Comfort in an Unheated Solar-Passive House at Manilla: Two Years Data

J Garry Speight
Manilla

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Introduction

Much smaller amounts of firewood, or other heating fuel, are needed if houses are built to use and store heat from the sun, and are insulated to stop the heat from getting away. I have had such a "solar-passive" house built at Manilla, 100 km west of Armidale. This house has no installed heater.

The house has proved very comfortable to live in. In two years there were only six evenings, in July and August 2000, when I used portable electric blower heaters. The total cost of power for two years' heating was $6.00.

In this paper I present some of the temperature data collected in the solar-passive house over a two-year period. The data show the ways in which the solar-passive house modifies the indoor climate. I then review the main features of house design and maintenance that are effective in reducing the need for heating fuel. I conclude with remarks about the social implications of houses that waste heat.

Climate

The following climatic information is taken from the Bureau of Meteorology's web site: http://www.bom.gov.au/

The climate of Manilla is very similar to that of Tamworth. It is classified as "Temperate, no dry season (hot summer)". There is a low proportion of cloudy days (24%), and a large temperature range. At Tamworth the mean annual temperature is 17.3 degrees, the daily temperature range 14.2 degrees, and the difference between January mean temperature and July mean temperature is 15.5 degrees.

Armidale's climate is slightly cooler, and there are more cloudy days (36%). It is classified as "Temperate, no dry season (warm summer)". Although Armidale's mean annual temperature of 14.7 degrees is 3.6 degrees cooler than that of Tamworth, both of the cited measures of temperature range are lower. They are 13.2 and 14.0 degrees respectively. As a result, July minimum temperatures, which reflect the need for winter heating, are only 2.6 degrees lower than at Tamworth. In general terms, the winter climate of Armidale differs little from that of Manilla and Tamworth. The greater part of any saving in heating fuel that can be achieved in Manilla can also be achieved in and near Armidale.

The Solar-passive House

The house is medium-sized, at 153 m^2, and faces within six degrees of north. It is framed in cypress-pine, with a textured acrylic finish. Part of the steel roof slopes gently to the north, and part slopes moderately to the south. There is a north facing clear-story between the two parts.

Diagrammatic cross-sections are shown in Figures 1a and 1b.

The house was designed according to principles that are well established, and have been published in a number of books.[1234] Some aspects of the design that limit heating in summer will not be discussed.

Solar Access

A total of 20 m^2 of window area faces north. This is 70% of the window area, and 13% of the floor area of the house. Eaves protect these windows from the summer sun. Sunlight enters from mid-March to mid-October. A few trees obstruct the winter sun to a small extent.

Insulation

Reflective foil insulation (R = 1.0) is used in the walls and the roof. Bulk insulation as glass-fibre batts is installed in the walls to the value R = 2.50, and in the roof to the value R = 3.80.

To protect the soil and footings under the main concrete slab from heat gains and losses, this mass has also been insulated. I had sheets of 50 mm polystyrene foam placed vertically inside the strip footings to a depth of 300 mm to 900 mm. The edge of the floor slab, unfortunately, could not be insulated without risking termite entry to the house.

All windows on insulated walls are double-glazed awning windows. They are aluminium units with concealed frames (Rylock Victoria Series) that have a 5-Star winter rating. Room level windows are fitted with full-length heavy lined curtains and pelmets. The clear-story windows are not only double-glazed but use low-emissivity glass (Pilkington K-glass).

Windows and doors are well sealed. The ducts to fans in the kitchen, bathrooms, and toilet are self-closing.

Thermal Mass

Brick walls inside the house weigh about 25 tonnes. The concrete floor slab weighs 30 tonnes, and is mainly surfaced with dark-coloured ceramic tiles to absorb and radiate heat. Winter sunlight falls on much of the surface of these walls and floors.

As part of the thermal mass of the house, I include the volume of earth, gravel, bricks and concrete extending 500 mm below the floor slab. This makes a total of about 200 tonnes of thermal mass. I refer to the whole mass of material as the "heat bank". The internal brick walls are part of the heat bank, but their main function is to absorb and radiate heat, rather than to store it.

The cladding of the house has little thermal mass. It is light coloured to reflect heat. The walls are clad in fibre cement building board with an off-white textured acrylic finish. The roof is pale grey pre-painted steel.

Summer and Winter Regimens

The shading of north facing windows in summer, and their exposure to the sun in winter comprise only one aspect of seasonal change in the management of the house. I define a "summer regimen" and a "winter regimen" of house management. Curtains, windows, and doors are opened or closed, fans turned on or off, and awnings adjusted as required. Table 1 gives details.

