Background Paper

The Role of Thermal Mass in Energy-Efficient House Design

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Summary

Thermal mass is a key element of passive design. Passive design harnesses natural energy to help reduce dependence on mechanical heating and cooling, the major source of household energy consumption. Thermal mass acts to moderate temperature fluctuations naturally. Brickwork is an accepted and economical means of building thermal mass into a structure.

This background paper seeks to clarify the different elements of the thermal performance of building materials. Specifically, the difference between insulation (as measured by the R-value) and thermal mass is examined. Recent Australian research that confirms the effectiveness of thermal mass is also reviewed and the role of thermal mass in different climate zones is considered.

Austral Bricks is a member of the Clay Brick and Paver Institute, the Australian authority on bricks, brickwork and segmental clay paving.

Austral Bricks is a GreenSmart Leader, a program sponsored by the Housing Industry Association to promote environmental performance in Australia's building industry

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Introduction

Energy efficiency has become increasingly important to the community, regulatory bodies and industry in recent years. The implementation of regulations at Federal and State level, has led to an increased awareness of the need to reduce energy consumption and lower greenhouse gas emissions through energy efficient house design.

Energy use in the home is a significant factor in our overall energy consumption and a major contributor to greenhouse gases. A 1999 report issued by the Australian Greenhouse Office states that the largest proportion of household energy – a massive 39 percent – is consumed in space heating and cooling. (Refer to *Your Home Technical Manual*, section 4.0, published by the Australian Greenhouse Office, www.greenhouse.gov.au/yourhome/.)

This proportion has probably increased in subsequent years with the significant uptake in residential air-conditioning. According to Energy Australia's submission to the New South Wales Inquiry into Energy Consumption in Residential Buildings (2004), the proportion of homes with air-conditioners had grown 21 percent in the previous decade.

Not only will this impact upon energy consumption, it will also place additional burdens on electricity generation infrastructure especially during peak periods. Designing and constructing an energy efficient house has the potential to substantially and permanently reduce the amount of energy consumed in space heating and cooling.

Energy-Efficient House Design

Passive design is a well-established and accepted method of harnessing natural forces to reduce household energy consumption and only involves incorporating simple building techniques. Its interconnected principles act to maintain a level of thermal comfort naturally with reduced reliance on mechanical heating and cooling.

The following features work together to passively heat and cool a home:

- **Orientation** to assist the natural heating and cooling of home. For example, glass areas and shading on the north face will capture the low winter sun access, but exclude the high summer sun.
- **Ventilation** by capturing cooling breezes and utilising natural air flows from cross-ventilation to cool a home.
- **Insulation** to act as a impediment to heat flow, so as to retain heat during winter and slow the passage of summer heat through the building envelope.
- **Thermal mass** to naturally moderate temperature by incorporating dense wall materials that have the ability to act as a thermal battery.

