Passive solar heating

Passive solar heating uses free heating direct from the sun to dramatically reduce the estimated 40% of energy consumed in the average Australian home for space heating and cooling (DEWHA 2008).

Most Australian climates require both passive heating and cooling. Many heating and cooling design objectives overlap but different emphasis is required depending on your climate needs. Read Design for climate before this article to determine your climate zone and get an understanding of the strategies you’ll need. The detailed advice in this article and the one that follows it, Passive cooling, is complemented by advice relevant to specific types of home in the section Before you begin.

What is passive solar heating?

Passive solar heating is the least expensive way to heat your home. Put simply, design for passive solar heating aims to keep out summer sun and let in winter sun while ensuring the building’s overall thermal performance retains that heat in winter but excludes it and allows it to escape in summer. Passive solar design also depends on informed, active occupants who remember to open and close windows and isolate zone spaces, for example, each day.

It is also:

- low cost when designed into a new home or addition
- achievable using all types of Australian construction systems
- appropriate for all climates where winter heating is required
- achievable when buying a project home through attention to correct orientation, slight floor plan changes and appropriate glazing selection
- achievable when choosing an existing house, villa or apartment through looking for good orientation and shading.

Passive solar heating requires careful application of the following passive design principles:

- northerly orientation of daytime living areas (see Orientation)
- passive shading of glass (see Shading) and selection of appropriate glazing (see Glazing)
- appropriate areas of glass on northern façades (see Glazing; Thermal mass)
- thermal mass for storing heat (see Thermal mass)
- insulation and draught sealing (see Insulation; Sealing your home)
- floor plan design to address heating needs including zoning
- climate appropriate glazing solutions (see Glazing).

This maximises winter heat gain, minimises winter heat loss and concentrates heating where it is most needed.

How passive solar heating works

Solar radiation is trapped by the greenhouse action of correctly oriented (north-facing) glass areas exposed to full sun. Window orientation, shading, frames and glazing type have a significant effect on the efficiency of this process. (see Orientation; Shading; Glazing)
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Passive solar heating

Trapped heat is absorbed and stored by materials with high thermal mass (usually masonry) inside the house. It is re-released at night when it is needed to offset heat losses to lower outdoor temperatures. (see Thermal mass)

Passive solar heating is used in conjunction with passive shading, which allows maximum winter solar gain and prevents summer overheating. This is most simply achieved with northerly orientation of appropriate areas of glass and well-designed eaves overhangs. (see Orientation; Shading)

Re-radiated heat is distributed to where it is needed through good design of air flow and convection. Direct re-radiation is most effective but heat is also conducted through building materials and distributed by air movement. Floor plans should be designed to ensure that the most important rooms (usually day-use living areas) face north and receive the best winter solar access.

Heat loss is minimised with appropriate window treatments and well-insulated walls, ceilings and raised floors. Thermal mass (the storage system) must be insulated to be effective. Slab-on-ground edges should be insulated in colder climates, or when in-slab heating or cooling is installed within the slab. (see Insulation; Thermal mass)

Air infiltration is minimised with airlocks, draught sealing, airtight construction detailing and quality windows and doors.

Appropriate house shape and room layout is important to minimise heat loss, which takes place from all parts of the building, but mostly through the roof. In cool and cold climates, compact shapes that minimise roof and external wall area are more efficient. As the climate gets warmer more external wall area is appropriate, to allow for better cross-ventilation.

Passive solar design principles

Greenhouse (glasshouse) principles

Passive design relies on greenhouse principles to trap solar radiation.

Heat is gained when short wave radiation passes through glass, where it is absorbed by building elements and furnishings and re-radiated as long wave radiation. Long wave radiation cannot pass back through glass as easily.

Heat is lost through glass (and other building materials) by conduction, particularly at night. Conductive loss can be controlled by window insulation treatments such as close fitting heavy drapes with snug pelmets, double glazing and other advanced glazing technology.