I use motors on the curtains of north-facing windows, and on the sun porch shutter. These are very expensive. The reason for having them is that these curtains, in five different rooms, should all be opened and closed at the same time each day of summer and winter. In winter they should be opened each morning to let the sun in, and closed each evening to keep the warmth in. In summer, they should be closed each morning to keep the heat out. Then they should be opened each evening, along with the windows, to allow the house to cool. A clock controls the motors.

Ceiling fans in the clear-story spaces serve two functions according to the season. On summer nights they assist the stack effect by ejecting warm air through the clear-story windows. On sunny winter days they blow hot air down from the top of the internal brick walls. This allows the heat to be absorbed in other parts of the house, rather than being radiated away from the warm bricks at night.

Table 1. House Management Regimens 1999-2001

	Winter Regimen (Apr-Sep)	**Summer Regimen (Oct-Mar)**
Northern eaves	Expose all northern windows	Shade all northern windows
Northern curtains (5)	Open 06:40; closed 17:20*	Closed 06:00; open 18:00*
Sun porch shutter	Open 06:40; closed 17:20*	Closed 06:00; open 18:00*
Other curtains or blinds	Usually closed at night	Usually closed by day
Windows	Some open in warm weather	Some open in cool weather
Clear-story windows	Closed	Open
Clear-story fan direction	Downward by day; recirculating	Outward at night; stack effect
Clear-story fan control	Thermostat: on over 26 deg.	On 24:00; off 05:00*
Outside doors	Closed	Open 22:00; closed 07:00
Interior doors	Closed on cold nights	Open 22:00; closed 07:00
Laundry air-lock door	Closed	Open 22:00; closed 07:00
Sun porch air-lock door	Open on hot days	Open 22:00; closed 07:00
Panel-lift garage door	Open on hot days	Open 22:00; closed 07:00
Southern porch	East-facing awnings removed	East-facing awnings installed
Western verandah	Awnings: south down, west up	Awnings: west down, south up

* On automatic timers.

Awards

The house was a finalist in the category "Energy Efficient Home of the Year" in the 1999 NRMA HIA Housing Awards for NSW. It also was judged "Best New Project: Northwest/New England Region". This recognises the high standard of workmanship of the builder, Keith Freeman, of Manilla. Without his conscientious attention to detail, heat losses in winter would have been greater.

An assessor for the Nationwide House Energy Rating Scheme awarded the house "Five Stars". According to the NatHERS model of typical family use, one could expect to use 8000 MJ or 2300 kWh per year for heating and cooling. This would cost about $250.00. As a sole occupant, my annual heating and cooling cost has been one twentieth of this, mainly for electric fans.

Temperature Data

Indoor Versus Outdoor Maxima and Minima

Figure 2 is a scatter-plot of daily maximum and minimum temperatures. The diamonds relate the daily maximum temperature "indoors", on the wall of the dining room, with that "outdoors" on the back porch. These maxima do not actually occur at the same time, but they express the modifying effect of the house. The squares relate the daily minimum temperatures indoors and outdoors.

While outdoor temperatures ranged from minus one degree to plus forty-one degrees, only about 5% of indoor temperatures fell outside the "comfort zone" that extends from sixteen degrees to twenty-nine degrees.

Regression lines have been fitted to the two sets of data. They almost coincide. The slope of the regression line for minima is only 0.35, showing that the house damps out almost two thirds of the temperature variation. According to the equation, when the temperature outdoors is zero, that indoors is more than fifteen degrees.

Annual Log of Morning Temperatures

While I read daily maximum and minimum temperatures each morning at only a few stations about the house, I read instantaneous temperatures at many more. Some of these readings have been used in Figures 3 and 4.

Figure 3 shows the cycle of temperatures for the year 2000 at several stations. To damp out day-to-day fluctuations, I have plotted 13-day running means. The "Outdoors" curve is taken from readings on the verandah. It shows seasonal and weekly temperature trends in the environment. It reflects the published climatic range of about 15 degrees between January and July temperatures.

Two other curves are shown. The Dining Room represents air temperature in the core of the house, where solar-passive features are most effective. The Garage, although built against the house, is insulated only with reflective foil.

In summer both of these curves lie close to the "Outdoors" curve. One would prefer the house to be cooler than the environment, but this is hard to achieve. Ventilation at night brings in air that is not much cooler than the air it replaces.

In winter the curve for the Garage shows morning temperatures 3 to 4 degrees warmer than Outdoors. The Dining Room is 8 to 10 degrees warmer than Outdoors, and there is less variation.

Morning temperatures in the Dining Room fell as low as 16 degrees. This would be quite comfortable for a person in bed, but is rather cool for one having breakfast. This can be a problem in any house in this climate. If the house is unheated, there is a short period after one gets up when the temperature is cooler than it was in the late evening. If the house is heated, it is inconvenient and wasteful to reheat it for this very short time.

