BEDP ENVIRONMENT DESIGN GUIDE

PEMBERTON HOUSE, HOBART – IMPLEMENTING THERMAL DESIGN PRINCIPLES FOR HOUSING IN A COOL TEMPERATE CLIMATE

Detlev Geard

This case study looks at the passive heating design principles adopted in a Tasmanian House, discusses the designers consideration of the interplay between solar aperture, insulation and thermal mass, and analyses the thermal performance for a week long test in summer and winter.

Keywords
house, solar aperture, solar passive design, thermal insulation, thermal mass, thermal performance

1.0 PROJECT OUTLINE

1.1 Project details

Client: John and Karmen Pemberton
Architect: Detlev Geard
Consultants: Structural: Robert and Gandy
Contractor: Denis Young
Project Type: Private Residence
Floor Area: Living Pavilion 86m², Bedroom Pavilion 82m², Garage 42m²
Site Area: 662m²
Cost: $1720/m² at completion
Occupants: 4

1.2 Location and Climate

The Pemberton house is situated on a very steep site at the foothill of Mount Wellington, with extensive northerly views over the CBD and the River Derwent. The site is surrounded by single and double storey houses and required excavation to allow the building to sit closer on it.

The climate of Hobart is a typical maritime climate, with cool to cold winters and mild to warm summer conditions. Typical winter temperatures range from 4ºC to 12ºC, while typical summer temperatures range from 12ºC to 22ºC. The maximum sun altitude at noon is 71º in summer and 24º in mid-winter. Hobart is classified as cool temperate climate with 2100 Heating Degree Days at base 18ºC. There is ample sunshine during winter months to make the use of solar energy viable for space heating.

2.0 DESIGN INTENT

The design intent was a modern looking house, simple in design but thermally efficient with a moderate budget.

Other design consideration included:

- taking maximum advantage of the views over the City of Hobart and the River Derwent
- compact, but practical in design
- application of proven passive solar heating systems
- affordability

One of the main objectives in the brief was to achieve a thermally comfortable house with minimum auxiliary heating and cooling requirements. Passive solar design principles have been implemented through appropriate orientation, solar aperture, and the use of thermal mass and thermal insulation.

3.0 DESIGN AND CONSTRUCTION

3.1 Orientation, Layout and Site Planning

The house is separated into two pavilions with different floor levels. A large foyer area at the eastern side acts as an air lock and connects the pavilions. The long axis of the house faces east and west for maximum collection of solar energy, and access to views.

As there are no obstructions to the northern side of the house, optimum solar radiation is received all year round. A large deck at the eastern side of the house provides space for outdoor activities and can be accessed through glazed doors. A double garage, car parking and driveway access are located to the south of the house, being the highest part the site. There are various small flat, terraced and landscaped outdoor areas located around the house.

3.2 Building Form and Envelopes

The simple building design consists of two pavilions on different floor levels to suit the fall of the site. The floor level of the upper bedroom pavilion is 2.5m above the lower living pavilion making it possible for rooms on both levels to receive optimal solar radiation and take advantage of the views.

As the road access enters the site on the high part, the garage is situated on the highest part of the land for easy access, being 1.2m above the upper bedroom floor level stairs. The simple skillion roofs have an angle of 15º with a steeper roof angle for the entry foyer of 25º. This combines with the main glazed areas on the northern side for passive solar heating purpose and the views.

To conform to the planning scheme, some site excavation was necessary to minimise the building height and to better blend the shape of the house into the surrounding environment.

Region/Climate Zone	Value
Building Code of Australia	Zone 7
AccuRate region	Zone 26
Temperature	
Average yearly temperature over 24 hrs	12.38 ºC
Typical winter temperature swing	4-12 ºC
Sunshine	
Average sunshine hours	5.8
Yearly horizontal radiation values for Hobart	4.96 GJ/m²
Australian Capital comparison: Launceston 5.57, Melbourne 5.57, Sydney 5.59, Canberra 6.02, Brisbane 6.39, Adelaide 6.57, Perth 8.36, Darwin 9,60. *International comparisons:* England / Finland / Sweden 3.2, Germany 3.6, France 4.3, Italy 5.0.	
Maximum sun altitude on 21 December at 12 noon	71º
Maximum sun altitude on 21 March/September at noon	47.5º
Maximum sun altitude on 21 June at noon	24º
Heating Degree Days (base 18 ºC)	
Hobart	2100
Australian city comparisons: Launceston 2416, Sydney 642, Perth 645, Melbourne 1378, Adelaide 1000, Brisbane 238, Bathurst 2023. *International comparisons:* London UK 2637 ,Hockerton UK 3344, New York USA 2433, Moscow 4797.	
Cooling Degree Days (base 18ºC)	
Hobart	50
Australian city comparisons: Sydney 1000, Perth 1000.	