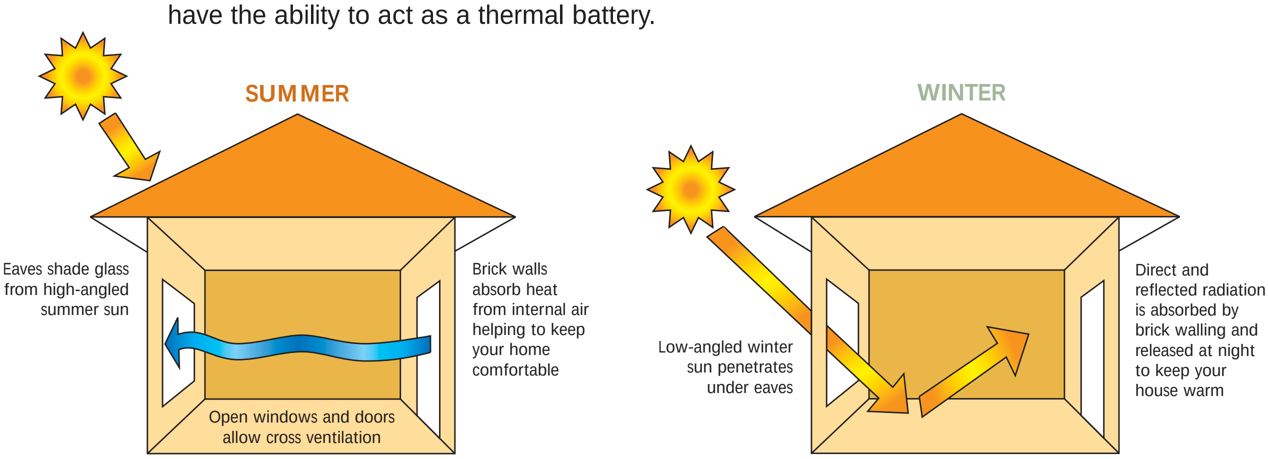

Figure 1 – The interconnection of passive design principles

What is Thermal Comfort?

Thermal comfort is influenced by factors that affect the way the body loses and gains heat. Other than the critical component of temperature, these factors include:

- Air movement (breezes or draughts)
- Humidity
- Radiant heat sources (eg direct sunshine) and heat sinks (eg cool surfaces)

Thermal comfort can be considered generally as a range of temperatures that is influence by these factors. For example, a higher temperature may still be comfortable
if cross-ventilation is present, whilst high humidity will reduce evaporative cooling and lower the upper temperature limit.

The thermal comfort range is also reliant on a certain level of acclimatisation, for example in Hobart the upper threshold is 29.3°C and in Darwin 32.8°C. (Source: thermostat settings for the AccuRate energy modelling software, with a wind speed of 1m/s.)

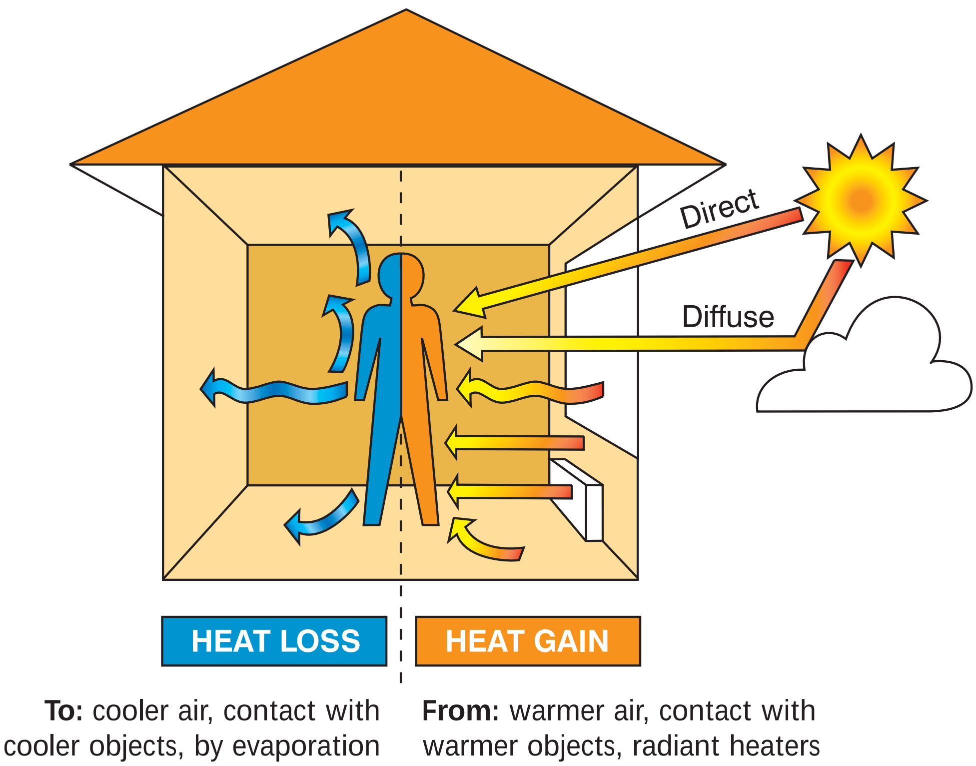

Figure 2 – Effect of heat loss and gain on the human body (illustration based on *Your Home Technical Manual*, section 1.1)

Materials for Energy-Efficient Design

Insulation and thermal mass – two of the elements of passive design – are reliant on building materials. The most common measure of the thermal performance of a building material is its R-value. An R-value is a measure of the thermal resistance of a material.