Log of Morning Temperatures in Autumn

Figure 4 shows data for the last three months. It introduces four more curves:

1. The Heat Bank temperature is measured 0.75 m below the floor of the Ensuite bathroom in the core of the house. The temperature here changes so slowly as to require no averaging. It takes more than two days for a change in temperature to affect this point.
2. A Lower Room at the west end of the house is built slightly into the ground. The floor slab is not effectively insulated from the surrounding soil.
3. An Upper Room is built over the Lower Room. Its walls and roof are insulated to the same standard as the core of the house.
4. An unoccupied Neighbour's House represents conventional, non-solar-passive construction. It was built in 1960, on a concrete slab, with weatherboard cladding a wooden frame. The low-pitched roof is steel. There is no insulation and there are only sheer curtains.

During the period shown in Figure 4, the regimen of management of the solar-passive house changes. On April 1 the winter regimen begins, as detailed in Table 1. All curves were close together and nearly parallel before April 1. By ten days after that date they are wide apart, and they remain so.

Morning temperatures in the Neighbour's House are generally warmer than Outdoors, but by less than 1 degree.

The Garage of the solar-passive house is slightly warmer than the Neighbour's House. The Dining Room is 6 to 8 degrees warmer than Outdoors, and the difference is increasing as the winter goes on.

After the change of regimen, the Heat Bank warms up, relative to Outdoors, over a period of about 40 days. Solar heat absorbed into the floors and internal brickwork takes that time to penetrate 0.75 m below the floor. By mid-May the Heat Bank is only a little cooler than it was in early March.

The Lower Room is about 2 degrees cooler than the Dining Room. I believe this is due mainly to the deficient insulation of the lower floor slab. There may be other factors as well.

The Upper Room is colder than the Lower Room, and only slightly warmer than the un-insulated Garage. This surprised me. I infer that there is too much surface area losing heat, and the room is too far from the brickwork of the heat bank. It seems that upper floors may be unsuited to solar-passive design in this climate.

Maximum/Minimum Temperature Logs

Figures 5a and 5b are logs of daily maximum and minimum temperatures over a recent 48-day period. Vertical bars represent the observed daily outdoor temperature range, while a shaded zone represents the daily indoor temperature range. The two figures contrast the response of the neighbour's conventional house and the solar-passive house.

In Figure 5a, showing data for the conventional house, one sees that the indoor and outdoor daily maxima are almost the same. Daily minima indoors are generally about 5 degrees warmer than those outdoors. A daily temperature range of 13 degrees outdoors becomes 8 degrees indoors. Although it is built on a concrete slab, the house does not store heat from one day to the next.

Figure 5b shows data for the solar-passive house. Compared to the conventional house, the indoor daily temperature range is reduced from 8 degrees to 4 degrees, but this is not the main difference. The indoor daily maximum is not closely tied to the outdoor daily maximum. There is a day or more of lag, and the curve is much smoother. In cases where the outdoor daily maximum drops by 6 degrees from one day to the next, the indoor daily maximum typically drops by only 1 degree. On cold days the indoor daily *minimum* temperature is usually warmer than the outdoor daily maximum. The action of the heat bank stabilises the indoor temperatures. They tend to remain constant, not only from day to day, but also from week to week.

Annual March of Mean Monthly Temperature

The annual cycle of relationships between indoor and outdoor temperatures is a curve with hysteresis. This is shown in Figure 6a. While people respond to daily maxima and minima, because they tend to exceed the limits of comfort, the annual cycle of temperature relationships is more conveniently shown using mean monthly temperatures.

In Figure 6a, the Outdoor temperature is taken on the back porch; the Indoor temperature is taken on the dining room wall. The figure includes a line showing where indoor and outdoor temperatures would be the same. For points to the left of the line, indoor temperature is warmer than outdoor temperature. For points to the right of the line, the opposite is true.

During the summer regimen, from October to March, the data points lie close to a straight line which diverges slightly from the "Indoor = Outdoor" line. October and November lie near that line, but by January and February the temperature is nearly 2 degrees cooler indoors than outdoors. This results from opening the house by night and closing it by day.

The change to the winter (solar-gain) regimen makes the April mean temperature indoors a full 6 degrees warmer than that outdoors. In May and June the excess is 8 degrees. By September the heat stored in the heat bank has been drawn down to the extent that the excess has fallen to only 4 degrees.

The cyclic behaviour of the heat bank itself is shown in Figure 6b. The pattern is like an ellipse. The length of the horizontal axis is 16 degrees, agreeing with the climatic data, and that of the vertical axis, the annual temperature range of the heat bank, is just over 4 degrees. While the maximum environmental air temperature occurs at the end of January, and the minimum at the end of June, the maximum and minimum temperatures in the heat bank (at 0.75 m depth) occur about two months later. This helps to stabilise the temperature of the house. It does, however, leave the house vulnerable to heat waves in autumn, when the heat bank is still very warm, and to cold snaps in spring, when the heat bank is exhausted.