Table 1. Hobart climate

(Source: Climate Service Centre, Bureau of Meteorology, Hobart)

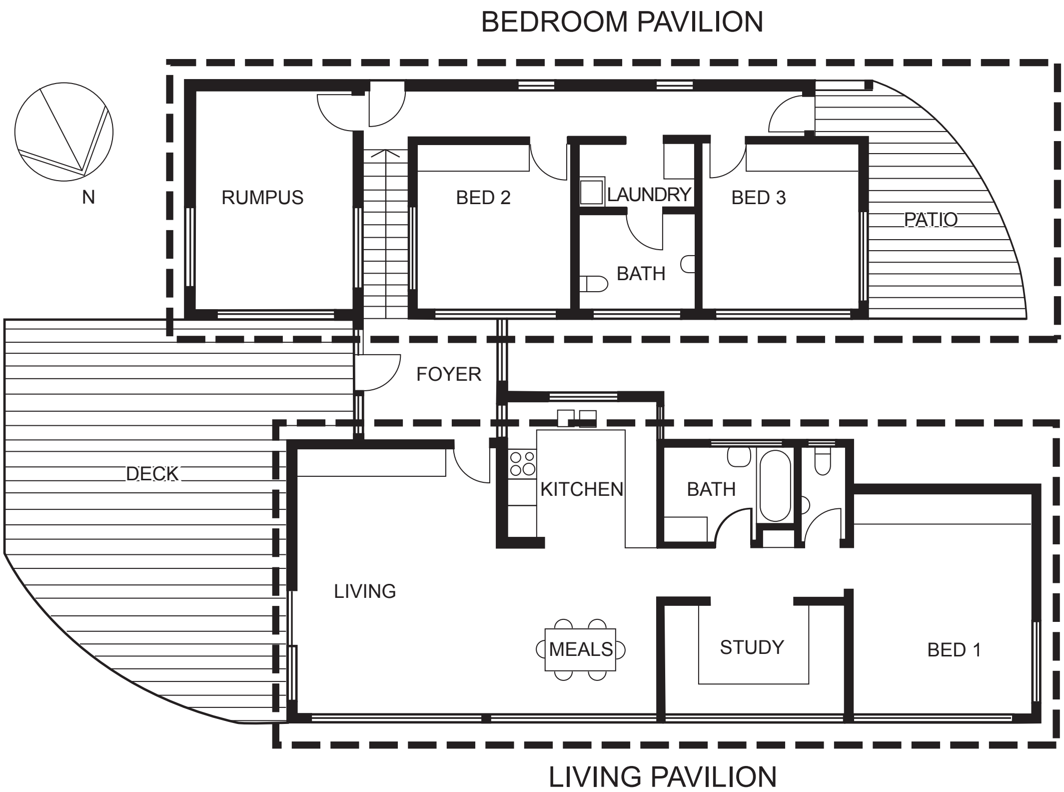


Figure 1. House floor plan

(Source: Detlev Geard)

3.3 Construction

Floor

Both floors are constructed of 130mm thick, concrete slab which is part suspended, and part on-ground. Where suspended, the slab has had 75mm polystyrene insulation panels fixed to its underside. The concrete slab forms part of the main thermal mass storage for the house due to its direct sun exposure through the northern glazed walls during clear winter days (refer to Figure 2). The surface temperature of the concrete floor exposed to direct solar radiation has been measured to be up to 32°C, when the floor has a conducive darker colour finish, such as dark grey or black. When the air temperature in the house falls below the surface temperature of the slab, heat will re-radiate up from the slab, warming the house during late afternoons and evenings. The heat flux absorbed by the concrete slab during the day can be as high as 200 W/m² which will then re-radiate at a steady 30 W/m² where the slab has been exposed to the sun. The portion of concrete slab not exposed to direct solar radiation will continue to absorb small amounts of heat until about 10pm when it then starts to re-radiate heat peaking at about 10 W/m² at 7am. (Sugo, Page, Moghtaderi, 2005)

Wall

The exterior is constructed of a reverse block veneer wall, with a 90mm concrete blockwork facing the interior of the house, thus providing increased thermal storage capacity. To reduce air movement and increase the insulative capacity of the stud framed external wall, sarking on the exterior side of the stud wall is fully taped to the top and bottom plates of the timber framing and at all windows and sliding door openings.

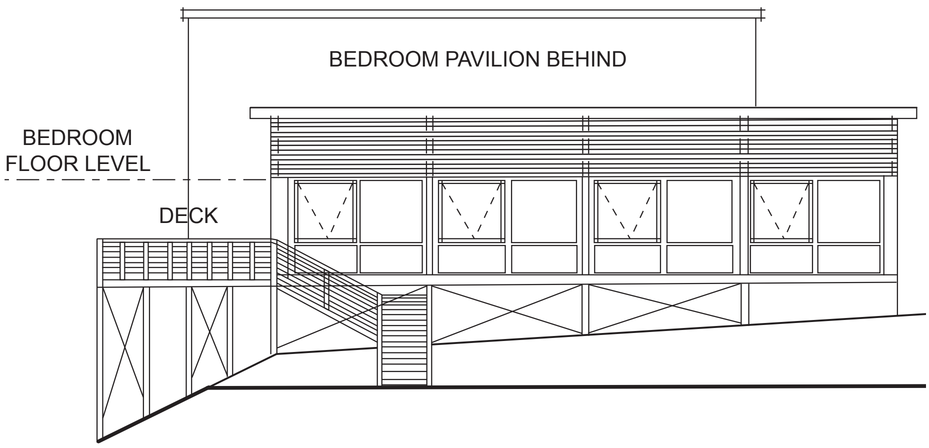


Figure 2. Section drawing
(Source: Detlev Geard)