Although the use of a single number is convenient and easily understood, the R-value is only a measure of the material's ability to insulate. The R-value is not a complete measure of a material's thermal performance. In fact, the thermal performance of the building fabric is reliant on a complicated interaction of properties. Broadly, materials with beneficial thermal properties will be either:

- Insulating materials, or
- Materials with thermal mass.

When only the R-value is considered, only one material property is being included – insulation. It is important to remember that an appropriate combination of both insulation and thermal mass (along with ventilation and orientation) will create a well designed home.

Insulating materials

A high R-value indicates a material with a high level or resistance to heat flow. The R-value of individual materials such as bulk insulation and reflective insulation is often stated. The R-value of a whole wall construction can also be determined by laboratory testing. Recent research at the University of Newcastle determined the following steady state R-values for typical masonry walls:

Table 1 – Measured R-values for masonry constructions

Wall construction	R-value
Brick veneer with reflective foil	1.14
Cavity brick	0.82

The relevance of the R-value to the thermal performance of masonry will be examined later. Walls with the same R-value will have the same insulation ability, but not necessarily the same thermal performance.

Materials with thermal mass

Dense materials with high thermal mass, such as clay brickwork and concrete slabs, have the ability to absorb heat when subjected to a temperature differential, thereby slowing its passage through the wall. The combination of thermal capacitance and heat conduction allow these materials to act as an extremely effective 'thermal battery'. In combination with the other passive design components, thermal mass helps stabilise temperature variations, as this chart sourced from the Australian Greenhouse Office illustrates. This natural moderation reduces our dependence on mechanical heating and cooling.

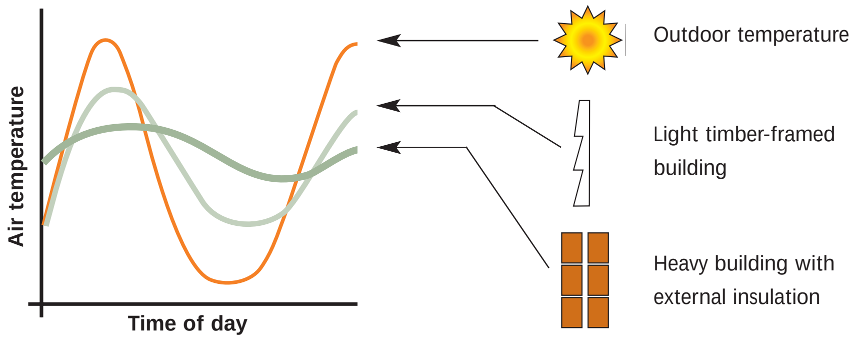

Figure 3 – Dense walling such as brick helps stabilise internal temperatures (illustration based on *Your Home Technical Manual*, section 1.7).

In **SUMMER**, thermal mass moderates temperatures by hindering the passage of heat through the wall. This thermal lag prevents the majority of the outdoor heat reaching the inside. Once the peak of the day passes and the outside temperature drops, the heat flow is reversed and begins to travel to the cooler exterior. Cross ventilation hastens this process by harnessing natural cooling breezes to help release heat energy that has penetrated to the interior, and cools the building's occupants. Isolated internal thermal mass is particularly effective at interacting with the interior of the home as it absorbs heat from the interior and provides coolth.

In **WINTER**, thermal mass absorbs heat from solar radiation and other sources and will reradiate the stored heat back into the home in the evening when it is needed (acting as a thermal battery). Thermal mass is especially beneficial during winter if it is exposed to winter sun.

There is no widely accepted method of quantifying thermal mass, and it is not adequately represented by the R-value. Indeed, materials that have thermal mass are thermally more effective than their R-value indicates.

Thermal Mass – Tested Performance

An ongoing research program conducted at The University of Newcastle (see **Downloads**) has demonstrated the moderating effect of the high thermal mass in brickwork. An extensive quantitative research program has been undertaken involving the comprehensive monitoring of test modules.

Analysis of the first two modules, one of brick veneer construction, the other of cavity brick, showed that external temperature fluctuations were moderated to a range more consistent with human comfort. The chart below shows the benefits of thermal mass during a summer heat wave.