Heat flow through building elements

Heat flow through any building element (e.g. wall, floor ceiling, window) is directly proportional to the temperature difference on either side of that element. This is called the temperature differential (also referred to as delta T or ΔT). The greater the temperature differential, the greater the heat flow through the element.

Think about temperature differential as pressure in your garden hose. The greater the pressure, the more water flows through the same hose. While the heat flow through different materials varies depending on their insulation properties (R-value), heat flow through each element with a similar R-value is directly proportional to temperature differential. Heat flow through windows is much higher because they typically have the lowest R-value of any construction material.

Because hot air rises convectively, air temperatures stratify in a home with the hottest air at the highest point. For example if you, on a cold −5°C Canberra night, are trying to keep your main living area at around 22°C (although most acclimatised Canberra residents find 19–20°C quite
comfortable), temperature stratification might lead to 30°C (ΔT 35°C) at the highest point in the room and 18°C (ΔT 23°C) at the lowest. That means that 33% more heat is flowing through higher level building elements than lower ones because the temperature differential is 33% higher. Again, windows are the weakest point.

**Orientation for passive solar heating**

For best passive heating performance, daytime living areas should face north. Ideal orientation is true north but orientations of up to 20° west of north and 30° east of north still allow good passive sun control. (see Orientation)

Where solar access is limited, as is often the case in urban areas, energy efficiency can still be achieved with careful design. Homes on poorly orientated or narrow blocks with limited solar access can employ alternative passive solutions to increase comfort and reduce heating costs. (see Challenging sites; Shading; Insulation; Thermal mass; Glazing)

Active solar heating systems that use roof mounted, solar exposed panels to collect heat and pump it to where it is needed are a viable solution where solar exposure of glass for passive heating can’t be achieved. This provides a more flexible solution that is more easily adjusted to adapt to climate change warming. (see Heating and cooling)

**Passive solar shading**

Fixed horizontal shading devices can maximise solar access to north-facing glass throughout the year, without requiring any user effort. Good orientation is essential for effective passive shading.

Fixed shading above openings excludes high angle summer sun but admits lower angle winter sun. Correctly designed eaves are the simplest and least expensive shading method for northern elevations.

Use adjustable shading to regulate solar access on other elevations. This is particularly important for variable spring and autumn conditions and allows more flexible responses to climate change.

The ‘rule of thumb’ for calculating the width of eaves is given below. This rule applies to all latitudes south of and including 27.5° (Brisbane, Geraldton). For latitudes further north, the response varies with climate. (see Shading)

Permanently shaded glass at the top of the window is a significant source of heat loss with no solar gains to offset it. To avoid this, the distance between the top of glazing and underside of eaves or other horizontal projection should be 50% of overhang or 30% of window height where possible. (see Shading)

**Heat loss through glass (and walls) is proportional to the difference between internal and external temperatures. Because the hottest air rises to the ceiling, the greatest temperature difference occurs at the top of the window.**

**Thermal mass and thermal lag**

Thermal mass is used to store heat from the sun during the day and re-release it when it is required, to offset heat loss to colder night-time temperatures. It effectively ‘evens out’ day and night (diurnal) temperature variations. (see Thermal mass)

*Thermal mass can significantly increase comfort and reduce energy consumption.*

When used correctly, thermal mass can significantly increase comfort and reduce energy consumption. Thermal mass is very useful for some climates but can be a liability if used incorrectly. Thermal mass must be externally insulated (so the stored heat is not lost) and internally exposed (so solar heat can flow easily into the material).

**Source:** Sustainable Energy Authority Victoria (SEAV)

Thermal mass must be externally insulated and internally exposed.
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Adequate levels of exposed internal thermal mass (i.e. not covered with insulative materials such as carpet) in combination with other passive design elements, ensure that temperatures remain comfortable all night and, if well-designed, on successive sunless days. This is due to a property known as thermal lag — the amount of time taken for a material to absorb and then re-release heat, or for heat to be conducted through the material.