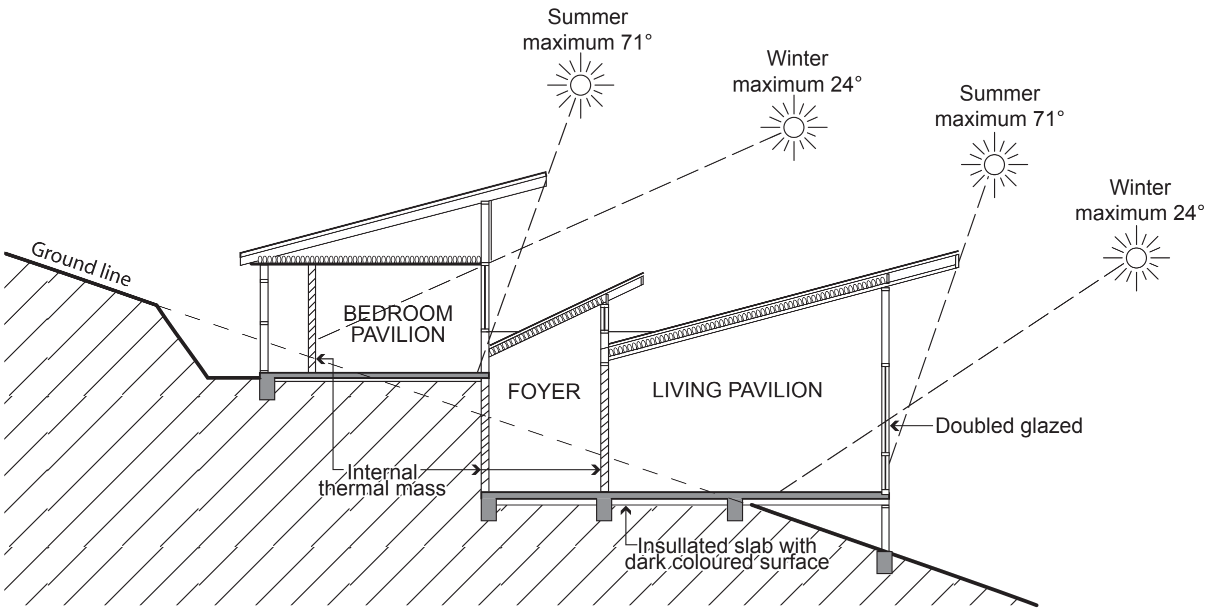


Figure 3. North elevation to living pavilion on lower ground level
(Source: Detlev Geard)

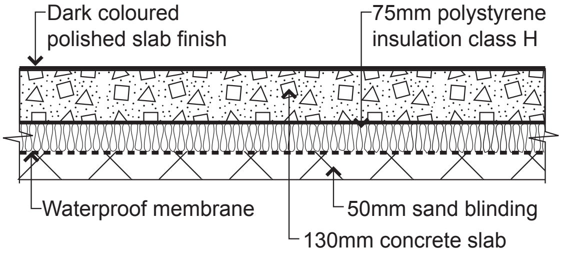


Figure 4. Concrete slab insulation detail

(Source: Detlev Geard)

Air change rates in standard construction can vary between 0.5 to 1 air changes per hour, although these can be reduced to about 0.2 an hour when buildings are well sealed, which includes 'wrapping' of the external building sarking. (Luther, 2008)

When the sealed air gaps within a wall section face a reflective surface of the building sarking, the insulation value of the wall will be increased by about R 0.43m²K/W.

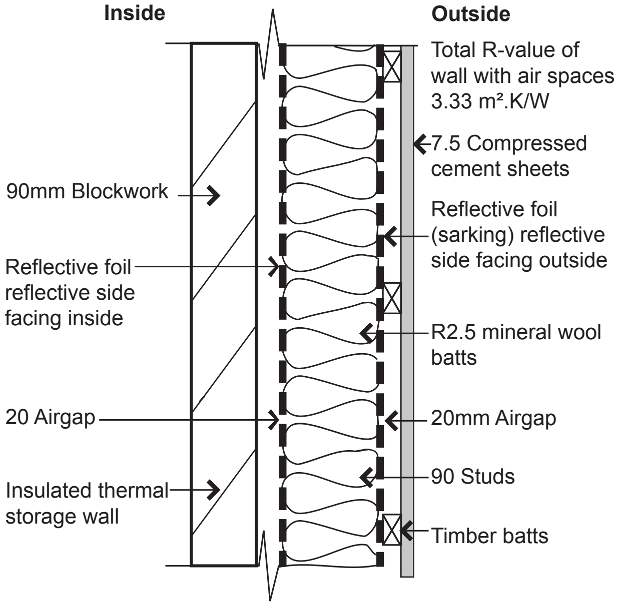


Figure 5. Typical wall construction

(Source: Detlev Geard)

To achieve this, the exterior walls of the Pemberton house include two airspaces facing a reflective building sarking, providing an overall R Value for the entire wall section of about 3.33 mK/W.

Roof

The roof at the living pavilion consists of 190mm deep rafters with corrugated sheet steel roofing over it. There is a raked ceiling in the living-dining-kitchen area and a flat 2.7m high ceiling over the remaining areas of the house.

The roof at the bedroom pavilion consists of prefabricated timber trusses with corrugated sheet steel roof over it.

Windows and Sliding Doors

The use of timber framed windows and doors were considered during the design stage, however the owner opted for less expensive and less maintenance intensive aluminium frames. Both window and sliding door aluminium frames are thermally broken, and are double glazed with a 12mm air gap between the layers of glazing. The thermal break consisting of a plastic insert between the aluminium framing extrusion provides an increased insulation value to the framing units.

The R-value of the thermally broken and double glazed, units with a 12mm air gap is around R 0.32m²K/W.

