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Monitored Thermal Performance of Passive Solar Designed Display Homes in Perth, Western Australia

G.M. James, M. Anda and K. Mathew
Environmental Technology Centre
Murdoch University
Murdoch WA 6150
AUSTRALIA
E-mail: g.james@murdoch.edu.au

Abstract

A number of sustainable demonstration homes have been built in Perth over the last 5 years. This paper will report on data gathered at two of them, provide a comparative assessment and present lessons learnt. A fundamental inclusion in a sustainable house is Passive Solar (PS) design. PS design is a simple methodology for the design of energy efficient buildings that can reduce the need for mechanical heating and cooling, therefore reducing the need for energy to operate active systems. PS design is a regionally specific design methodology whereby the general climate of a house site needs to be analysed to best ascertain what design features will be needed. In Australia, due to the extremes of conditions, house designs will vary greatly by state, which is also due to the established building industry. The uptake of this design rationale has been very slow, with houses mainly relying on air-conditioning. The design of a PS building follows several basic principles: Orientation, Glazing and Protection, Thermal Mass, Insulation, Ventilation and Zoning. A PS house uses a system of windows, walls and insulation to control the flow of energy to maintain temperatures at comfortable levels for occupation. Separate components are not monitored, just the capacity for the building to have stable internal air temperatures, which is what inhabitants will detect. The range of temperatures for Thermal Comfort (TC) is 18 to 28^{O}Celsius. The Subiaco Sustainable Demonstration Home (SSDH) is a collaborative effort between the local council and the building industry to create a house that uses fewer resources than normally built homes during its construction, use, and eventual demolition. Harvest Lakes, the first Housing Industry Association (HIA) GreenSmart estate in Western Australia, showcases 'The Elements' Sustainable Demonstration Home (ESDH) as an example of a possible sustainable future of residential construction and living. With a PS design based on a standard plan, the ESDH could easily be replicated in various other locations around Australia. Each house has been monitored for at least the last year using stand-alone temperature data-loggers to record the air temperatures in different rooms to give an indication of the effectiveness of the PS design in terms of maintaining temperatures within established TC thresholds. Results collected to date indicate that a PS building can be thermally comfortable, but it does require occupants to 'drive' them to maximise the benefits of the design.

1. INTRODUCTION

Sustainable display homes have been built or retrofitted in five suburbs of Perth Western Australia in recent years. An integral part of a sustainable building is its capacity to maintain internal temperatures at comfortable levels for the occupants without the use of active systems

This report looks at the monitored thermal performance of two of these houses, the Subiaco Sustainable Demonstration Home and 'The Elements' Sustainable Demonstration Home. Despite being designed using Passive Solar principles, both houses have very different features.

Thermal monitoring projects were undertaken whereby air temperature and humidity monitoring dataloggers were placed in several rooms of each house and set to record data at 5 or 10 minute intervals. The data has been collated and analysed with the results shown in graph and table form.

2. PASSIVE SOLAR DESIGN

2.1. Passive Solar Principles

A fundamental inclusion in any sustainable house is Passive Solar (PS) design. PS design is a simple methodology for the optimised design of energy efficient buildings to control the flow of energy in and out, thereby reducing the need for mechanical heating and cooling and the need for fuel to operate these energy hungry active systems.

PS design is a regionally specific design methodology whereby the general climate of a house site needs to be analysed to best determine what design features will be needed. In Australia, house designs will vary greatly across States and Territories due to the variability of climatic conditions, but also due to the varying building industry methods of construction. The uptake of this design rationale in recent years has been very slow, with houses mainly relying on air-conditioning, which are becoming increasingly cheaper to purchase, but more expensive to operate.

The design of a PS building follows six basic principles:

Orientation – the most important factor for PS design which allows for the greatest control of energy into a building. The SSDH and ESDH are orientated within 5 degrees off north. It is possible for a house to accidentally be passive solar if it is orientated correctly.

Glazing and Protection – during winter, glazing allows short-wave radiation through which is absorbed by the building fabric. Internally emitted long-wave radiation is then blocked from escape by the windows, keeping the building warm. External protection in the form of solar louvres, shade sails or vegetation is required to block absorption of heat during hot summer months.

Thermal Mass – a PS building requires a method of absorbing the energy from incoming solar radiation. Thermal mass is used to reduce temperature peaks and troughs by slowly releasing or absorbing energy when needed (Hollo, 1995).

