Conclusions

If the main consideration is based purely on a financial return on investment then a commercially installed southern reflector would not be highly attractive, but, in the author's opinion and that of the two other owners, the intangible benefits alone (1-4 above) would justify the addition of reflectors to an existing single storey house.

If we could quantify these intangible advantages, the use of southern reflectors would be an excellent return on investment, making a significant contribution to low energy, happier indoor living and a reduction in the use of fossil fuelled heating, particularly if there is a reasonable amount of internal mass in the rooms receiving the reflected heat. If the rooms in a house without reflectors would have remained unheated there would, of course, be no financial saving and no saving in polluting gases - and the rooms may well remain effectively under-used.

If reflectors are properly integrated into a new house (5 above) then all rooms (north and south) would be equally useful and valuable to the occupant, giving much better return on total house investment.

From an estate planning point of view, (6 above) southern reflectors ensure more than adequate lighting and sun penetration to all internal areas allowing east and west windows to be eliminated (usually difficult to shade adequately in summer). This single factor alone makes terrace development easier to achieve, with several thermal and economic benefits.

If well constructed, reflectors should last for the life of the house.

The final advantage of southern reflectors is their ability to perform without any noise, with virtually no attention needed, virtually no maintenance, no pollution and at NO running cost. These are the sort of inherent values that all sustainability devices should strive to achieve if they are to be really successful.

We will have got nearer to our goal when we are able to say that we have eliminated the aphorism *"Passive homes require active occupants"* .

Acknowledgements

The author is very grateful for the overall peer review, and particularly the resolution of the Thermal and Economic Analysis willingly provided by Emeritus Professor R. John Sandeman, OAM, Visiting Fellow - Physics Faculties, Australian National University.

References :

Phillips, R.O. (2002), ***Sunshine and shade in Australasia***, CSIRO Publishing. Melbourne.

Table 1 (below) summarises the above more clearly.

item	Loss factors	Loss %	Energy reduction	Remaining energy kWh
	Incident energy for 183 winter days on 6 m^2 panel x 5 hours/day = 183 x 5 x 6 x 800 kWh.			**4392**
1	Sun angle changing 10m to 4 pm in Canberra during 1 Apr. to 30 Sept. azimuth and altitude sun angle data.	27	-1186	3206
2	Reflection off panel surface (Based on measurements)	33	-1058	2148
3	Loss through window glass – 4 mm clear single glazed.	16	-343	1805
4	Cloud cover in 53 of 183 days	29	-523	**1282**

Table 1 Summary of the reduction of the total radiation incident on the Mk4 reflector array in Pearce

Additional non-quantifiable advantages

The above figures describe only the quantifiable characteristics of the reflectors, but the author believes that the following *intangible and unquantifiable benefits are of at least equal in human value* and must be considered if a holistic evaluation is to be obtained viz :

1 - psychological delight *(having cheerful sunshine in southern rooms has, in the owners' opinions, had a marked effect upon their mental wellbeing),*

2 - avoidance of the recognised malaise - Seasonal Affective Disorder, *(due to deprivation of sunlight - a serious consideration in the UK , but not so problematic in Australia),*

3 - increased usefulness of the sunlit rooms, *(effectively an increase in available house size during winter months),*

4 - **increased internal comfort** *(during the insolation period which carries over into the evening period as a result of internal mass. This could be quantified in terms of less need for top-up heating in the evenings from natural gas and reduced atmospheric pollution),*

5 - increased design freedom for architects in designing houses *(southern rooms can now be as attractive for living in as northern rooms. This has not been possible for over 6000 years of architectural history),*

6 - **subdivisional planning of estates can now be more effective** *(due to houses being more square on plan rather than elongated E-W to make more efficient use of the northerly sun).*

An average over this 183 day period gives the loss as 27%. It is noted that the greatest loss during the 6 months period is at the equinox with a value of 44%. Titling the panel upward by 10 degrees can decrease this loss to 33%.