Figure 6. View of the living pavilion from north-west at street level

(Source: Detlev Geard)

	R-value (m²K/w) **of:**				
Glass type	**Glazing**	**Frames**			**Window unit**
3mm float glass single glass	0.17	Aluminium Aluminium with thermal break Wood/plastic	10% 10% 20%	0.070 0.146 0.321	0.14 0.14 0.20
4-12-4 float/air/float double glazed unit	0.32	Aluminium Aluminium with thermal break Wood/plastic	10% 10% 20%	0.077 0.192 0.345	0.20 0.27 0.34
4e-12-4 low-e/air/float double glazed unit	0.50	Aluminium Aluminium with thermal break Wood/plastic	10% 10% 20%	0.077 0.192 0.345	0.22 0.32 0.44
4e-12a-4 low-e/argon/ float double glazed unit	0.70	Aluminium Aluminium with thermal break Wood/plastic	10% 10% 20%	0.077 0.192 0.345	0.25 0.35 0.50

Table 2. Insulation values of glazing types, frames and window units

(Source: Detlev Geard)

However the total R-value of the total window unit, which includes the aluminium frame for 10 per cent of its area, is reduced to R 0.27 m²K/W. If the window units were manufactured out of plastic or wood, the total R-value, with an allowance for 20 per cent of its area as framing would have increased to R 0.34 m²K/W.

4.0 ENVIRONMENTAL CONTROLS

4.1 Introduction to Passive Heating Systems

There are a number of important factors influencing the design of passive solar buildings, including the following which were considered in the Pemberton house:

- **The local climate:** The design of the building needs to suit the local climate to achieve comfortable interior conditions. The use of glazing, thermal mass, insulation, ventilation and shading will vary considerably for a building in a hot tropical climate to that of a cool, temperate climate. The design for a cold to cool temperate climate includes large northern glazed areas and interior thermal mass for heat storage. If, however, the design was for a tropical climate, it would include little or no thermal mass.
- **Orientation and sizing of solar aperture:** Correct sizing of the solar apertures in northern glazed areas to allow for maximum solar heating is an important design decision. Sizing of solar apertures depends on the local climate, the floor area to be heated and the amount of thermal mass and insulation of the building. Too great an area of glazing or 'solar aperture' will result in overheating the building in summer and enable too much heat loss in winter. If the solar aperture is too small, the building will not warm up sufficiently in winter.
- **Inclusion and sizing of thermal mass:** In winter, thermal mass such as concrete floors and masonry walls can absorb and store solar energy that has entered the building. The stored energy is then slowly released during late winter afternoons and nights. Conversely summer heat is absorbed in the cooler thermal mass, thus reducing the air temperature in the building. At all times of the year, exposed internal thermal mass tends to dampen out the diurnal temperature swing.
- **Insulation and sealing of the building fabric:** Adequate insulation and sealing of the building will slow down the rate at which energy is lost in winter and gained in summer. Well insulated buildings result in smaller interior temperature variation with increased thermal comfort and lower heating and cooling bills.
- **Ventilation and shading:** Cross ventilation is most effective for summer cooling, with an air speed of 0.5m/sec equating to a 3°C drop in temperature at a relative humidity of 50 per cent (Your Home, 2005, Passive Cooling). Windows and doors should be located to allow for cooling breezes to enter and leave the building. Mechanical fans might be required to create more cooling. Shading over glazed areas and outdoor spaces reduce unwanted solar heat gain, resulting in reduced interior summer temperatures.

  Solar Aperture (North Glazing)

For the optimal performance of a solar passive design building, correct sizing of the solar aperture (northern glazing) is related to the floor area of the house to be heated and the amount of thermal mass within the insulated building fabric. Various existing design guidelines for sizing northern glazing in a temperate climate can range between 15 per cent and 35 per cent of floor area, depending on location and the amount of thermal mass inside the building (Baverstock and Paolino, 1986, and Willrath, 1992).

From the guideline given in Figure 7 above it can be seen that the correct sizing of northern glazing for Hobart should be 17 per cent of the heated floor area of the house with an internal thermal mass capacitance of 95 MJ/K for a 200m² house. An AccuRate thermal simulation indicates that for the cool temperate climate zone for Hobart (Zone No. 26) and with the same floor area and internal thermal mass, heating loads are lowest when the size of northern glazing is about 15 to 20 per cent of the floor area to be heated.

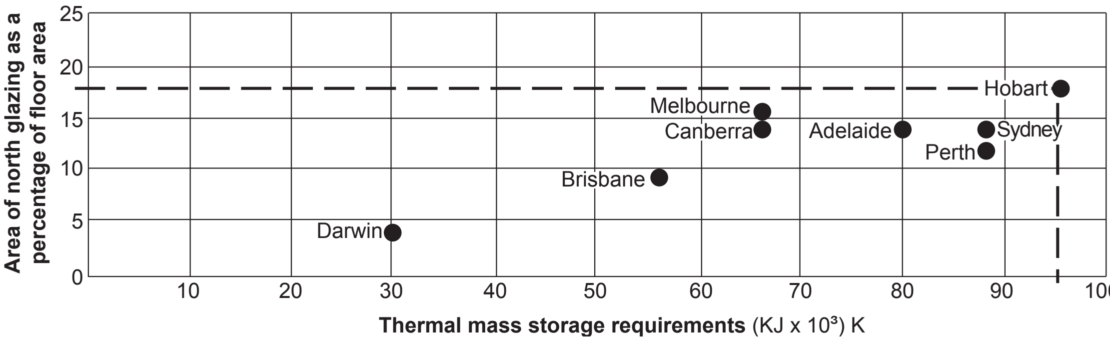


Figure 7. Inter-relationship between climate, northern glass area and thermal mass
(Source: adapted from Baverstock, G and Paolino, S, 1986)

