Thermal Performance of Lightweight Solar Housing for Peri-urban Villages

Goodfield D, Anda M, Hammond R and Mathew K

Environmental Technology Centre, Murdoch University, AUSTRALIA
E-mail: m.anda@murdoch.edu.au

Abstract. This study concerns an investigation into the thermal performance of prefabricated lightweight houses for peri-urban villages in the Perth Metropolitan region of Western Australia. Several styles of residence were selected for comparison taken from three constructed "lifestyle villages". National Lifestyle Villages Pty Ltd (NLV) is committed to quadruple bottom-line sustainability and the aim was, therefore, to provide indicators of how old and new dwellings compared under the same external conditions. The buildings themselves are prefabricated and brought to site in two halves, framed in steel clad with fibre-cement boarding, roofed in zincalume sheeting, and timber floored with applied fibre-cement sheeting. Although designed using passive solar design principles and other energy conservation measures they possess little thermal mass to improve the thermal performance. Research by the author indicated several feasible and low-budget innovative improvements for future designs, and how best to retrofit existing dwellings. NLV's aim is to provide homes for over 40,000 people in 100 villages Australia-wide by the year 2025. Any improvement in residential thermal performance can be translated not only into energy savings and greenhouse gas reduction on a significant scale, but can enhance comfort levels for residents whilst reducing their energy costs.

Keywords: thermal performance, lightweight construction.

INTRODUCTION

Solar efficient buildings have evolved and been built in a settlement environment for thousands of years, notably by the ancient Greeks in Ionia, Asia Minor as long ago as 600 BCE. North American Indians made shelter in winter at the base of the Rio Grande taking advantage of the thermal storage capacity of the south-facing canyon walls to keep them warm.

Heating and cooling technologies, and fuel for power have become increasingly affordable since the mid-1940s for the majority of people, particularly in the developed world. The natural consequence has been acceptance of the use of technology as the cultural norm at the expense of using natural systems. This is as much the case in the built environment as in any other.

Extensive research shows that the burning of fossil fuels has been largely responsible for global warming and climate change. The case for energy efficient building practice is based both upon the need to reduce carbon emissions and, in domestic residential building, provide less reliance on conventional fossil fuel power. As a significant proportion of energy consumed in the home used is for heating and cooling, any reduction would contribute significantly to reducing carbon emissions. Furthermore, making homes more energy efficient generally provides more liveable environments, and in low-income households less disposable income would be need to be expended on power bills.

The local climate predetermines the extent to which the occupants of a building need to be protected, and have active or passive systems and elements installed or introduced into the building envelope or its adjacent locale. The dwellings under examination in this investigation are within the Perth climate zone, which is generally

CP941, *Renewable Energy for Sustainable Development*
edited by P. Jennings, G. Ho, K. Mathew, and C. V. Nayar

described as a being within a temperate zone, moving gradually towards a dry warm temperate zone as the effects of global warming become increasingly evident. Thermal comfort within buildings is primarily controlled by air temperature, radiant heat, humidity and airflow, and can be dominated by any one or combination according to the climate zone. Temperature and humidity are the predominant factors bearing on the thermal comfort zone (TCZ), the zone in which generally 80% of the population experience thermal comfort. Perth inhabitants are rarely troubled by excess humidity and so this study concerns itself purely with temperature where the TCZ lies between 18 deg. C and 28 deg. C.

Due to home sales, and subsequent occupation, some data collection was ceased before sufficient had been recorded. Nevertheless, it was possible to compare data from five dwellings from three NLV locations. The three sites have been progressively developed, making incremental changes relating to the development of a more sustainable environment, commencing with Lake Joondalup, Pineview and finally Bridgewater.

AIMS AND OBJECTIVES

The study first aimed to establish how the selected styles of building at three NLV villages performed under seasonal conditions in terms of their comparative thermal performance. Data analysis would highlight how effective the principles of solar passive design that had been incorporated into observed dwellings and how effective they have been in improving the thermal performance within.

Secondly, the study's second purpose was to recommend modifications to existing homes on how to improve thermal comfort levels and energy efficiency, and to suggest how best, using cost effective measures, to modify future designs in order to achieve this, without compromising the building's energy efficiency and accredited First Rate 5-Star energy rating.

METHOD

Two i-button temperature data loggers were installed in each of the selected buildings. Installation points were selected on the north and south-facing sides at the top of the internal window frame. An external logger was placed in a shaded area above the doorframe on the outside of one building at each location. Following activation by computer the loggers were left to record temperatures for approximately five weeks, after which the data was downloaded and the process repeated over a period covering all four seasons at each of the three locations. The following settings and assumptions were made:

- Buildings were of similar construction and therefore had similar thermal mass.
- Although the colour schemes on the exterior of the buildings differed, this did not significantly vary the reflectivity of the sun's radiation.
- NLV salespersons, when showing the unoccupied dwellings to prospective customers, did not leave doors and windows open for any length of time.
- The vertical blinds, particularly in windows on the northern elevation, were all drawn (half open) to the same extent.
- Glazing areas were all similar.