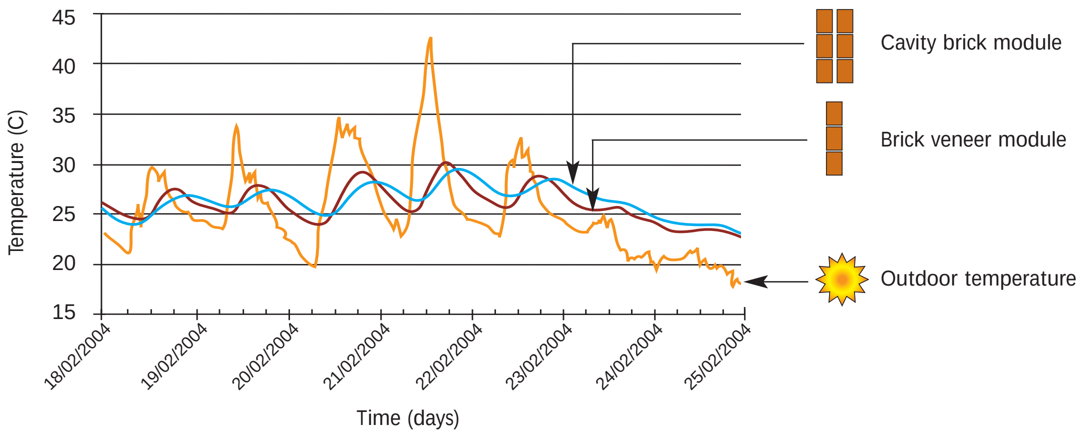

Figure 4 – The internal temperature of the brick test modules was relatively stable.

It is important to note that the cavity brick construction moderated the temperature fluctuations to a larger extent than the brick veneer construction, although it has a lower R-value. The R-value is not representative of the overall thermal performance of a material and should not be the only consideration when selecting a material.

More recently a fourth module was built using insulated lightweight walls. The findings are preliminary but as the chart below shows, the lightweight module was subject to greater temperature variations than the insulated cavity brick module over the same period. This variance can only be attributed to the greater thermal mass of the cavity brick module, as both walls have similar R-values.

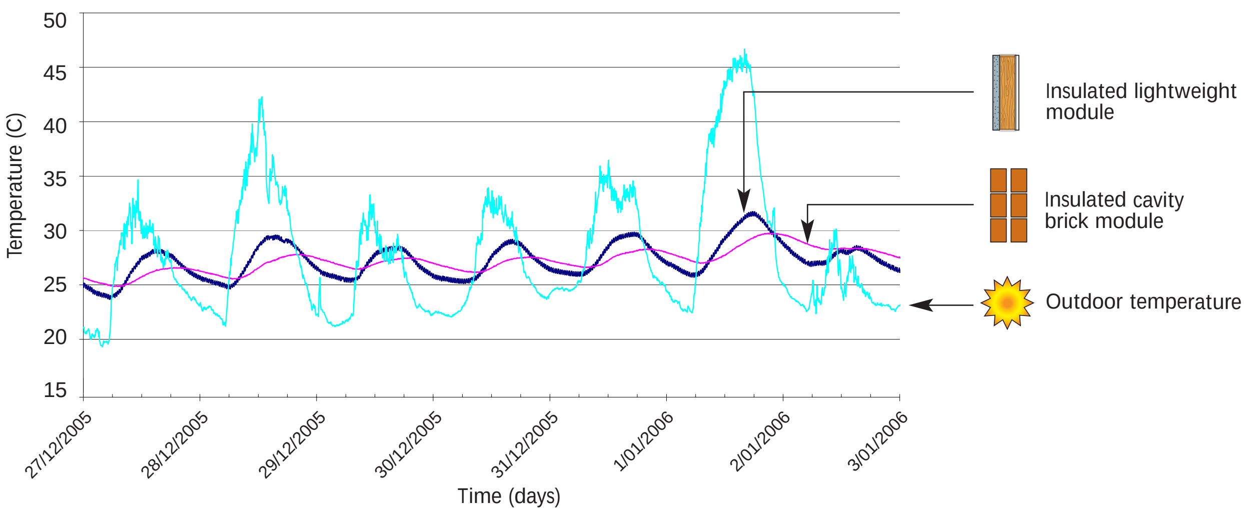

Figure 5 – Air temperatures inside the insulated lightweight module showed greater fluctuations than those in the insulated cavity brick module during heatwave conditions.