Provided the full reflected image is directed through the window, the overall efficiency can be improved by tilting to enlarge the image as much as possible and before cutting occurs at the window upper edge. Over the winter solstice period the losses reduce to 19% and remain within 19% to 21% from mid May to mid July.

2. Measurements have been taken of the ratio of the reflected to incident power from the panel using a standard Spectra-Physics power meter with a $1cm^2$ detector and a broad spectral range through the visible. The loss shown (33%) is an average over seven independent readings.

3. Losses in transmission through the 4mm window glass (16%) have been based on the solar heat gain coefficient standard value of 87% for 3mm clear window glass used by the Australian Industry and in turn based on American Standards (see "Specifiers Guide to Architectural Glass" at www.glasswebsite.com). For double glazing (3mm-3mm clear) the value would need to be increased to 24%.

4. **Cloud cover** loss (>2% cloud) April to Sept = 53 days out of 183 days = 29% *(BOM)*

The net result of this analysis is that the average daily radiated energy into the house from the panel is 1282/183 = **7.0** kWh / day over the full period of 183 days while a statistical sunny day provides **9.86** kWh /day. In real terms this is the equivalent of having a 1kW electric radiator on in the irradiated room for **9+** hours each sunny day.

The effective efficiency of the array is 1282/ **4392**kWh = **29**%.

When the capital cost of $3800 is considered, (for the Mk 4 reflector) having virtually no maintenance cost, absolutely no running cost, and a theoretical saving of 1282kWh @ 9.9c/kWh = **$127per year.**

Payback period would thus be $3800 /127 = **29.9 years.** In comparison at the average country rate of 15c/kWh, the pay back period is 19+ years.

The above was a commercial cost based on supply and construct. A very different picture is evident when such a system is *constructed by an owner on an existing framework (as in Figure 1)*, would produce a payback period of something like **9 years - a better incentive to DIY, particularly when the intangible benefits are taken into consideration**.

Figure 7 Mk 4 horizontally pivoted array 11 am

Thermal and economic analysis of a southern reflector :

Although all design aspects of the development of southern reflectors since 1993 have been almost entirely empirical, this analysis indicates that the tangible physical results are significant, quite apart from the unmeasurable benefits described later :

The Mk 4 reflector array shown above is used for this analysis

Table 1 shows the analysis for including the various losses which reduce the energy input into the house from the accepted overall energy onto the full area of the panels. In this analysis the panel is sited 15 degrees West of North as it is parallel to the South wall of the house and this is taken into account in the loss due to the changes in the sun angle to the panel over the 5 hours. However the effect of this 15^0 angle to the overall radiation onto the panel is less than 1%.

The accepted insolation in Canberra region = ~800W/m^2/hour, while the potential gross reflecting time during 183 days of desirable input in Canberra - April to September = ~ 5.25 hours / day av. *(Bur. of Meteorology statistics - BOM).* So - 6m^2 x 183 days x 5.00hours x 800W / m^2= **4392 kWh** gross *potential* incoming radiation over the cool season. The wall is full glass with an area greater than the reflector, so full acceptance of reflected image is assumed.

The individual items in Table 1 are explained below :

1 As the sun 'moves' across the sky from 10 am to 3 pm in June in Canberra the sun azimuth angle changes from 30 º E to 43º W and its altitude angle over the same period changes from 26^0 E through 32º N to 18º W.

However at the March and September equinoxes these values become 45 º to 60º (azimuth East to West) and 45º through 55º to 35º (altitude E through N to W)\. These changes reduce the overall energy incident onto the panel for the 5 hours by the cosine of all the angular changes. A numerical integration of both the azimuth and altitude changes has been done using the chart data from April through to September: Philips(2002).

The summer angle has a wide range of optimal absorption, (determined by an ammeter fixed close to the adjustment arm) and has been found to be effective anywhere between 25º and 45º *(coinciding well with latitude 35º + or - 10º).*

Winter angle for the reflector is determined by the window / reflector geometry and a vertical position is generally acceptable. The pivoting models allow easy changes.