Insulation – is integral to the control of internal building temperatures by slowing the transmission of heat from outside to inside during summer, or the reverse in winter. Insulation can be bulk or reflective and is selectively installed in the roof, ceiling or walls of a building as required (Hollo, 1995).

Ventilation – is the only method of naturally cooling a building in summer (James et al, 2004b). A PS house will need to be purged of excess heat during summer by the movement of air through and out of the building. Proper sealing during winter is also required to limit energy loss from problems such as draughts.

Zoning – is used to ensure living spaces are within appropriate temperature ranges. In the southern hemisphere, the north side of a building will always be warmer than the south, meaning living areas are the preferred use for the area. Bedrooms are therefore preferably placed on the cooler south side.

2.2. Monitored Passive Solar Houses

House 1 – Subiaco Sustainable Demonstration Home

The Subiaco Sustainable Demonstration Home (SSDH) is a collaborative effort between the local council and the building industry to create a house that uses fewer resources than normally built homes during its construction, use, and eventual demolition.

It is a simple two-storey design on a small block. It is a custom one-off construction, but could be replicated in many parts of Australia and still perform. The house is passive solar, energy efficient, low-allergen and has universal and adaptable features for the handicapped or disabled. The house features three bedrooms plus a study, two bathrooms, two powder rooms and two separate living areas. Wet areas are also clustered for reduced material use and energy efficiency of the gas boosted solar hot water system.

The floor plan of the SSDH is shown below in Figure 1.

Figure 1: SSDH floor plan

House 2 - 'The Elements' Sustainable Demonstration Home
Harvest Lakes, the first Housing Industry Association (HIA) GreenSmart estate in Western Australia, showcases 'The Elements' Sustainable Demonstration Home (ESDH) as an example of a possible sustainable future of mainstream residential construction and living. With a PS design based on a standard plan, the ESDH could easily be replicated in various other locations around Australia.

The house is a single-storey design with three bedrooms plus a study, two bathrooms, theatre, and large open-plan living area. The house has been designed to be replicated, with the builder currently offering it for construction in the Perth area. It also includes an innovative automatic night-cooling system that opens louvres and pumps hot air from the house when it gets too hot inside.

A floor plan of the ESDH is shown below in Figure 2.

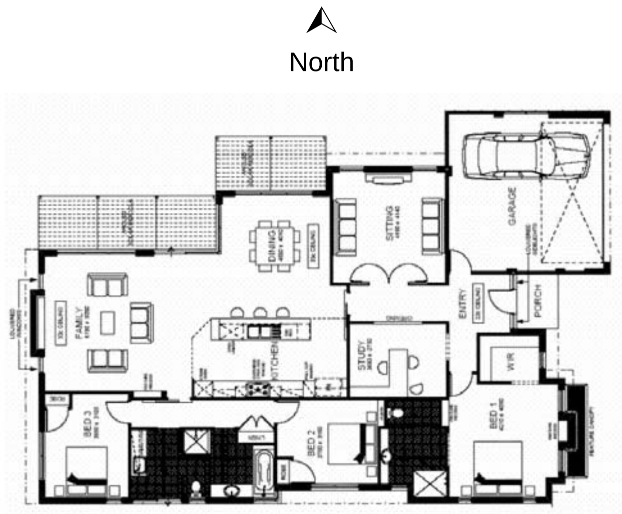

Figure 2: ESDH floor plan

3. METHODOLOGY

The monitoring systems for both the ESDH and SSDH use the same type of standalone data-logging equipment to measure air temperatures and humidity levels. The dataloggers are set up to record data at five or ten minute intervals and operate 24 hours per day.

The focus of monitoring internal temperatures at both display homes is to ascertain how well the cited PS design works to make the internal temperatures of the building comfortable for human habitation.

The results shown in this report are calculated averages for different zones (living and bedrooms) in each house. Results should ideally be within the established TC thresholds of 18 and 28^{O}Celsius throughout the year (Hedge, 2003).

4. RESULTS

Results in this paper are from the 1st to 17th February 2006 and 15th to 31st May 2006. A summary of the data collected during February are shown in Table 1 below. May results are shown in Table 2.