The thermal lag of the brick veneer and cavity brick constructions was able to be quantified by this research. Thermal lag is a measure of the extent to which thermal mass absorbs heat and slows down its transfer. As the illustration below shows, the higher the level of thermal mass, the longer the lag time.

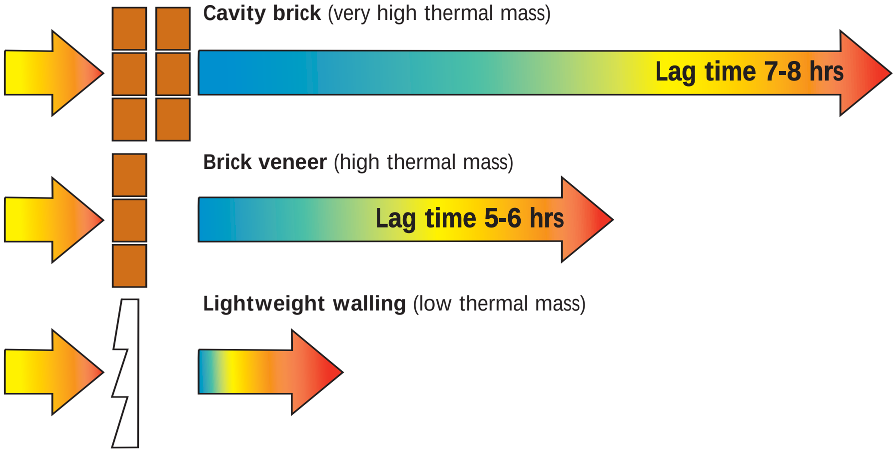

Figure 6 – Brick walls slow the passage of heat through the wall.

The research also showed that only a small proportion of heat striking a west-facing cavity brick wall in summer passes through the wall. Most is reflected and some is absorbed, leaving less than one percent (5-6 W/m^2) to penetrate the wall. This can be compared to the massive 120W/m^2 measured to enter through a *shaded* north-facing window.

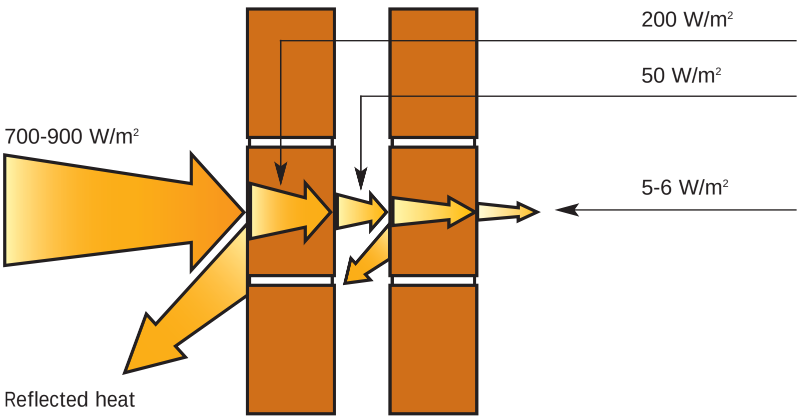

Figure 7 – Less than one percent of heat penetrates a west-facing cavity brick wall.

In summary, this research has demonstrated that the R-value is not a good representation of the thermal properties of a material. The thermal mass of brickwork has a demonstrated ability to naturally modify temperatures, thereby reducing the need to artificially heat and cool. It is therefore important to consider more than just the R-value for an energy efficient house design.

Building with Thermal Mass

Windows are a critical element, accounting for around 49% of heat loss and 87% of heat gain (Australian Glass and Glazing Association). University of Newcastle research has shown the importance of insulating the roof and ceiling, with roof temperatures of up to 70°C recorded.