Advantages

The unit is usable all the year round - an economic improvement.

It requires minimal occupier attention.

There has been no maintenance so far.

Large reflector panels (3 / 1500 x 950mm) give a more evenly spread image with no hot spots due to concavity and convergence.

When the PV side is facing south it should theoretically still generate 27% of its full potential (according to the BCSE chart). Today, 27 May, at noon it was generating 2amps when facing the sun and when reversed to face south it generated 0.2amps = 10%, but the PV panels could have been cleaner ! Measuring the direct solar influx from the north and also the south with an emission radiation meter gave a figure of 11%. A more quantitative evaluation may be undertaken in the future.

Disadvantages

Heavy steel framing makes assembly more difficult and expensive.

Design care is needed to avoid cumulative rotation of the centrally exiting electricity cable.

There is a small dilemma around May and September, dependent on the weather pattern - whether to choose warming sunlight or electricity generation - we can't have both!

Southern reflector commercial version - Mk 4

This reflector array was constructed in 2004 on a Canberra townhouse. It has five panels each 1200mm square horizontally pivoted for angular adjustment of the internal image and to allow them to be pivoted to horizontal during the summer months to shade the garden underneath.

The previously cold, gloomy and little used southerly rooms are now 8º warmer on the coldest of sunny winter days, much more cheerful and more effectively utilised.

Being only a two bedroomed unit this has made the available usable space significantly more comfortable and hence 'bigger'. The occupant now makes use of the second bedroom as a sewing room, even in winter (which did not previously happen).

The supporting framework of powder coated tubular steel is well anchored to the facia board with strong connections to the roof trusses as the $6m^2$ panels present a significant area to the wind. Both sides of the panels are reflective and from certain angles tend to 'disappear', minimising their visual impact on the garden space.

The 40º roof pitch has not significantly reduced the usefulness of the array, but the western neighbour's gable end cuts off the sun around 3pm.

Figure 4 Heat storage wall

Reversible reflector with photovoltaic panel - Mk 3

The Mk1 and Mk2 models still have the major disadvantage of only being useful during the cooler months. The double sided Mk 3 model (Figs. 5 / 6) now makes the device useful for the full 12 months - a reflector in winter and an electricity generator in summer. This works extremely well with 100% usage.

Figure 5 PV panels in summer mode

Figure 6 Reflector in winter mode - note reflection on window behind

The Mk 3 reversible unit is of a similar area to the Mk 1 fixed panels but sized to match the six PV panels (252W) which add to the main array to make a total generating capacity of 2.94kW which now supplies 100% of our electricity consumption .

The horizontal axis enables adjustment for optimum PV absorption in summer and for optimum positioning of the reflected image in the room in winter. The best angles have now been determined, requiring only two adjustments every year.

Advantages

The reflected sun is always at 90º to the window during all sunlit hours.

The full area of the reflector is utilised.

Its form has been designed as a sculpture to suit its position in a garden landscape.

Disadvantages

The Mk2 as built is essentially a professional research tool rather than a model for recommendation to the public. A simplified version is under development.

The commercial cost as built would be too expensive. Many parts have been recycled from car components so design would be dependent upon availability or expensive manufacturing.

It is only useful during the cooler months when internal sunlight is welcome.

Difficulty has been experienced with the burning of surrounding plants when the heliostat is parked in one position during the summer months.

Because of its rotational swept area and its location it had to be built at a greater distance away from the window. Consequently, the reflected angle of the sun is at a lower altitude and some glare is experienced in the room. This could be minimised in future installations by making it closer to the window.

Unfortunately the several reflector panels are not exactly flat (0.9mm stainless steel) producing dappled images on the receiving wall with varying absorbances which are hard to measure consistently. *(see photo figure 4).* The reflection from the Mk 3 reversible reflector with its larger panels is much more constant.