Thermal lag times are influenced by:
- temperature differentials (∆T) between each face
- thickness
- conductivity and density
- texture, colour and surface coatings
- exposure to air movement and air speed.

Rates of heat flow through materials are proportional to the temperature differential between each face. External walls have significantly greater temperature differential than internal walls and thermal mass must be insulated externally. The more extreme the climate, the greater the temperature differential and the more insulation required. Even 300mm-thick adobe and rammed earth walls require external insulation in cool and cold climates. Avoid using high mass in hot climates.

The useful thickness of thermal mass is the depth of material that can absorb and re-release heat during a day–night cycle. For most common building materials this is 50–150mm depending on their conductivity. Longer lag times are useful for lengthy cloudy periods but must be matched by solar input (see ‘Glass to mass ratios’ below).

Relative thermal lag of some common building materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Thickness (mm)</th>
<th>Time lag (hours)</th>
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<tbody>
<tr>
<td>AAC</td>
<td>200</td>
<td>7.0</td>
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<tr>
<td>Adobe</td>
<td>250</td>
<td>9.2</td>
</tr>
<tr>
<td>Compressed earth blocks</td>
<td>250</td>
<td>10.5</td>
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<tr>
<td>Concrete</td>
<td>250</td>
<td>6.9</td>
</tr>
<tr>
<td>Double brick</td>
<td>220</td>
<td>6.2</td>
</tr>
<tr>
<td>Rammed earth</td>
<td>250</td>
<td>10.3</td>
</tr>
<tr>
<td>Sandy loam</td>
<td>1000</td>
<td>30 days</td>
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</tbody>
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Source: Baggs 2009

Low mass solutions with high insulation levels work well in milder climates with low diurnal ranges. Low mass construction gives faster response times to auxiliary heating and will prove more flexible in warming climates. Additional flexible thermal mass options are available. (see Thermal mass)

Planning and design

Floor planning

Plan carefully to ensure passive solar gain to the rooms that most need it.

In warmer temperate climates, external wall materials with a minimum time lag of 10 to 12 hours can effectively even out internal–external diurnal temperature variations. In these climates, external walls with sufficient thermal mass moderate internal–external temperature variations to create comfort and eliminate the need for supplementary heating and cooling.

NOTE: The use of high mass solutions is becoming questionable because climate change will increase summer temperatures and cause longer and more extreme heatwaves. In general, moderate mass or well-insulated lightweight construction is generally a more appropriate solution for the life span of housing built today.

Extremely high thermal mass levels (e.g. earth covered housing) can even out seasonal temperature variations. Summer temperatures warm the building in winter and winter temperatures cool it in summer. In these applications, lag times of 30 days are required in combination with the stabilising effect of the earth’s core temperature.

These water filled balustrades provide high thermal mass suitable for current climate conditions but have the potential for low cost mass reduction (if drained) as climate change progresses.

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In general, group living areas along the north façade and bedrooms along the south or east façade.

Living areas and the kitchen are usually the most important locations for passive heating as they are used day and evening. Bedrooms generally require less heating. It is easy to get warm and stay warm in bed. Children’s bedrooms can be classified as living areas if considerable hours are spent there.

Utility and service areas such as bathrooms, laundries and garages are used for shorter periods, require smaller windows and generally require less heating. These areas are best located:

- to the west or south-west, to act as a buffer to hot afternoon sun and the cold westerly winds common to many regions
- to the east and south-east, except where this is the direction of cooling breezes.

Detached garages to the east and west can create protected north-facing courtyards, provide shade from low angle summer sun and direct cooling breezes into living spaces.

Compact floor plans minimise external wall and roof area, thereby reducing heat loss and construction cost. Determine a balance between minimising heat loss and achieving adequate daylighting and ventilation.

Consider specific regional heating and cooling needs and the site characteristics to determine an ideal building shape.