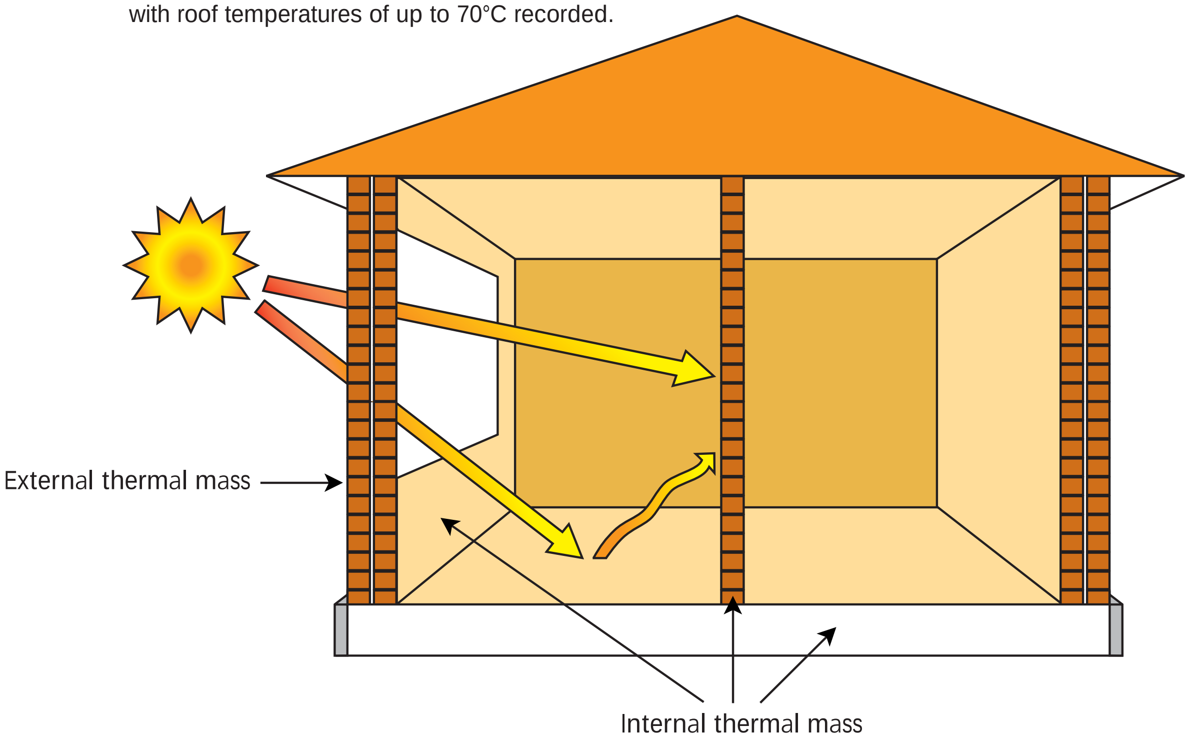

Figure 8 – Provision and role of thermal mass and the effect of other building components

The provision of thermal mass in passive design requires the use of dense materials. By definition, lightweight materials have low thermal mass. Brickwork is an accepted, proven and economical means of building thermal mass into a building.

Internal thermal mass is able to interact directly with the interior of the home. A skin of internal clay brickwork is a good source of exposed internal thermal mass, as are brick feature walls and fireplaces. Brick partition walls also provide thermal mass (and have the additional advantage of being more sound absorbent than stud walls).

Internal thermal mass is also able to interact with nearby heating and cooling devices and enhance their use by reducing periods of operation and decreasing temperature settings (Source: *Your Home Technical Manual*, section 1.7).

A concrete slab is also an excellent source of thermal mass, especially when it utilises ground coupling. Unfortunately carpets and timber floors act to insulate the slab and do not allow the thermal mass to interact with the interior of the home (Source: *Your Home Technical Manual*, section 1.7).

The thermal mass of external brickwork also has demonstrated benefits. The research at The University of Newcastle has demonstrated that brick veneer construction has the ability to naturally moderate temperature fluctuations.

Climate-Specific Information

Thermal mass is an intrinsic component of passive design. All the interactive features of passive design are necessary to achieve energy efficient design. Indeed, it is important to optimise the use of the passive design features for each climate. For example, the greater the daily temperature range (diurnal swing), the more beneficial thermal mass becomes. The use of thermal mass in different climates is discussed below. *Your Home Technical Manual* should be referred to for more detail on passive design techniques.