In the Pemberton house, the northern glazing in the lower pavilion is 32 per cent of the floor area and the in the upper pavilion 30 per cent of the floor area. When the house was designed in 2001, a northern glazing ratio of up to 35 per cent of the floor area was recommended. The Pemberton house has been sized for a maximum winter solar gain with consideration of a higher summer ventilation effort, which includes cross-ventilation and interior shading on the northern side. Table 3 notes however, for the minimum total energy consumption for heating and cooling, a solar aperture of 20 per cent of the heated floor area and a northern overhang of 0.60m would have been desirable.

4.2 Thermal Mass

The use of thermal mass in a building is most effective when the diurnal range (average different temperature between day and night) is moderate to wide. In cool or cold climates where supplementary heating is often used, buildings with appreciable solar gains will benefit from mass construction regardless of diurnal range. When used correctly, thermal mass can significantly increase thermal comfort and reduce energy consumption.

The amount of thermal mass to be included within the building relates closely to the climate, the solar aperture or northern glazed area and the use of insulation. Design guidelines recommending the amount of thermal mass required for optimal performance provide different sizing methods and can be given as:

- ***Thermal capacitance of mass:*** Thermal Capacitance (MJ/K) is the measure of the amount of heat a material can store and is the product of volume x density x specific heat. The value is given for a whole building, or per m² for easy comparisons between buildings.
- ***Weight of thermal mass:*** The weight of thermal mass (Kg/m²) can be easily calculated and values per kg/m² are often used to compare the amount of thermal mass between buildings.
- ***Mass surface area to north glazing area ratio*** Mass to surface to north glazing ratio (e.g. 6:1) is a convenient method of sizing thermal mass, assuming the thermal mass is evenly distributed throughout the building, with an average thickness between 100 and 150mm. A mass surface to north glazing ratio of 6:1 is recommended for cool temperate climates. (Your Home, 2005) In the Pemberton house the mass area to north glazing area ratio is 5.5:1. The amount of thermal mass in the Pemberton house has been calculated as shown in Table 3.

Table 5 presents a comparison of the amount of thermal mass in different construction and housing types to provide an appreciation and understanding of sizing thermal mass in buildings.

It is worth noting that in the colder climate of the UK, the large thermal mass in the Hockerton House in Nottinghamshire is used to carry the house through the entire winter period without any additional heating. The thermal mass is charged during the summer months and discharged over winter. The yearly temperature in the houses falls to only 18ºC in winter and rises to a maximum of 23ºC in summer. The site has a 3344 Heating Degree Days to base 18ºC whereas Hobart has 2100.

The need for a lower amount of thermal mass in Australian examples is due to the availability of more solar radiation and milder temperatures during the winter months, compared to the UK example.

Solar aperture (north glazing) **% of heated floor area**	**AccuRate heating energy prediction** MJ/m² per annum	**AccuRate cooling energy prediction** MJ/m² per annum	**AccRate total energy prediction** MJ/m² per annum	**Star Rating**
5	101.4	0.3	101.9	7.3
10	85.0	0.5	85.7	7.6
15	76.4	1.0	77.6	7.8
20	74.7	1.9	76.9	7.8
25	77.5	3.5	81.3	7.7
30	79.0	7.4	86.9	7.6
35	82.1	12.0	94.1	7.4

Floor area 200m² N- Roof overhang 0.60m Climate Zone 26 (Hobart)

Table 3. AccuRate simulation for a test house with varying size north glazing

(Source: Detlev Geard)

Material	**Volume** m³	**Density** kg/m³	**Mass** kg	**Specific heat** KJ/kg.K	**Thermal capacitance** MJ/K
Floor slab	11.18	2400	26,832	0.92	24.68
Block walls	7.51	1680	12,616	1.0	12.62
Plaster board	0.86	950	817	0.84	0.69
Totals	40,265 *or* 468 Kg/m²	37.99 *or* 0.44MJ/K/m²			

Table 4. Calculation of thermal mass for the Pemberton house

(Source: Detlev Geard)

House description and reference	Thermal capacity per m² (MJ/K/m²)	Thermal capacity per house (MJ/K)	Mass per m² (kg/m²)	Building element description
Low Mass	0.05	8	37.4	Timber framed, timber floor, plasterboard walls and ceiling
Pemberton house case study	0.42	36.7 Lower pavilion only 86m²	468	130mm slab floor, 140mm internal block walls, core filled
Typical mid mass house	0.41	82	481	Slab floor, most internal or brick walls
Environment Design Guide DES 4 (August 1995) (Baverstock, Paolino)	0.475	95 for 200m³ house	558	Slab floors, internal brick walls
Autonomous House Southwell Nottinghamshire, England (Vale, Vale)	0.78	137.8 for 176m² house	723	Precast concrete floor, 150mm dense concrete blocks walls
Typical high mass house Hockerton England (Vale, Vale)	1.77	202 for 114m² house	2100	300mm slab floor, 300mm internal dense concrete blocks walls, 300mm internal concrete ceiling, earth sheltered

Table 5. Thermal mass comparison of different building types

(Source: BEDP Environment Design Guide; Baverstock, Paolino; Vale, Vale; Geard.)