RESULTS AND OBSERVATIONS

A comprehensive database was built containing data recorded over approximately a twelve month period. It was possible to compare each dwelling in terms of its thermal performance for any chosen period and compare this to the ambient temperature and comparisons of performance have been extracted from the overall data for two periods as set out in Table 1 below.

Key to Notes in Table 1:

A – (arrowed) - Performance of north and south-facing rooms as a factor of ambient temperatures

$$\% = \frac{\text{recorded events room within Thermal Comfort Zone}}{\text{recorded events ambient temperatures within TCZ}}$$

B – (arrowed) - % of recorded events within TCZ.

C – (arrowed) -Summer performance levels highlighted (Dec-Jan-Feb).

D – (arrowed) – Winter performance levels highlighted (Jun-Jul-Aug).

E – Shows a significant contrast between the summer and winter data. Clearly shows the structure resists the effects of summer temperatures, compared to the winter months, by a factor of between two and three.

F – TC levels were 59 – 79% in summer with little major difference from site to site.

G – TC levels were 9 – 30% in winter with Bridgewater performing notably better.

H – Notable differences in performance between north and south-facing rooms, particularly in winter months.

TABLE 1. Extract of thermal performance results from three NLV locations.

LOCATION & HOUSE ORIENTATION	HOUSE STYLE, & ROOM ASPECT	Dec	Jan 2005	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	NOTES (See Key)
BRIDGE-WATER N/S	"Canterbury" North-facing Room.	1.1 75%	1.0 56%	1.1 79%	1.1 80%	1.3 82%	1.3 86%	2.0 25%	2.4 30%	2.2 26%	2.5 24%	A B, E, F,G, H
	"Canterbury" South-facing	1.1 79%	0.9 53%	1.0 73%	1.0 73%	1.5 92%	1.1 92%	1.8 20%	1.6 21%	1.5 17%	1.9 18%	B E, F,G, H
	"Cassia" North-facing	1.0 71%	0.9 53%	1.1 76%	1.0 73%	1.3 82%	1.4 89%	2.0 26%	2.1 27%	2.0 23%	3.2 30%	C, E, F, G, H
	"Cassia" South-facing	1.0 74%	0.9 53%	0.9 73%	1.1 80%	1.4 90%	1.0 66%	0.9 12%	0.9 11%	0.9 10%	1.4 37%	D, E,F,G, H
LAKE JOONDALUP N/S	"Saffron" North-facing	0.8 59%	0.8 60%	0.9 61%	0.9 66%	0.7 52%	1.2 62%	2.7 27%	3.0 27%			E, F,G, H
	"Saffron" South-facing	1.0 73%	1.0 75%	1.0 74%	1.1 76%	0.8 60%	1.2 59%	1.2 11%	0.9 8%			E, F,G,H
PINEVIEW	"Saffron" North-facing	0.8 59%	0.9 60%	0.9 67%	0.9 64%	1.3 67%	1.4 73%	2.3 23%	2.6 23%			E, F,G,H
	"Saffron" South-facing	0.9 67%	0.8 64%	1.0 71%	1.0 69%	1.3 68%	1.3 71%	1.8 18%	1.6 14%			E, F,G,H
	"Wattle" North-facing	1.0 71%	1.0 72%	1.1 75%	1.1 76%	1.3 67%	1.3 70%	1.5 15%	1.3 12%			E, F,G,H
	"Wattle" South-facing	1.0 72%	1.0 74%	1.1 78%	1.0 80%	1.3 68%	1.3 68%	1.2 12%	1.0 9%			E, F,G,H

CONCLUSIONS

The dwellings at Lake Joondalup were all constructed without, or at most with little consideration of solar passive design principles. They were also distinguishable from their later counterparts at Pineview and Bridgewater in that the former had exterior wall insulation installed throughout and suitably located attached carports. The buildings at Bridgewater exhibited further contrasts in thermal performance as these were constructed with solar passive design principles incorporated, as well as with wall and underfloor insulation.

This investigation has highlighted the benefits of improving thermal performance and energy efficiency through the use of solar passive design principles and other energy conservation measures. The results generally indicate an improved trend in thermal performance from the older styles to the most recent respectively. However, those taken during early spring highlight the need to investigate thoroughly the introduction of thermal mass, in order to improve the thermal performance in times of cooler ambient temperatures. It can be seen that this encouraging trend is more evident under summer conditions than in winter.