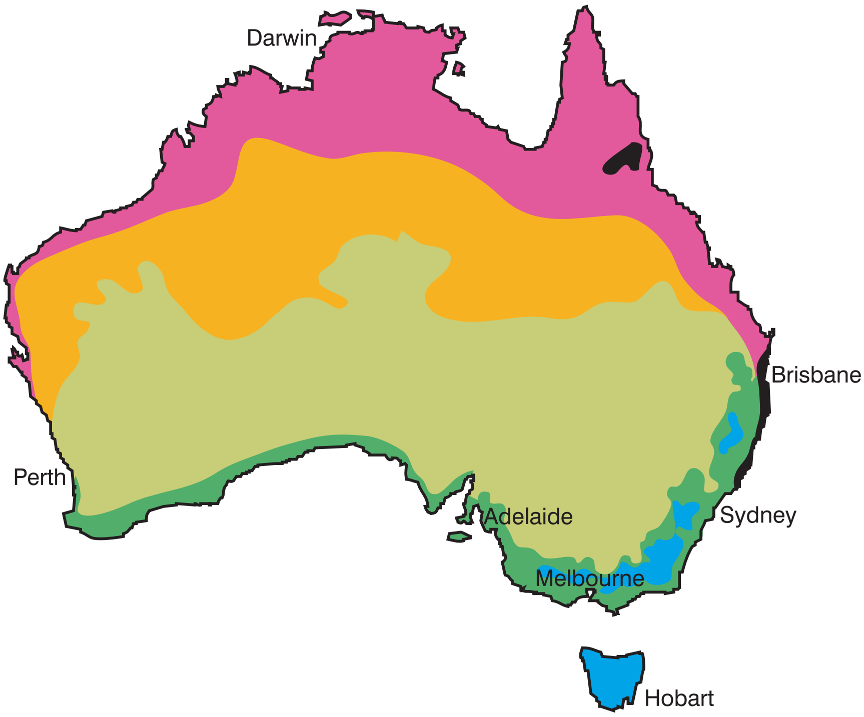

Figure 9 – Passive design principles apply across Australia's climate regions (illustration based on *Your Home Technical Manual*, section 1.1).

Cold temperate and cold climates

Ballarat, Launceston, Hobart, Canberra, Orange, Goulburn, Alpine Regions

High thermal mass designs are strongly recommended for cold and cold temperate climates. For the best results, maximise solar access to the thermal mass. The thermal mass can store this heat and release it at night when it is needed.

Temperate climates

Sydney, Wollongong, Newcastle, Perth, Adelaide, Esperance, Melbourne, Nowra, Mount Gambier, Albany, Bendigo, and parts of the east coast of Tasmania

High thermal mass solutions are recommended for temperate climates. The thermal mass can be used in temperate climates to naturally heat in winter and cool in summer. The research at the University of Newcastle has demonstrated the ability of brickwork to naturally moderate temperatures in summer and in winter in a temperate climate.

Hot dry summer with a cold winter

Bourke, Kalgoorlie-Boulder, Mildura, Wodonga, Whyalla

This climate has a high diurnal temperature swing, making thermal mass very important. The heat gained from solar radiation in winter will be released by the thermal mass at night when it is required. Good design during summer will allow shaded thermal mass to act as a heat sink, thereby naturally moderating the internal temperature.

Hot dry summer with a warm winter

Alice Springs, Longreach, Mount Isa

Thermal mass is also of use in hot dry climates with a warm winter, which exhibit a considerable diurnal temperature swing. By using thermal mass that is shaded in summer and is exposed to cooling breezes over night, the natural cooling potential can be realised.

Warm humid

Brisbane, Rockhampton, Coffs Harbour

Thermal mass used in conjunction with good passive design principles in warm humid climates can be beneficial, particularly where there is a diurnal temperature swing. Thermal mass, especially on the lower floor, will act to natural moderate temperature swings and reduce the need to artificially heat and cool. Thermal mass that is shaded from summer sun and cooled by night breezes will act to cool the home. Recent research by Williamson and Demirbilek (2003) demonstrated the benefits of using thermal mass in brickwork in Brisbane using energy modelling software.