Heat storage wall *(completed May 2006*

The house is normal brick veneer construction with little internal mass, so in an effort to remedy this a 50mm concrete paving slab wall was built, leaving a 10mm air gap behind to encourage convection.

The surface of the plasterboard wall behind was painted with aluminium paint to reflectany radiant heat back to the slabs.

Spot recordings of surface temperature have been taken and one hot spot reached 51º around noon with about 30º in the surrounding areas.

Prior to the erection of this wall the internal room temperature often reached around 24ºon a sunny winter's day, purely from solar gain.

Thermochrons (computerised data recorders) are now in place to chart the thermal performance of the wall during the 2006 winter. Some data may be available in time for the September conference, but casual temperature readings in the areas surr ounding the heat storage wall have been a little higher than usual.

The wall has been painted dark green to maximise absorption.

In previous winters the angle of the heliostat placed the image more on the floor, but now that the image is raised to warm the wall more glare has been experienced when seated at the dining table. The glare is not a great problem, particularly when the benefits are taken into account.

Disadvantages :

The reflected image from fixed reflectors moves laterally from a small image on the west wall around breakfast time to a full image on the north wall around the middle of the day to a small image on the east wall around late afternoon. Also, when the sun is at high altitudes the reflected image can be smaller in area than the actual reflector area decreasing toward noon and increasing afterwards.

Supporting structure and panels entail extra cost (but the following analysis of the financial value of gained heat over an otherwise bare window reduces this cost to some extent.)

Southern reflectors are not suitable for ground floor windows in a two storey house or for multi-storey apartment blocks.

They are only useful during the cooler months of the year (6-7 months in Canberra).

In the warmer months the reflected image is outside the house (which is desirable), but the heat may affect any plants which are sunlit.

Despite these disadvantages the resulting effects are worth the effort. Subsequent versions - the Mks 2, 3 and 4 have overcome some of these problems.

Southern reflector Mk2 - a vertical axis semi-rotating heliostat

The heliostat is a compound array of flat mirrors, of irregular shape about 2.5m wide x 2m high, rotating slowly from east to west at 1.875º every 15 minutes to match the 'movement' of the sun. An electronic timer controls a roof mounted helical windlass which is connected to the heliostat by overhead cables.

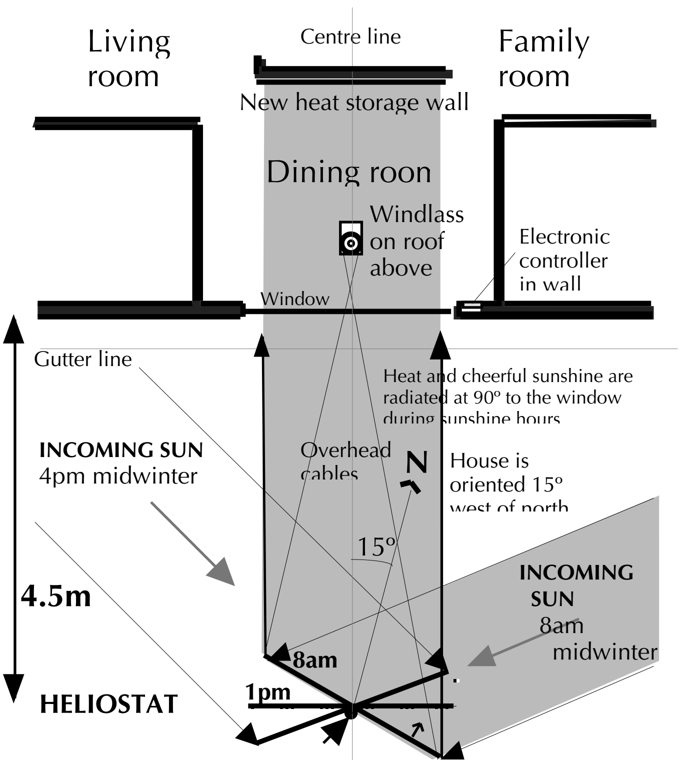

Figure 3 Heliostat / house relationship

Design parameters :

The size, angle and position of the reflector panel is a compromise between the following factors :

Ridge height, length and position relative to the reflector determine the first and last times that sunlight illuminates the reflector.