The study should provide NLV with significant data and information on how sustainable improvements can be made in future designs. Such improvements would reduce the recurrent cost of power bills for the residents and reduce the villages' overall energy requirement. As the residents are generally over 45 years and from a low-income background, such expenditure reduction may be significant when related to their disposable income.

Furthermore, reduction in energy requirement translates directly into a reduction in the production of greenhouse gases, also part of NLV's sustainability policy. A Perth combined gas and electric single residential household of average occupancy 3.3 people typically consumes 13 kWh/day of principally coal-derived electricity. Electricity bills at the first village where occupancy rate was on average 1.5 had electricity bills typically in the range 8-15 kWh/day. Through the abovementioned building improvements and solar water heaters on all houses it is expected that Bridgewater electricity consumption could be reduced by 5 kWh/day on average across the 380 houses. Such an outcome would deliver a greenhouse gas abatement of approximately 700 tonnes pa.

RECOMMENDATIONS

It is clear from the results and observations that incremental improvements in thermal performance and energy efficiency have been made, but it is also evident that further modifications to the overall design could solve some of the issues raised in this paper. These improvements could include:

1. Improvement to thermal resistance levels in the form of more insulation.
2. Modification to ventilation pathways to enhance night cooling.
3. Installation of reversible roof fan system in the ceiling to:
   (i) in winter, to draw heated air from the roof space into the living areas, and
   (ii) in summer, to withdraw hot air from the living areas and vent it to the outside atmosphere. (Australian Broadcasting Corporation, 2005; Air

Group Australia, 2005; Calais & Anda, 2003; Environmental Technology Centre, 2005; Solectair, 2005)

4. Introduction of a suitable and acceptable form of thermal mass to improve thermal performance during the day and at night.

   Option 1: Custom-made water tanks which could also be used for irrigation in summer. (Berrill, 2005; Sydney Building Information Centre, 2005)

   Option 2: Hollow-core concrete slab constructed in an area of maximum solar access. (Bilgen & Richard, 2001).
5. Integration of phase change materials into the structure (Schossig *et al,* 2005*)*.
6. Modification of shading structures in combination with the introduction of thermal mass, and consideration to planting more mature landscaping for similar reasons.
7. It is also recommended that the types of glass used be investigated. The NLV structures have a larger proportion of glazed area than would normally be recommended for buildings of their size. In some instances the loss of thermal performance could be attributed to this high ratio. The same amount of light entering the dwellings can be maintained and the thermal performance improved by installing say grey in lieu of clear float glass. The solar heat gain of 6mm grey glass is 54% as compared to 88% for clear 3mm float (Berrill: 2005).
8. The style and type of shading structure applied to window areas can also significantly affect solar heat gain and loss (Berrill: 2005).
9. Further statistical analysis of the comprehensive data recorded at the three lifestyle villages should prove useful in determining the best, or at least improved, room zoning, shading, and glazing options to improve the dwellings' overall thermal performance.

The above list highlights various strategies that could be investigated further by the construction of prototypes followed by comprehensive monitoring process.

REFERENCES

Australian Broadcasting Corporation, 2005. *The New Inventors Show* on 26/6/05, sourced via internet at http://www.abc.net.au/newinventors/txt/s1400041.htm#otherinfo2, accessed on 6/7/05.

Berrill, T. (2005). *Energy Efficient Building Design: Resource Book,* Queensland T.A.F.E.

Bilgen, E & Richard, M.A., 2001. *Horizontal Concrete Slabs as Solar Collectors* in Solar Energy Vol. 72, No. 5, pp. 405–413, 2002, Elsevier Science Ltd.

Calais, P. & Anda, M., 2003. *Performance Testing of a Domestic Heat Transfer Unit: Final Report,* January 2003, Environmental Technology Centre, Murdoch University, Murdoch.

Environmental Technology Centre, 2005. *Advanced Technologies: Solar air heating and cooling system* sourced via internet at http://wwwies.murdoch.edu.au/etc/pages/waalitj/wpages/feats.htm, accessed on 6/7/05.

Schossig, P., Henning, H.-M., Gschwander, S., & Haussmann, T., 2005*Micro- encapsulated phase - change materials integrated into construction materials,* Science Direct Journal Solar Energy Materials & Solar Cells Vol. 89 (2005) at 297–306.

Solectair, 2005. *Heat Transfer System* sourced via internet at http://www.solectair.com.au/, accessed on 6/7/05.

Sydney Building Information Centre, 2005. *The Steel House of the Future* accessed via internet at http://www.housesofthefuture.com.au/hof_houses03.html#environmental, accessed on 20/7/0