsr_figures.pdf

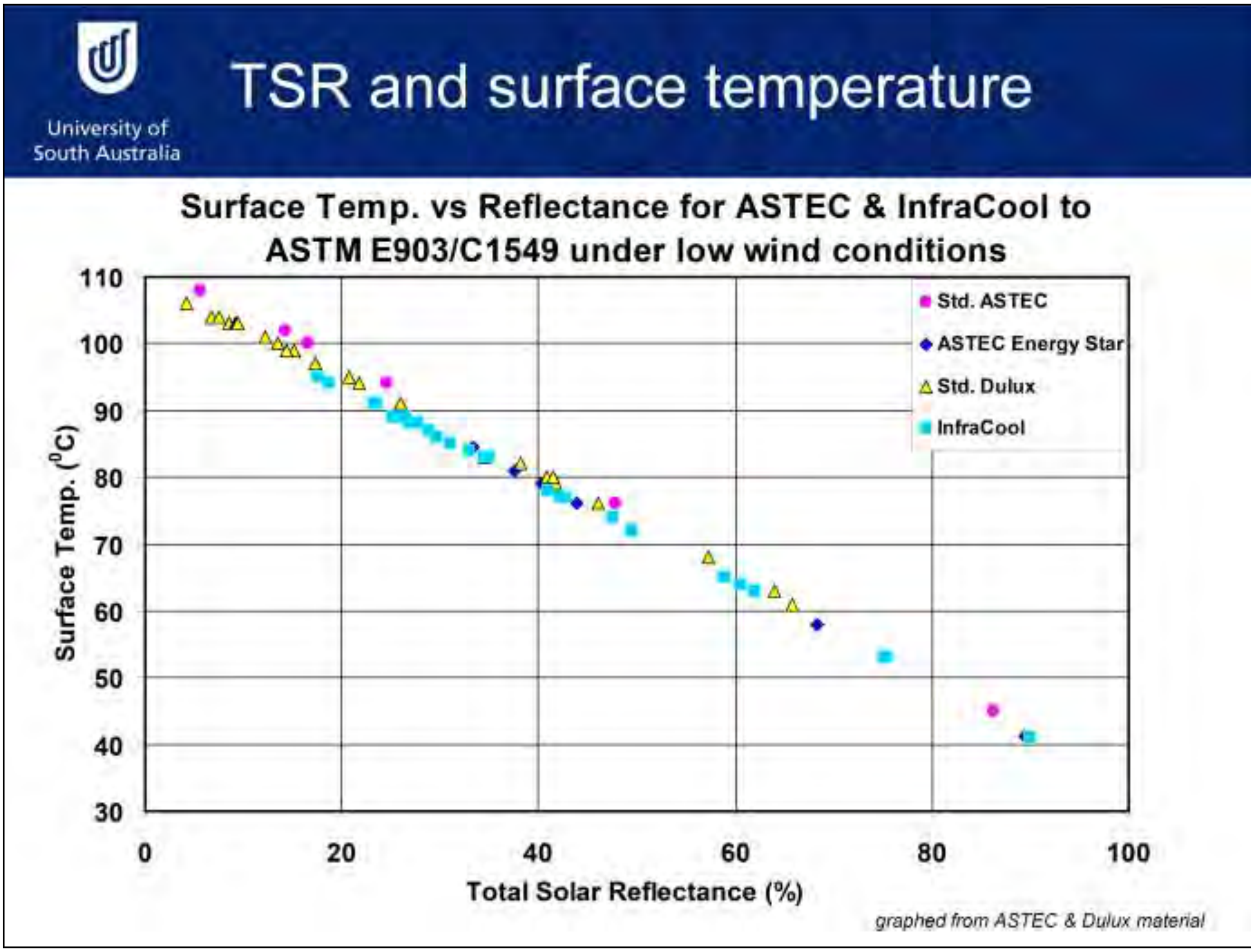
# ASTEC EnergyStar colours






The benefits of heat reflective paint in lowering surface temperature are relatively small for the cooler light coloured paints. The larger benefits for darker colours just mean they go from being abysmal to just being very bad in surface temperature.

The main benefits of the heat reflective paints is that they are usually formulated so that the surface is harder and/or slipperier. Different manufacturers will differ markedly in their ability to formulate their heat reflective paints to shed dirt, moulds etc.




All of the paints above fall within the normal band of materials. It is only that with a heat reflective paint it will have higher TSR and thus lower surface temperature than the standard paint for the same visible colour.

It can be seen that both of the heat reflective paints are slightly cooler as a band than the set of standard ones. This is most likely because both manufacturers have taken some trouble to increase emissivity, and that leads to a cooler surface for the same TSR.