Bottom corner of the facia board determines the optimum height of the top edge of the reflector.

The distance of the reflector panel from the window determines position of the final image in the room - placing the reflector further away from the window reduces the angle of reflection giving greater penetration, but increases the possibility of glare.

The lower edge of the reflector panel should be above standing eyelevel of a person in the room so as not to restrict the view from inside.

The orientation of the window should not be more than about 30º from south so that the reflected image is not diminished by too acute an angle of incidence.

Large trees on the north side of the house could affect the positioning of panels and their shadow times should be plotted to avoid the placing of ineffective panels.

Advantages :

Three fixed arrays are now in operation in Canberra and all occupants are of the opinion that the value of the penetrating sunlight, creating a more cheerful atmosphere, is *just as important* as the radiant heat entering the room.

Up to 8º above normal internal temperatures have been recorded on cold (0º ambient), sunny, winter days in Canberra. The cheerfulness and the added warmth makes the rooms more comfortable and useful, in effect increasing the useful size of the house.

The gained heat is free and there is no electrical energy needed, nor any associated noisy equipment. Maintenance is effectively zero. Most dirt is washed off by the rain and any residual dirt does not seem to affect performance.

The panels are 'set and forget', not needing any regular angular adjustment, other than a possible 5º adjustment between spring and summer and autumn which only takes a minute.

Even if there is no sunlight the reflectors reflect *extra* daylight into the room from a cloudy sky compensating for the normally horizontal or low angle daylight which is usually restricted by trees and bushes around the house. Reflected moonlight has been experienced occasionally.

Currently, solar houses require a plan aspect ratio of about 2 : 1 to ensure optimum and effective solar gain in the northern half of the house. The use of southern reflectors now make it possible to reduce this ratio to almost 1.2 : 1, making it better suited to the narrower blocks which are becoming more common.

Sunlight is now possible in every room, both north *and* south, reducing or eliminating the need for east and west windows. This makes terrace development more practicable and economical. *(see EcoSolar house - separate paper by author).*

Most housing sites can receive far more solar insolation than any occupied house could utilise in any one day. Established evergreen trees can, of course, interfere with the absorption of this insolation, but this aspect is not discussed in this paper.

An average conventional house in Australia might receive a penetration of 0 to say 30 KWh of heat energy through suitable windows (assuming no curtains, blinds or shutters) and virtually none through southern windows. It has been customary since the dawn of architecture to regard useful (ie. winter) insolation as only incident to east, north and west walls (southern hemisphere).

Southerly rooms in houses have consequently been regarded as second class rooms, because they are cold, cheerless and become less enticing, effectively reducing the area of useful internal space during the cooler months.

Around 1993 the author experimented with a mirror on the southern side of a developer's house in Mawson, ACT and concluded that heat, light and desirable sunlight could be easily reflected from an area near the southern roof gutter through an adjacent window without interfering with the normal functions of the window - ie. light, view and ventilation.

Fixed reflectors Mk 1

The first on-site trial was a set of three polished stainless steel panels 0.9mm thick, each about 1200 x 1000mm, (sizes determined by the existing pergola) fixed in a vertical position and directly opposite a southern floor to ceiling bedroom window.