Hot humid climates

Townsville, Darwin, Broome

Because of the minimal diurnal temperature swing, low mass constructions are widely used in tropical climates. However, the Australian Greenhouse Office's *Your Home Technical Manual* (section 1.7) quotes recent research which shows "that innovative, well insulated and shaded thermal mass designs have been able to lower night time temperatures by 3 to 4°C in hot humid areas with modest diurnal ranges."

Downloads

Research Paper 18: A Comparative Study of the Thermal Performance of Cavity and Brick Veneer Construction, Clay Brick and Paver Institute (www.cbpi.com.au/resources/research/cbpi_research_paper_18.pdf)

Research Paper 19, The Study of Heat Flows in Masonry Walls in a Thermal Test Building Incorporating a Window, Clay Brick and Paver Institute (www.cbpi.com.au/resources/research/cbpi_research_paper_20.pdf)

Thermal Mass: What's The Consensus?

Please note: Use of the following quotations and logos does not imply endorsement by these organisations.

Australian Greenhouse Office "Clay brickwork has high thermal mass. If a building with internal clay brickwork walls and concrete floors is subjected to a heating and cooling cycle that crosses the comfort zone, the brickwork and concrete will maintain a stable level of heat energy for an extended period. In summer, they will remain relatively cool and in winter, the same building will remain relatively warm. This phenomenon is recognised in the BCA (Building Code of Australia) Volume 2, which permits, in some climate zones, an exemption from adding wall insulation in cavity brickwork buildings."

(www.greenhouse.gov.au/yourhome/technical/fs34g.htm)

California Energy Commission "What truly sets a passive design home apart from a standard tract home is thermal mass. If solar heat is to be used when the sun is not shining, excess heat must be stored. Everyone has leaned against a sun-warmed brick or stone. Its warm and comfortable and takes a while to cool off. That's thermal mass."

(www.consumerenergycenter.org/homeandwork/homes/construction/solardesign/thermal.html)

US Department of Energy "Thermal mass stores heat by changing its temperature, which can be done by storing heat from a warm room or by converting direct solar radiation into heat. The more thermal mass, the more heat can be stored for each degree rise in temperature."

(www.eere.energy.gov/consumer/your_home/designing_remodeling/index.cfm/mytopic=10260)

Sustainable Energy Development Office (Government of Western Australia) "Your choice of building materials can make a significant difference to the performance and comfort of your home. Dense materials such as brick, stone, concrete and rammed earth heat up and cool down slowly - they have what is called a high 'thermal mass.' Lightweight materials such as weatherboard and fibre cement allow the home to heat up and cool down quickly. These materials have a low thermal mass."

"In summer, thermal mass can also help keep your home cooler during the day, provided you properly ventilate your home overnight. The aim is to allow the night air to cool down the mass inside your home, resulting in more comfortable conditions the next day."

(http://www1.sedo.energy.wa.gov.au/pages/building.asp)

Oak Ridge National Laboratory (US Department of Energy) "In certain climates, massive building envelopes-such as masonry, concrete, earth, and insulating concrete forms (ICFs) can be utilized as one of the simplest ways of reducing building heating and cooling loads. Very often such savings can be achieved in the design stage of the building and on a relatively low-cost basis. Such reductions in building envelope heat losses combined with optimized material configuration and the proper amount of thermal insulation in the building envelope help to reduce the building cooling and heating energy demands and building related CO^2 emission into the atmosphere. Thermal mass effects occur in buildings containing walls, floors, and ceilings made of logs, heavy masonry, and concrete."

Thermal Mass – Energy Savings Potential in Residential Buildings
(http://www.ornl.gov/sci/roofs+walls/research/detailed_papers/thermal/index.html)

American Institute of Architects Colorado "Although brick has a relatively low R-value, its mass can provide thermal storage to temper a living space and store solar gains. The durability, compressive strength, acoustical performance, chemical makeup and fire resistance of brick make it a more sustainable choice."

Sustainable Design Resource Guide, Division 4: Masonry (www.aiasdrg.org)