Low wind conditions are more prevalent in SA on very hot days.

## Using hollow microspheres

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The other way to scatter radiation is to use microspheres with RI less than that of the paint medium where the hollow in the microsphere scatters inefficiently at visible wavelengths but efficiently in the IR.

David Page of Florida approached NASA resulting in INSULADD hollow microsheres.

Marketed generally in Australia by Thermilate but there is an INSULADD distributor in Queensland

Acryloc seem to be the major supplier in SA.

Hy-Tech and 3M also market similar additives.

There is one disadvantage in opting for microspheres as a means of reflecting more of the Sun's IR energy. That is the changeover from inefficient scattering of visible light (to keep the colour nearly the same) to efficient scattering in the IR takes place slowly over a wide range of wavelengths. It is only by 1200 nm that the efficiency is reasonably high but there is only a relatively small amount of the Sun's energy out beyond 1200 nm.

# INSULADD comparisons

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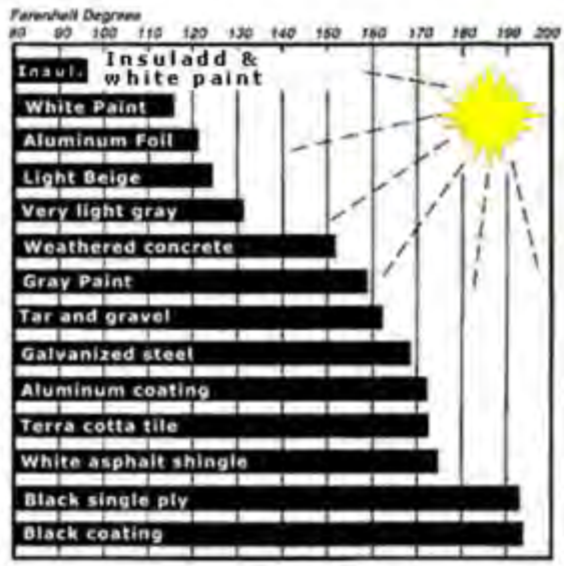
Temperatures of coatings and other material in sunlight conditions in Central Texas - August Ambient of 90 $^{0}$F (33 $^{0}$C) - Clear Sky.




from http://www.insuladd.com/howitworks.html

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# Acryloc comparison

| Colour | Cooler than CRC Equiv by |
|---|---|
| Arctic White | 3° |
| Blue Ridge | 16° |
| Brunswick Green | - |
| Bushland | |
| Charcoal | 22° |
| Classic Cream | 13° |
| Cottage Green | 40° |
| Deep Ocean | 15° |
| Dune | |
| Headland | 15° |
| Ironstone | 39° |
| Jasper | 37° |
| Manor Red | 19° |
| Night Sky | 36° |
| Pale Eucalypt | |
| Paperbark | 25° |
| Plantation | 28° |
| Sandbank | 29 |
| Shale Grey | 26° |
| Sienna Clay | 14° |
| Stone | 29° |
| Surfmist | |
| Wheat | 31° |
| Wilderness | 27° |
| Windspray | 29° |
| Woodland Grey | 17° |

- This comparison of surface temperatures by Acryloc (using INSULADD/Thermilate) was carried out under infra-red lamps. The effects would not be as large in sunlight.
- The trend of lesser effect for lighter colours is similar to that found with ASTEC's technology.

*scanned from Acryloc brochure, 2008*

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# SkyCool with high Emissivity

SkyCool paint combines high solar reflectance TSR > 85 % with a high emissivity of 0.94 – 0.96.

The advantages of reduced airconditioning during summer are counteracted to some degree by increased need for heating during winter.

In 2010, discussions with Prof. Geoff Smith of UTS in Sydney aided SkyCool achieve their good results. He intimated that it was by trying different materials and looking at emissivity results that they achieved their very high Emissivities. There did not seem to be a theoretical framework for selecting materials that would help increase Emissivity.

# Colorbond

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Colorbond now have a high reflectance product called Coolmax in the commercial colour "Whitehaven". Its TSR of 77 % is lower than ASTEC or Dulux heat reflective membranes, probably due to being thinner.

It is reported by Colorbond to have "excellent resistance to dirt retention and maintenance of solar reflectance" so they obviously recognise the importance of that in coating formulation.

Standard Colorbond colours have now been heat reflective since 2008 so the new and "fashionable" very dark colours have TSRs of around 25 %. They now absorb 75 % of the Sun's energy rather than the previous 90 %.