Table 1: Summary of results from 1-17 February, 2006

	Outside Ambient	SSDH		'The Elements'	
		Living	Bedrooms	Living	Bedrooms
	^{O}C	^{O}C	^{O}C	^{O}C	^{O}C
Average	23.9	24.1	23.7	26.2	25.6
High	35	28.8	28.6	30.4	29.6
Low	11.61	20.1	18.2	21.9	21.2
Hours in monitoring period		408 hrs	408 hrs	408 hrs	408 hrs
Hours **above** TC		8.9 hrs	9 hrs	84.4 hrs	50 hrs
Percentage **above** TC		2.2%	2.2%	20.7%	12.3%

Table 2: Summary of results from 15-31 May, 2006

	Outside Ambient	SSDH		'The Elements'	
		Living	Bedrooms	Living	Bedrooms
	^{O}C	^{O}C	^{O}C	^{O}C	^{O}C
Average	14.8	20.6	18.8	19.5	18.2
High	25.1	23.4	22.2	23.8	21.5
Low	3.8	17.3	15.6	16.1	14.6
Hours in monitoring period		408 hrs	408 hrs	408 hrs	408 hrs
Hours **below** TC		14.1 hrs	73.4 hrs	91.8 hrs	165.6 hrs
Percentage **below** TC		3.5%	18.4%	22.5%	40.6%

Figure 1 shows the zone temperatures in the SSDH between the 1st and 17th February, 2006. During this time, the SSDH went **above** the established TC threshold on one day.

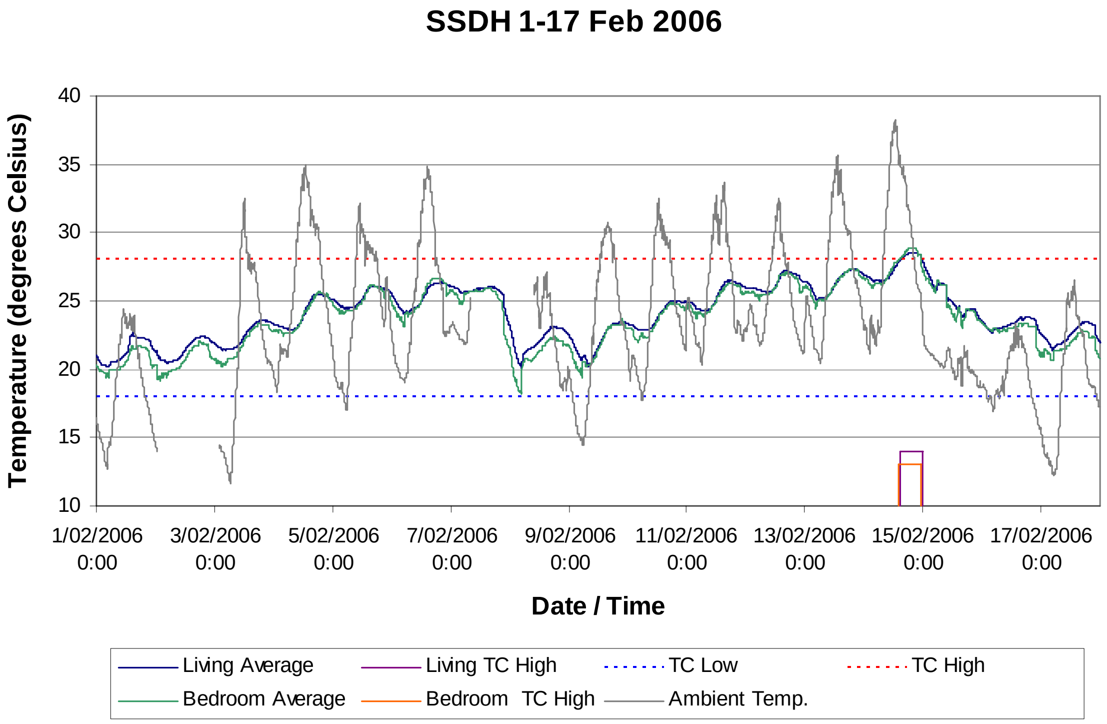

Figure 1: SSDH – February 1 to 17, 2006

Figure 2 shows the zone temperatures in the ESDH between the 1st and 17th February, 2006. During this time, the SSDH went **above** the established TC threshold on nine days.