However, it should be stated, that to achieve a 'zero energy' house for heating and cooling in a cool temperate climate of Australia, the amount of thermal mass and insulation would need to be increased to a higher level.

4.3 Thermal Insulation

The following table compares the insulation details of the Pemberton house to a standard building practice brick veneer house. The higher insulation values for the Pemberton house were selected to sufficiently insulate the thermal mass for minimum temperature fluctuation and increased thermal comfort in the house.

4.4 Ventilation and Shading

The Pemberton house is situated on an exposed and windy site and is subject to cool breezes from nearby Mount Wellington. Cross-ventilation which is provided by sliding and stacking doors at the eastern and western side of the house and by large window openings at the northern and southern side of the house, is only required during the summer months.

Fixed roof overhangs at the northern side of the house prevent the sun from entering the house during most of the summer months. Internal micro-line venetian blinds are installed internally to reduce glare and are only used during the summer months. The initially designed awning over the northern windows which was not constructed for budgetary reasons is actually not required, as the house does not overheat in summer.

4.5 Operation

The owners are very aware of the principles of passive solar design and operate the building manually from day to day, depending on climate conditions.

5.0 POST OCCUPANCY EVALUATION

The house has been monitored in a free running stage (with no additional heating or cooling) for one week in winter and one week in summer. Hourly internal and external temperatures were collected by a data logger, fixed to the rear wall in the living room, 1200mm above floor level.

The typical temperature range in the house during the winter months is between 15°C and 19°C in free running mode, while a typical temperature range of a standard brick veneer house with a timber floor in the same climate can be between 7°C and 25°C (Geard, 2008).

	Pemberton house	Brick veneer house (standard building practice)
Walls	Total R value 3.33 R 2.5 mineral wool batts 2 reflective air spaces	Total R value R 2.36 R 1.5 fibre glass batts 1 reflective air space
Roof	R 3.5 fibre glass batts R 1.5 foil faced fibre glass blanket over roof battens	R 3.5 fibre glass batts over ceiling
Floors	R 2.2 expanded polystyrene under entire slab floors	No insulation under flooring
Glazing	R 0.32 double glazed, 12mm sealed air gap, 4-12-4	R 0.17 single glazed 4mm thick

Table 6. Insulation Comparison

(Source: Detlev Geard)

The smaller temperature fluctuation of 6ºC in the Pemberton house as compared to 18ºC in the standard brick veneer house is due to the double glazing, and the storage effect of the thermal mass and increased thermal insulation, especially under the concrete floor. One of the main advantages of thermal mass in winter is the much warmer temperature experienced in the mornings, compared to that of a light weight brick veneer building.

The cooling effect of thermal mass in the house can be clearly seen in the Figure 8. Due to sufficient night cross-ventilation and the fixed northern roof overhang which shades the northern glazing, the house does not overheat in summer. The typical temperature range in summer is 19ºC to 24ºC.

A comparison of the AccuRate simulated performance between the Pemberton house model based on the materials actually used and another model of the same design, but with standard brick veneer construction (i.e. single glazed, un-insulated timber floor, R1.5 wall and R3.5 ceiling insulation) was made. For the winter month of August and the summer month of February the actual model achieved a considerably diminished temperature fluctuation to that of the conventional model. As shown in Figure 9, the temperatures in the actual model are close to the recommended thermal comfort band of between 18º and 22ºC.

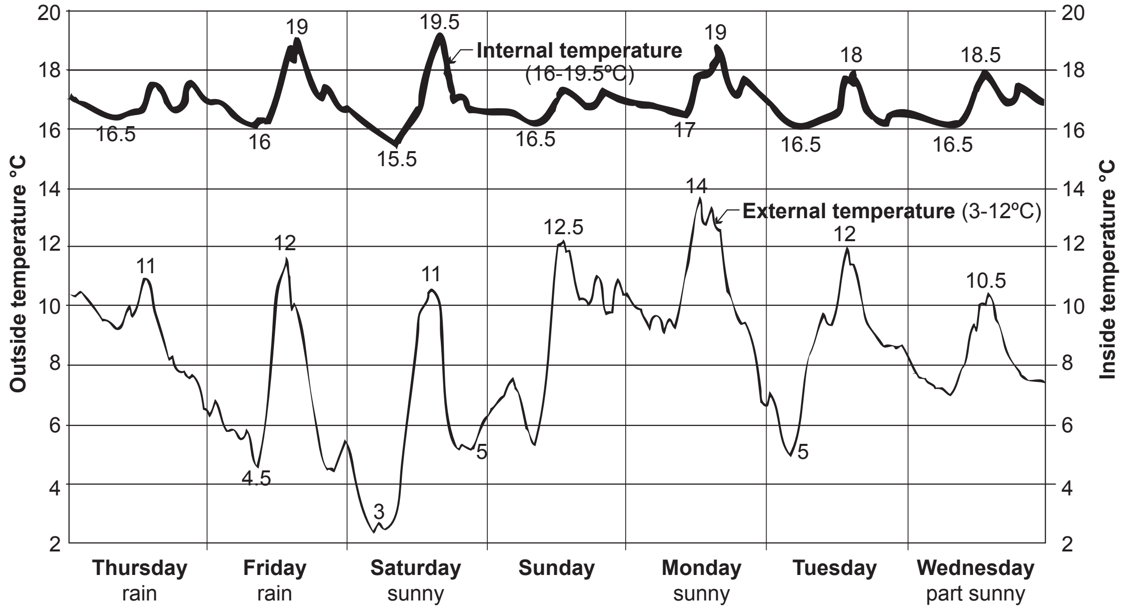


Figure 8. Winter performance for July 2005 monitoring in free-running mode
(Source: Detlev Geard 2005)