A thin layer for the Colorbond coating is necessary so that the flat sheet can be rolled to form the shape. This means the coating layer is partly transparent in the infrared, leading to a lower than optimal TSR for the pigments used.

# Current Colorbond TSRs

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| Colour | Total Solar Reflectance | Colour | Total Solar Reflectance |
|---|---|---|---|
| CLASSIC CREAM™ CLICK HERE | 68 % | SURFMIST® CLICK HERE | 68 % |
| PAPERBARK® CLICK HERE | 58 % | EVENING HAZE® CLICK HERE | 57 % |
| SHALE GREY™ CLICK HERE | 57 % | SANDBANK® CLICK HERE | 54 % |
| DUNE® CLICK HERE | 54 % | WINDSPRAY® CLICK HERE | 52 % |
| PALE EUCALYPT® CLICK HERE | 40 % | BUSHLAND® CLICK HERE | 38 % |
| HEADLAND® CLICK HERE | 37 % | WILDERNESS® CLICK HERE | 35 % |
| JASPER® CLICK HERE | 32 % | MANOR RED® CLICK HERE | 31 % |
| WOODLAND GREY® CLICK HERE | 29 % | LOFT® CLICK HERE | 29 % |
| MONUMENT® CLICK HERE | 27 % | IRONSTONE® CLICK HERE | 26 % |
| COTTAGE GREEN® CLICK HERE | 25 % | DEEP OCEAN® CLICK HERE | 25 % |

*sourced from Colorbond information*

These TSR values are for Colorbond since they changed colour formulations in 2008 to increase infra red reflectance and made the surface less sticky for dust and dirt.

The darker colours previously had TSRs around 10 %.

The effect of going from the darker to the lighter standard Colorbond colours is roughly the same as the differences in the previous graphs between TSR=50 % to TSR=10 % or TSR=90 % to TSR=50 % because the best standard colours are not particularly good and nowadays the darker ones are not as bad as they used to be.  Of course if lighter and heat reflective paint membranes were to be used, then the benefits would be greater.

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# My white family room roof


*captured from Google Earth*

In 2008, I had my family room cleaned, primed and given 2 coats of acrylic gloss white paint. This has had a massive effect on airconditioner usage in the summer heat.

Nowadays if I were doing this for the existing family room, I would have paid for well-formulated heat reflective paints with harder, slippery surfaces that dirt and leaves didn’t adhere to as easily. I have to get up on the roof  in November and gently clean off dirt and leaf residues from the trees that have shed onto it.

For an existing roof that needs to reflect more of the Sun’s energy then the best option is a heat reflective paint membrane.

I have recently had an extension made to my house (not visible in this image) where I was able to get the builder to acquire Whitehaven (normally only available for large commercial projects) for the new roof. This is definitely not ideal in terms of temperature but was compromise based on ease of cleaning (as I get older) as a sprayed membrane will still have some surface roughness with primer & 2 layers of paint otherwise having to be applied

# Cost implications

In 2008, using Acryloc (with Thermilate addditive) would have cost \$1400 compared with an actual \$1000 to high pressure water clean, prime and put 2 coats of standard Vivid White on 50 $m^2$ of corrugated iron roof.

In 2010, \$500 - \$1000 extra on a \$3000 job to coat a 180 $m^2$ house roof with Dulux-AcraTex compared with standard paint.

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# Heat reflective paint conclusions

- It is possible to increase TSR by increasing the amount of energy reflected in the (invisible) infra-red part of the sun's spectrum where the sun's energy is still strong and still leave the visible colour unchanged.
- That can be done in most cases by selecting suitable pigment types.
- Additive particles could also be introduced to paints such that they only reflect in the infra-red without influencing colour.
- The emissivity can sometimes also be raised leading to better shedding of heat to the sky and lower surface temperatures.
- Heat reflective coatings should not retain dust and dirt.

The main benefits for light-coloured heat reflective paints is that well-formulated ones will have hardened surfaces that dust and dirt do not stick to as easily and they have been formulated to have higher emissivity than normal.

Dried acrylic paint (used for most exterior paints) has a relatively "sticky" surface for dust, dirt and leaves. If the paint hasn't been formulated to reduce the stickiness then you will be up on the roof every start of Summer to wash the roof so that dark dirt/dust/leaves are not reducing the effectiveness of the heat reflective surface (and your capital investment) This would be a major consideration for moving to a light, well-formulated, heat reflective paint rather than just a normal acrylic one.

It can be seen from Slide 42 that by good paint formulation, the emissivity of a heat reflective paint can also lead to cooler surfaces. That is not necessarily the case for all heat reflective paints.