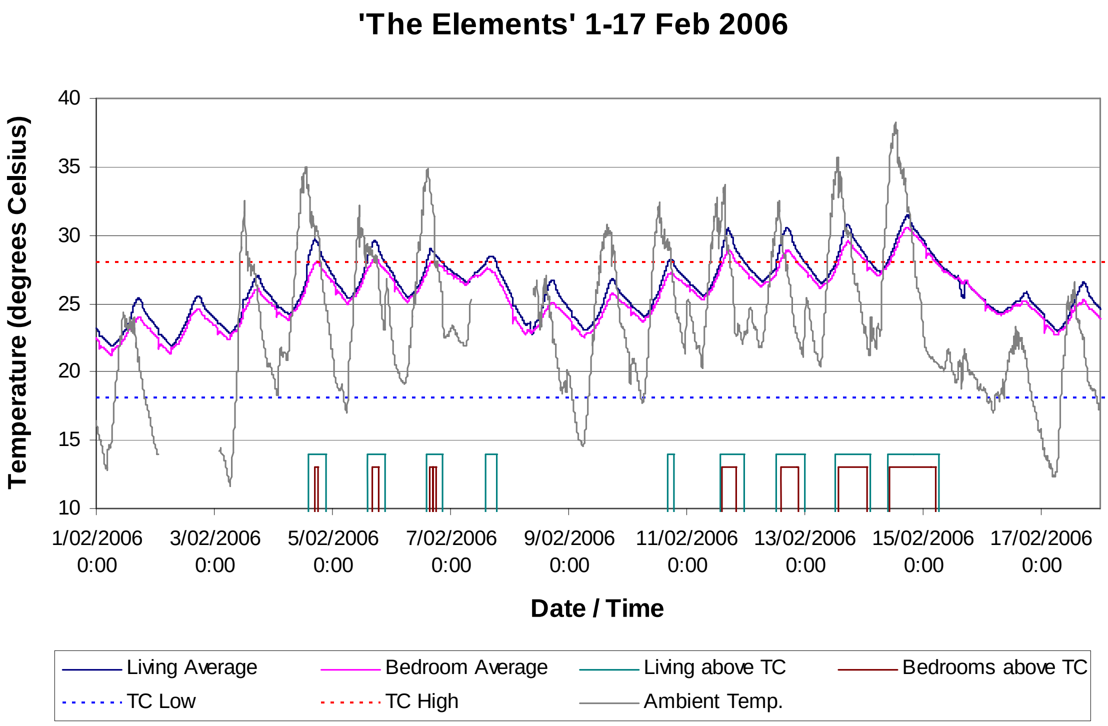

Figure 2: 'The Elements' – February 1 to 17, 2006

Figure 3 shows the zone temperatures in the SSDH between the 1st and 17th February, 2006. During this time, the SSDH went **below** the established TC threshold on eight days.