**Locating thermal mass**

As a first priority, locate thermal mass where it is exposed to direct solar radiation or radiant heat sources. Insulated or internal suspended slabs that are not earth-coupled make ideal thermal mass storage for solar heat gains, as do masonry walls, water filled containers and phase change materials. They should receive direct solar radiation. (see *Thermal mass*)

Thermal mass also absorbs reflected radiant heat. Thermal mass walls between northern living areas and southern sleeping areas are ideally located as thermal lag radiates daytime solar gains into sleeping areas at night and provides acoustic separation. Locate additional thermal mass predominantly in the northern half of the house where it absorbs most passive solar heat.

Earth-coupled concrete slabs-on-ground are not an ideal storage medium for solar gains. They have an almost endless capacity to absorb heat with very little temperature rise due to their capacity to ‘wick’ heat away through earth-coupling. Their main role in passive design is to maintain overnight temperatures at deep earth temperature levels (16–19°C at 3m depth) that can easily be topped up by solar gains or auxiliary heating next day.

In cold climates, insulate under areas of slab-on-ground that are exposed to direct solar radiation and insulate all edges.

**Consider use of low thermal mass materials and high levels of insulation in south-facing rooms.**

Air movement within the house heats or cools thermal mass. Locate mass away from cold draught sources (e.g. entries) and expose it to convective warm air movement in the house (e.g. hallways to bedrooms). Consider the balance between heating and cooling requirements. (see *Thermal mass*)

Locate thermal mass where it is exposed to direct solar radiation.

Edge insulation is desirable for earth-coupled slabs, especially in colder areas. Earth-coupling should be avoided where groundwater action or temperatures can draw heat from slabs.

**Air movement and comfort**

Air movement creates a cooling effect on our bodies by increasing the evaporation of perspiration. Draughts increase the perception of feeling cold. Air movement of 0.5m/s (barely enough to move a sheet of paper) creates a cooling effect equivalent to a 3°C drop in temperature. (see *Design for climate; Passive cooling*)

Avoid convection draughts by designing floor plans and furnishing layouts so that cool air flowing from windows and external walls towards heaters or thermal mass sources is directed through traffic areas such as hallways and stairs. Create draught free nooks for sitting, dining and sleeping.
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Use ceiling fans to circulate warm air evenly in rooms and push it down from the ceiling to living areas. For low ceilings, use fans with reversible blade direction to minimise draughts.

Adverse effects of draughts.

Locating heaters

Internal thermal mass walls provide an ideal location for heaters, especially radiant units such as wood heaters or hydronic heating panels. Thermal lag will transfer heat to adjoining spaces over extended periods. (see Heating and cooling)

Locating heaters next to an outside wall can result in additional heat loss (unless they are well insulated), as increasing the temperature differential between inside and out increases the rate of heat flow through the wall. Do not locate heaters under windows.

As heaters create draughts when operating, try to locate them where they can draw cooled air back through passageways rather than sitting areas.

Design for heat distribution

Convection currents are created when warmer air rises to the ceiling and air cooled by windows and external walls is drawn back along the floor to the heat source. With careful design, convective air movement can be used to great benefit but with poor design can be a major source of thermal discomfort.

Analyse warm air flows by visualising a helium filled balloon riding the thermal currents. Where would it go? Where would it be trapped? Cool air flows are drawn by gravity and fall towards the lower levels of your rooms — use incense sticks to track air flows in your existing home.

Single storey homes

- Minimise convective air movement in winter with wall and ceiling insulation and glazing. The convection that still occurs is a major means of passive heat distribution in any home.
- Controlled convection can be used to warm rooms not directly exposed to heat sources; it can also reduce unwanted heat loss from rooms that do not require heating.
- Opening or closing doors controls the return air flow but impacts on privacy. Use vents that can be opened or sealed.
- Openable panels (louvres or transom windows) over doors promote and control movement of the warmest air at ceiling level while retaining privacy.
- Floor to ceiling doors are effective in facilitating air movement but are often closed for privacy.