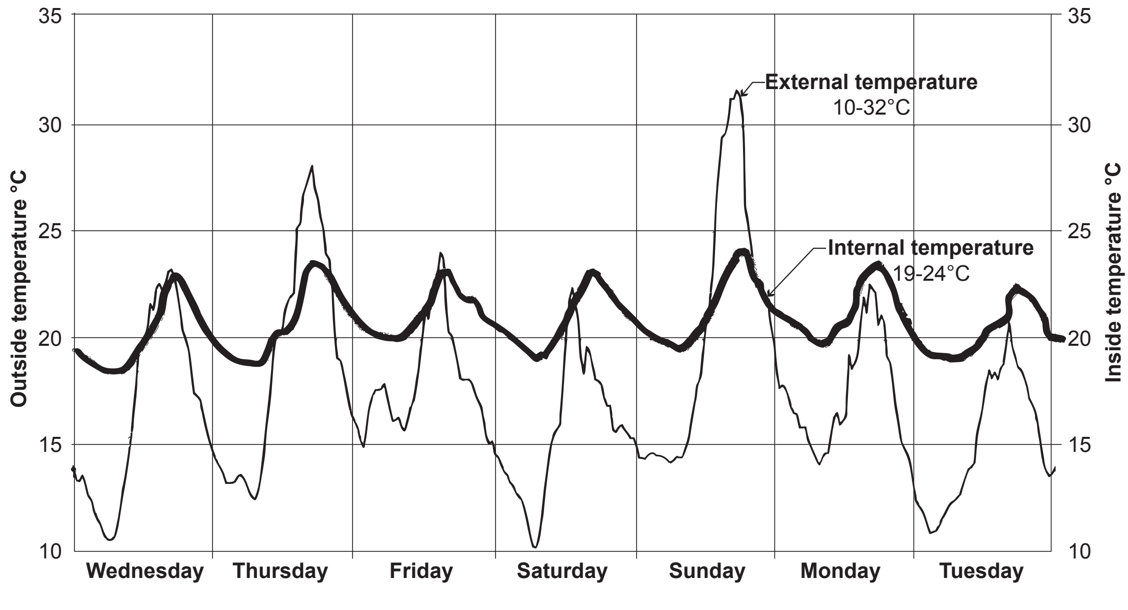
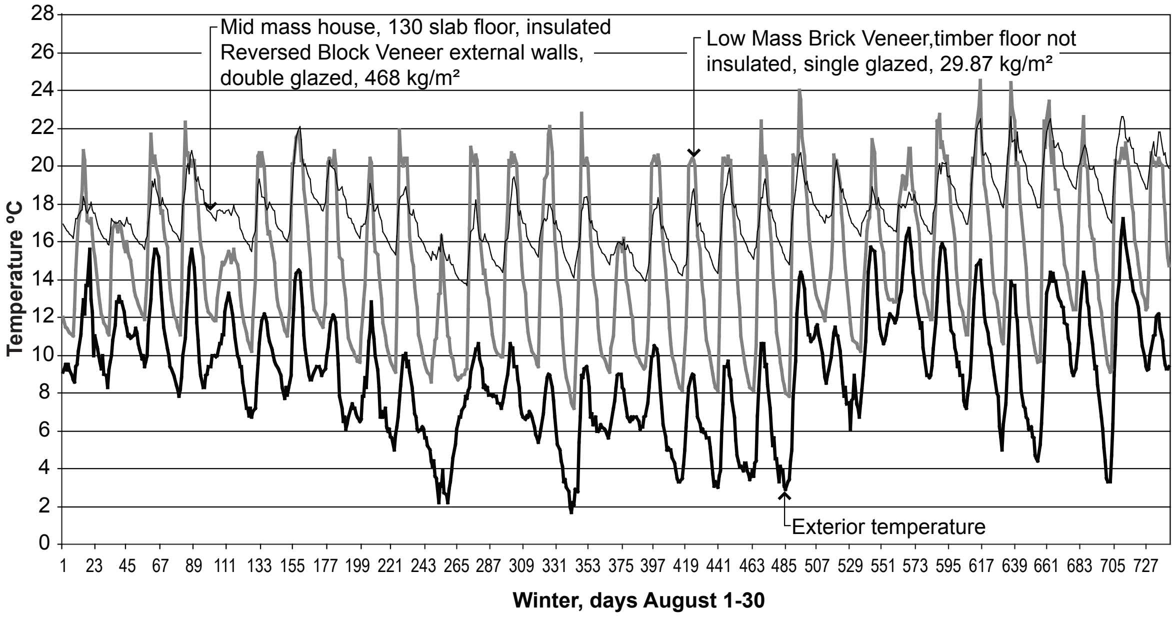
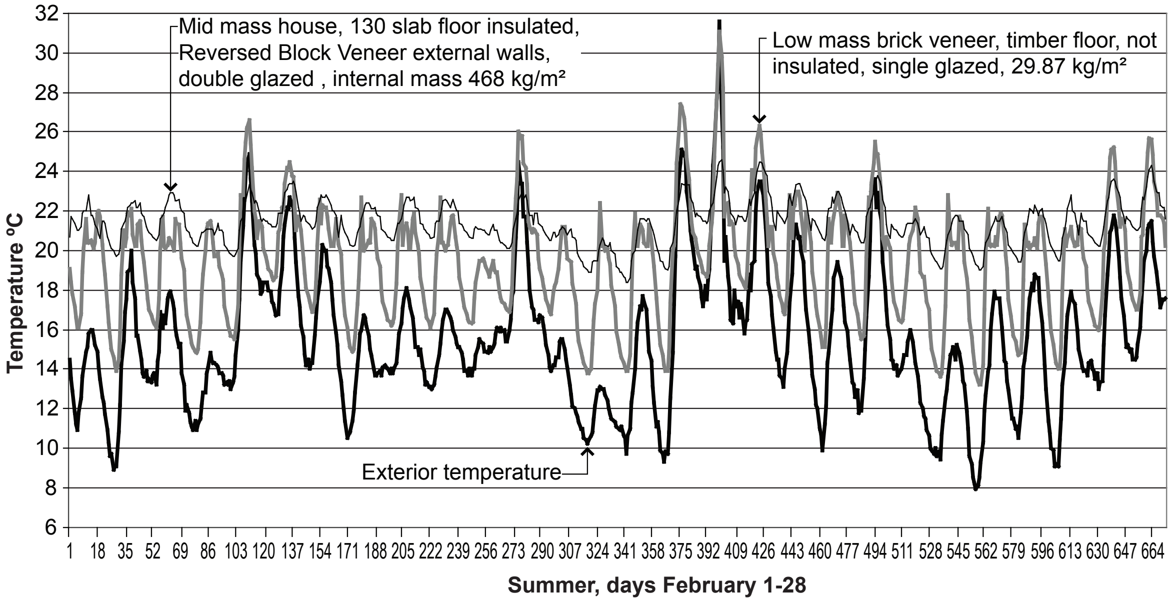