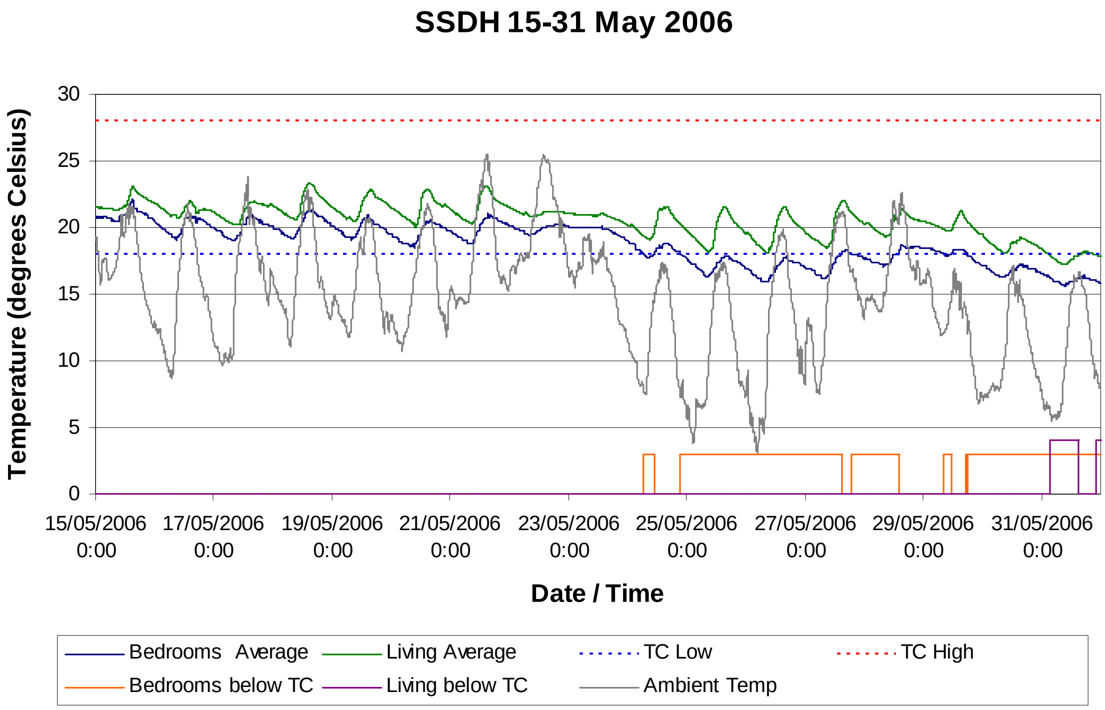

Figure 3: SSDH – May 15 to 31, 2006

Figure 4 shows the zone temperatures in the ESDH between the 1st and 17th February, 2006. During this time, the SSDH went **below** the established TC threshold on ten days.

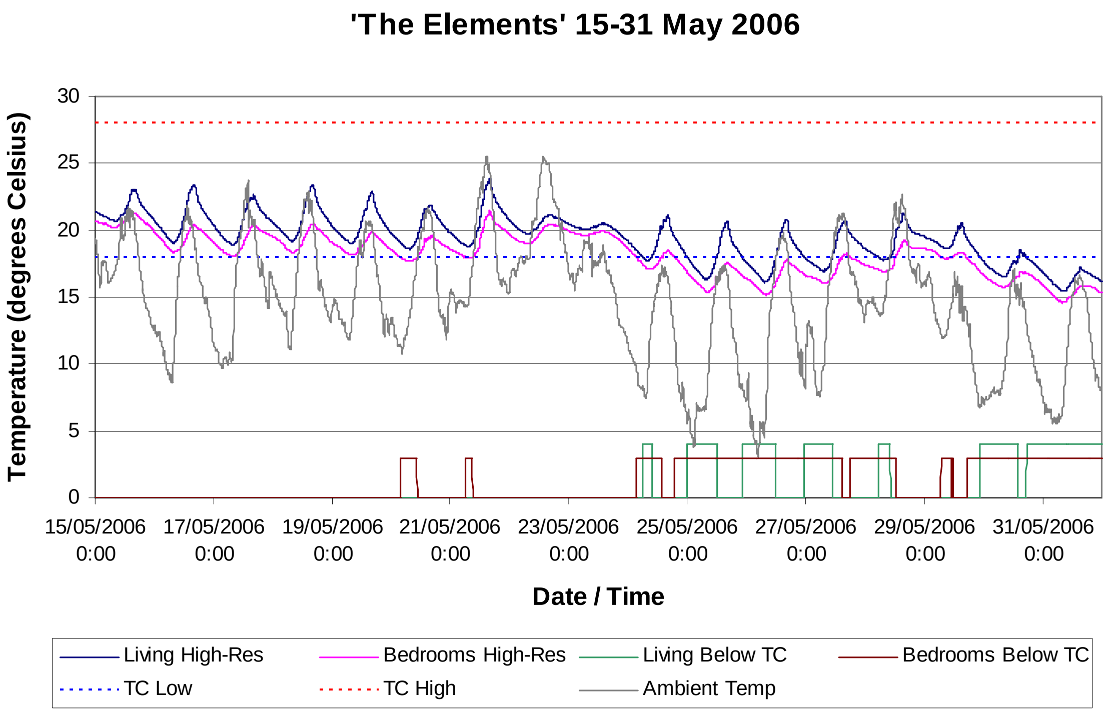

Figure 4 'The Elements' – May 15 to 31, 2006

5. DISCUSSION

5.1. Not-Passive Solar Design

Monitoring data collected at both the SSDH and ESDH indicate that the single most important factor for enabling TC is the occupants themselves. The SSDH and ESDH are both display homes and are therefore not permanently lived in. They are occupied for 10-15 hours per week which is not enough time for the users to have any real effect on their performance.

Passive Solar design gives the capacity for a building to perform well, but it is the users that maximise the possible benefits. The results presented in this report represent times when there is nobody opening and closing windows and window treatments at the appropriate times. PS buildings require more input than their name suggests (James et al, 2004a).