Multi-storey homes

- Place most thermal mass and the main heating sources at lower levels.
- Use high insulation levels and lower (or no) thermal mass at upper levels.
- Ensure upper levels can be closed off to stop heat rising in winter and overheating in summer.
- Use stairs to direct cool air draughty back to heat sources, located away from sitting areas.
- Avoid open rails on stairwells, balconies and voids. They allow cool air to fall like a waterfall into spaces below.
- Use ceiling fans or heat shifters (see Heating and cooling) to push warm air back to lower levels.
- Minimise window areas at upper levels and double glaze. Use close fitting drapes with snug pelmet boxes.
- Maximise the openable area of upper level windows for summer ventilation. Avoid fixed glazing.
- Locate bedrooms upstairs in cold climates so they are warmed by rising air.

Preventing heat loss

Preventing heat loss is an essential component of efficient home design in any climate. It is even more critical in passive solar design as the primary heat source is only available during the day.

The building fabric must retain energy collected during the day for up to 16 hours and considerably longer in
cloudy weather. To achieve this, pay careful attention to each of the following factors:

- windows and glazing
- insulation
- draught sealing
- air locks.

Windows and glazing

In terms of energy efficiency, glazing is a critical element of the building envelope, transferring both radiant and conducted heat. In insulated buildings it is where most heat is lost and gained.

Avoid over-glazing — excessive areas of glass can be an enormous energy liability.

Daytime heat gain must be balanced against night-time heat loss when selecting glazing and sizing windows. In winter, there are five hours or less of solar heat gain but 19 or more hours of night-time heat loss. Low conductivity or U-value (e.g. double glazing) and high solar heat gain coefficients (SHGC) are required in cool and cold climates but should be adjusted as cooling needs increase. (see Glazing for an explanation of U-value and SHGC)

Window frames also conduct heat. Use timber, PVC or thermally separated metal window frames in cooler climates (and hotter climates where air conditioning is used).

Views are an important consideration and are often the cause of over-glazing or inappropriate orientation and shading. Plan carefully, especially for shading and advanced glazing options, to capitalise on views without decreasing energy efficiency. There are many ways to reduce heat loss through glazing. (see Glazing)

Insulation

High insulation levels are essential in passive solar houses. Try to insulate above the minimum levels required by the current Building Code of Australia (BCA), Volume Two, Part 3.12.1. The BCA reference is AS/NZS 4859.1:2002 Materials for the thermal insulation of buildings — General criteria and technical provisions (incorporating Amendment 1). (see also Insulation)

Ceilings and roof spaces account for 25–35% of winter heat loss and must be well insulated. To prevent heat loss, place most of the insulation next to the ceiling as this is where the greatest temperature control is required.
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Passive solar heating

The role of the roof space

Sealed roof spaces provide a thermal buffer zone that increases the effectiveness of insulation.

Sealed roof spaces provide a thermal buffer zone.

Some heat always escapes into the roof space through your insulation. If the roof space is sealed, this escaping heat is trapped and can raise the temperature of the roof space by up to 17°C and reduce the temperature differential across both your ceiling insulation and roofing material (which should include insulation in cooler climates).

As discussed earlier, heat flow through any building element is directly proportional to the temperature differential on either side. Sealed roof spaces are warmer and this reduces the differential and increases the effectiveness of your insulation in the cooler months.

Roof spaces should be able to be ventilated in summer — often best achieved with thermostat controlled, self-sealing exhaust fans in gables or ridges that can be switched off in winter. When activated in summer, the fan only operates when the roof space is warmer than the outside air. (see Passive cooling)

Whirly bird roof ventilators are less effective in mixed (heating and cooling) climates because most are unable to be sealed in winter and automated in summer.

It is important to vent exhaust fans and range hoods to the outside in all cases to avoid condensation and fire risk from the build-up of cooking by-products.

Glass to mass ratios

The ratio of solar exposed glass to exposed thermal mass in a room is critical and varies significantly between climates and designs. This is due to variations in diurnal and climatic temperature ranges. (see Design for climate; Thermal mass)

Too much thermal mass for the available solar heat input creates a heat sink and increases auxiliary heating needs. Insufficient thermal mass causes daytime overheating and rapid heat loss at night.