Costs of Solar-Passive Measures

New Houses

Cost-free Measures

Some factors in solar-passive house design cost nothing. Many houses lose a lot of heat because the area of windows is too great. The area could be reduced for an actual cost saving. Most windows should face due north, and they should not be shaded from the path of the winter sun.

The house should be a simple shape, so that one part of the house does not shade another. I believe that second storey rooms lose too much heat.

The site should be well chosen. One can avoid, for example, frost hollows, steep south-facing slopes, and blocks that prevent aligning the long axis of the house east west. This may cost money, but it may not, given the state of public ignorance.

Cost-effective Measures

Table 2 lists the actual costs (in 1998) of energy-efficient measures included in my house. Not all of these are cost effective. In particular, neither the installed heat-pump hot-water service, nor a solar hot water service are likely to return their cost under the present electricity pricing regime[5]. Motorised curtain tracks are an expensive luxury, but without them the quality of this set of temperature data would have been lower.

The three listed energy-saving measures that I believe to be cost-effective are insulation, double-glazing, and brickwork for the heat-bank. The net cost of each was about $5000. In the case of double-glazing, I found Rylock Australia, based in Victoria, to be the *only* company offering high-efficiency windows at a reasonable price.

The list does not include some cost-effective items that could be considered unavoidable expenses. The concrete floor contributes to the heat-bank. It is largely tiled, rather than being carpeted. Heavy curtains are fitted, and are topped with pelmets. There are several fans to encourage air circulation. These cost little and are cheap to run.

Table 2. Cost of Energy-efficient measures for the Manilla House

Feature	Detail	Materials	Labour	Deduct*	Net Cost
Insulation	Footings: styrene foam	$600	$60		$660
	Walls: R2 batts	$800	$100		$900
	Walls: foil	$330	$300		$630
	Roof: R3 batts	$1170	$160		$1330
	Roof: foil	$440	$400		$840
	Total Insulation	$3340	$1020		**$4360**
Double glazing		$12,500		$7,000	**$5,500**
Brickwork	Interior	$3,200	$3,500	$1,900	**$4,800**
Hot water service	Heat pump (Quantum)	$3,200		$900	**$2,300**
Curtain track	Motorised	$6,000	$1,000	$400	**$6,600**
Shower roses	Water-saving	$140		$70	**$70**
					$23,630

*Deduct cost of non-energy-efficient alternative**.**

Existing Houses

Extensions and Renovations

When extending or renovating a house, one may include any of the measures mentioned. That will ensure that at least part of the house requires little heating. This can become the main living area.

It is astonishing to see renovations in progress that will clearly make a house more difficult to heat.

Making old houses more comfortable

If a house does not have insulation in the ceiling, installing it will often be practical and cost effective, yielding a dramatic improvement in comfort and fuel economy. Simple forms of double-glazing can also be tried. Old houses, even if well built originally, tend to become draughty with age. One can improve comfort by stopping the worst air leaks. Well fitting heavy curtains are essential.

Outside the house, few people seem to have noticed how trees have grown up to shade the house from winter sun. These should be cut down. There should be no trees to the northeast or the northwest, and only low trees or shrubs anywhere to the north of the house. For summer shade, the most valuable shade trees will be east, southeast, west, and southwest of the house.

Awnings fitted to north facing windows are seldom retracted or removed in winter, and it is rare for curtains to be drawn back in daytime. One wonders what would persuade the occupants to let in the sun.

Social Questions

Affluent people able to build new houses are often ignorant or irresponsible in their approach to house design. However, the proportion of the housing stock that will be improved by educating them will grow only slowly.

Many of the houses that need the greatest amounts of energy to maintain winter comfort are old, and poorly built. Typically, those least able to afford fuel for heating occupy them. In fact some occupants of heat wasting houses receive subsidies to help them pay for fuel.

This social problem has been addressed with striking success in the USA. The U.S. Department of Energy's Weatherization Assistance Program (http://www.eren.doe.gov/buildings/weatherization_assistance/) has, since 1976, "weatherized" over 5 million homes at no cost to the occupants. The Department claims a remarkable cost-benefit ratio of 1:1.8 in terms of energy saved. Professionally trained crews from state or community agencies audit the energy status of houses of low-income families, and install appropriate energy-saving measures.

I have not heard that such a system operates in Australia. It seems very sensible. Australia's mild climate does not demand such high use of heating fuel, but the social costs of fuel use are significant. In the case of firewood smoke, whole neighbourhoods are affected by air pollution from heavy use of firewood. Certain houses could be so badly sited, and with such intractable problems of energy loss, that the occupants might be better relocated at public expense.

Reference

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[5] Anon. (1999) Hot water from sun and air. Choice December 1999, pp 29-37. (Australian Consumers' Association)

List of Figures