5.2. Design Comparison

The diversity of design possible whilst still following passive solar principles is shown in both the SSDH and ESDH. The SSDH is a two storey structure on a small block that has several design limitations due to the site. The ESDH is a single storey residence that is based on a project builder's standard plan.

They have totally different lifestyle focuses, and are very different, but the fundamentals of good design are included which is the most important factor of a PS building. It is primarily the design that allows a PS building to perform, with materials being secondary.

An analysis of the plans indicates there are weaknesses in their designs that will have an effect on their performance.

The SSDH had site limitations that meant the garage could only be placed in the north-east corner. This blocks sun to almost half of the ground floor, meaning it is more difficult to keep warm.
The ESDH seems to have ventilation problems that limit the flow of air through and out of the building. It has three distinct zones that are only linked with single doorways.

5.3. Performance Comparison

A comparison of the data collected from the two houses indicates that the SSDH remains within established TC levels for longer than the ESDH.

Summer (early February)
Monitoring data (Table 1) during the summer period shown indicates the SSDH was above TC levels for much less time than the ESDH.

Winter (late May)
Monitoring data (Table 2) during the winter period shown indicates the ESDH was below TC levels for much longer than the SSDH. Figure 3 also shows that it was mainly in the bedrooms of the SSDH that were cool, while the living areas were within TC levels, unlike the ESDH (Figure 4) where it was both zones getting cool most of the time. The primary reason for a PS house to be cool is the lack of sunlight exposure.

In determining which house is the better performer, it is necessary to consider the general climate of Perth. Residing in what is considered a Warm Temperate zone (ABCB, 2002), Perth has cool winters and hot summers. This means there is a need to skew the focus of design of a building towards keeping cool.

The SSDH appears to be the better performer because it has better ventilation, which is the only way of naturally cooling a building (James et al, 2004a).

5.4. Standard Construction Techniques

The ESDH and SSDH have been designed using completely different methodologies, whereby one was designed for a particular site (SSDH), and the other was an altered standard plan from a project builder (ESDH).

The SSDH and ESDH are both examples of how it is primarily the design and not the building materials that are the integral factor for a passive solar building. The SSDH and ESDH are both constructed using standard construction techniques for Perth. The ESDH is completely double-brick construction, whilst the SSDH is primarily double-brick with the small addition of one reverse-brick veneer wall and a rammed earth stairwell.

5.5. Low Uptake of Passive Solar

PS design is still a niche market in the mainstream Australian building industry. It works contrary to the current purchasing method of a buyer picking their favourite plan and then placing it on any block. An energy efficient building requires site analysis for PS design, which is considered to be a limitation, not a strength.

5.6. Monitoring during occupation

The SSDH and ESDH both require monitoring during permanent occupation. Data collected so far is not truly representative of their possible performance. Only temperature monitoring has been possible whilst the houses were display homes because other environmental factors (electricity and water) require permanent occupation to collect relevant data.

The SSDH has been sold to a private owner at auction. The conditions of sale include a requirement for at least one further year of monitoring, but no development limitations have been imposed, meaning the new owners may just install air-conditioning and not use the PS design to its full capacity.

The ESDH is due to be occupied and monitored for a period of 12 months.

The future monitoring programs for both houses are still in development. The SSDH and ESDH are both cited as ‘sustainable housing’ that require less resources to operate than normal housing. Future monitoring of both houses will include electricity and water monitoring, and possibly more intensive thermal monitoring to better ascertain how much of the thermal performance is due to the house, and how much can be attributed to the occupant.

6. CONCLUSION

Passive solar design is a site specific methodology for design which is not often enough implemented in Australia. The topic has been studied in detail and employed throughout the world, but it is still not a mainstream idea, or embraced by the Australian building industry. It is actually considered a hindrance to building and selling houses as it limits the design options available, which is not welcomed by consumers.

Despite their comprehensive temperature monitoring, the data collected at both the SSDH and ESDH to this point is only valuable for comparison with future monitoring results when the houses are occupied.

Passive solar buildings are not as passive as the title suggests, as they still require some input from occupants to react to the external environmental conditions to manage the buildings internal temperatures to within established TC thresholds. It is the human factor that allows a PS building to perform well above the standard for normal homes.

The SSDH has proven to be a better performer because it can remain cooler during Perth’s hot summer than the ESDH. The SSDH is also slightly warmer in winter than the ESDH.

Monitoring of the houses will continue and the results will hopefully prove to the general public the benefits of employing the Passive Solar design rationale.

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