Figure 9. Summer performance for February 2005 monitoring in free-running mode
(Source: Detlev Geard)



Winter temperatures comparison



Summer temperature comparison

Figure 10. AccuRate simulation, Pemberton house comparison with standard construction house

House type	Heating load MJ/m² per annum	Cooling load MJ/m² per annum	Total load MJ/m² per annum	Star rating
Low mass house (29.87 kg/m²), timber floor, single glazed 28m² north glazing wall insulation R 1.5 brick veneer, bricks to outside, 10 plasterboard walls inside ceiling insulation R 3.5	187.6	37.6	226	4.5
Mid Mass house (476kg/m²) 130 slab insulated R2 28m² north glazing wall insulation R 2.5 reversed block veneer Blocks to inside ceiling insulation R 5.0	75.9	4.8	81.1	7.77

Comments: Saving of mid mass house, double glazed and insulated slab 64.2 per cent

Table 7. AccuRate energy load comparison between Pemberton and house with standard brick veneer construction of the same design

(Source: Detlev Geard)

Table 7 represents an AccuRate energy load simulation comparison of a standard construction brick veneer house for the same floor plan as the Pemberton house (lower pavilion only), indicating a projected saving in heating and cooling energy requirements of 64 per cent.

6.0 CONCLUSION

In the design of solar-passive designed buildings care must be taken to achieve the desired ratios between solar aperture, thermal mass and insulation. Rather then follow rule of thumb passive solar system guidelines, the use of thermal performance programs such as AccuRate, can assist the designer to carefully balance the amount of glazing, thermal mass and insulation to be used in a building design for a given climate. There is a need for more case studies of buildings in various Australian climate zones and access to detailed thermal performance analysis. The establishment of a data bank of existing passive solar buildings in Australia, including detailed design, construction and thermal analysis would be of great assistance to the building design professions. The use of building envelope thermal performance modelling programs need to be utilised as a basic design tool for every building designer.

The owners of the Pemberton house are very satisfied with its thermal performance. Additional heating is only used occasionally during late afternoon or nights between June and August, when the internal temperature can drop below 17ºC. There is no additional cooling needed in summer.

As a comparison, the Hockerton zero-energy house mentioned earlier requires no heating or cooling and considering the cooler climate in Hockerton (UK), with 3344 Heating Degree Days as compared with 2100 for Hobart, it should be very possible to design zero energy buildings in the cool temperate regions of Australia.

A requirement for zero heating energy in the Permberton house, could possibly be achieved by the following changes: (AccuRate simulation 8.3 MJ/m^2.annum, 9.7 Stars)

- decrease solar aperture to 20 per cent of heated floor area
- increased roof insulation to R 10
- increased wall insulation to R 5
- provide double glazing that are filled with argon gas and are made with low e-glass
- increased thermal mass to 900 kg/m^2 (say a 300mm concrete floor slab)

The predicted temperature range would then be between 19ºC and 23ºC in winter and between 21ºC and 26ºC in summer.

While there are various guidelines for sizing passive solar heating systems available, they can differ substantially and need to be tested and fine-tuned against the actual thermal performance of the built Australian examples of passive solar buildings.

To ensure the design of successful solar buildings, the interaction between the climate, solar aperture, thermal mass and insulation must be fully understood by designers. At the design stage computer thermal simulation tools can help the designer to balance the key parameters and understand their interaction.

GLOSSARY

Heating Degree Day: is an expression of a climatic heating requirement, expressed by the difference in degrees Celsius (ºC) between the average outdoor temperature for each day and an established indoor base temperature, often 18ºC. The total number of Heating Degree Days over the heating season indicates the severity of the winter in that location.

(Source: Wash, Spencer, 1980)

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