Figure 1 shows a section through a southerly room which has a full height window and it can be seen that the determining points which limit access of the incoming solar radiation and the optimum size of the reflector panels are :

the ridge height and position,

the lower edge of the facia board,

the distance of the reflector panel from the window,

the bottom of the panel and the standing eye level *(shown by red circles)*

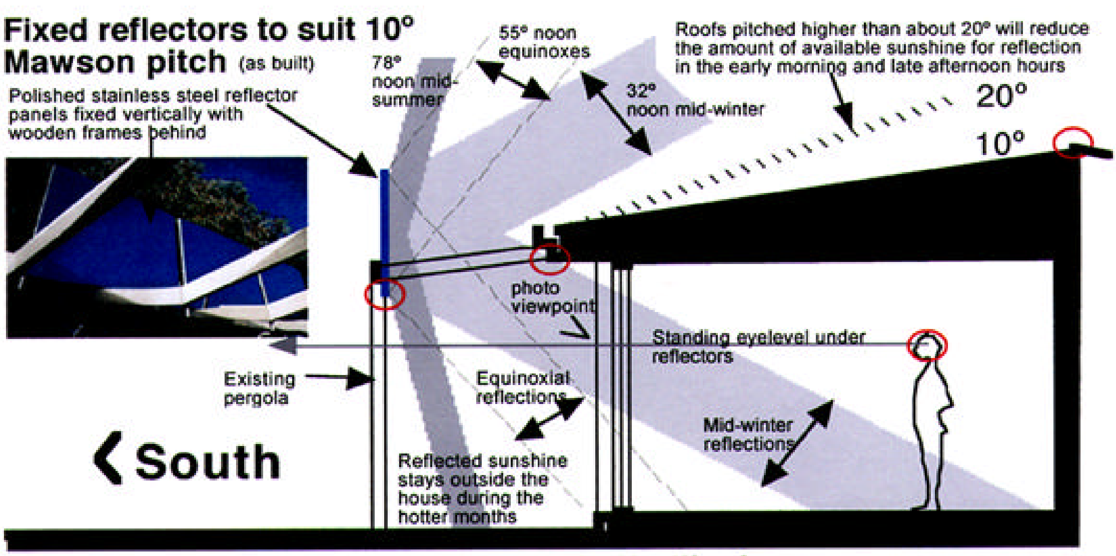

Figure 1 Sunpaths from reflector fixed to existing pergola with a 10° roof

Southern domestic reflectors - *capturing unused solar radiation*

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ABSTRACT

Since architecture started some 6000 years ago it has always been assumed that desirable solar penetration through windows can only occur on the sunlit sides of a building (in Australia on the east, north and west sides). This assumption is no longer a valid design guide, particularly for houses which would benefit from extra free heat in those regions having cool to cold winters.

Almost all existing, habitable southerly rooms in these regions (broadly 30º to 50ºS latitudes), particularly those without central heating, tend to be cold, gloomy and cheerless during the heating season and are consequently less used. Often these are bedrooms used as studies, offices or sewing rooms and require casual heating, usually of a polluting nature.

Since solar heat energy is free and often abundant in many areas in the cool temperate zones it could be used to better advantage in the heating of a house during the cooler months of the year by finding a means of reflecting otherwise 'unused' sunlight through southern windows.

Experimental reflective surfaces placed near a southern gutter have been found to reflect sufficient free heat (up to 8º above normal) into a southern room to justify its cost and with a bonus of extra light.

A further advantage has been experienced which is not quantifiable - cheerfulness -, now recognised as a major factor in personal wellbeing and a possible remedy for Seasonal Attitudinal Disorder (SAD).

The availability of sunshine into otherwise gloomy southern rooms can now improve their attractiveness and usefulness, increasing the effective size of the house during the colder months.

A commercial version has been designed and built and a calculation of its efficiency will be presented.

The full paper will describe the design iterations aimed at increasing the effectiveness and acceptability of southern reflectors as retrofitted to three existing houses in Canberra and their logical development as an integral element in a new, fully integrated EcoSolar house.

INTRODUCTION

This paper relates largely to housing in the cool temperate regions of Australia, but has relevance to similar areas between latitudes 30-50º south or north or areas of high elevation.