The amount of thermal mass used should be proportional to the diurnal temperature range. Higher diurnal ranges (inland) require more mass; lower diurnal ranges (coastal) require less. As a rule of thumb, in climates where diurnal ranges are consistently less than 6–8°C, low thermal mass construction performs better. Consider climate warming when making decisions.

The area of north-facing glass with solar access should range between 15% (temperate climates) and up to 25% (cold climates) of the area of exposed thermal mass in a room. Double glazing with heavy drapes and pelmets or equivalent window coverings is highly desirable in cool and cold climates.

In cooling climates with minor heating requirements (e.g. Brisbane) thermal mass levels are dependent on the diurnal range as above but, additionally, the cooling effect of earth-coupling of concrete slabs (where achievable) can provide significant benefits. Slab-on-ground construction is ideal provided that slabs are protected from summer heating and contact with sunlight.

Detailed analysis of glass to mass ratios is complex. House energy rating software such as that developed by the Nationwide House Energy Rating Scheme (NatHERS) can simulate the interaction of the complex range of variables in any design for 69 different Australian climate zones.

While the NatHERS software is most commonly used as a rating tool for council approval, its capacity as a design tool in ‘non-rating mode’ is currently under-used. Seek advice from an assessor accredited by the Association of Building Sustainability Assessors or the Building Designers Association of Victoria, who is skilled in using the software in non-rating mode. (see Thermal mass, especially ‘References and additional reading’)

Draught sealing

Air leakage accounts for 15–25% of winter heat loss in buildings.

• Improve the performance of existing windows and doors by using draught-proofing strips. Install these between the door and frame, at the door base and between the openable sash of the window and the frame.

• Use airtight construction detailing, particularly at wall–ceiling and wall–floor junctions.
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- Control ventilation so it occurs when and where you want it.
- Choose quality windows and doors with airtight seals.
- Seal gaps between the window and door frames and the wall before fitting architraves in new homes and additions.
- Avoid using downlights that penetrate ceiling insulation (see Lighting).
- Duct exhaust fans and install non-return baffles.
- Avoid open fires and fit dampers to chimneys and flues or block them off if unused.
- Do not use permanently ventilated skylights.
- Use tight fitting floorboards and insulate the underside of timber floors.
- Seal off air vents; use windows and doors for ventilation as required. This may not be advisable for homes with unflued gas heaters that require a level of fixed ventilation. (see Sealing your home)

Airlocks

Airlocks at all frequently used external openings (include wood storage areas if wood heating is used) are essential in cool and cold climates, preventing heat loss and draughts. For efficient use of space, airlocks can be double purpose rooms: laundries, mud rooms and attached garages are excellent functional airlocks. Main entry airlocks can include storage spaces for coats, hats, boots and a small bench.

Allow sufficient space between doors so that closing the outer door before opening the inner door (or vice versa) can be done easily. Inadequate space often leads to inner doors being left open. Avoid using sliding doors in airlocks. They are invariably left open, are difficult to seal and can’t be closed with a hip or elbow when both hands are full.

Always design doors to blow closed if left open in strong winds, or consider using spring closers on external doors.

Passive heating in renovations

Passive heating in renovations is examined in much greater detail in Renovations and additions. The following summary lists key additional issues to consider when applying passive solar principles.

Existing brick homes often have adequate thermal mass. To improve passive heating in these homes, insulate external cavity walls, ensure that thermal mass is balanced by increased solar access, and design openings and convective flow paths to ensure that additional solar gains are distributed effectively within the home.
Passive design

Passive solar heating

Existing lightweight homes (including brick veneer) lack thermal mass. It can be simply and cost effectively added with water-filled containers and phase change materials. (see Thermal mass)

Opportunities for improving or adding passive solar design features when renovating an existing home include the following:

- Increase existing insulation levels and insulate any previously uninsulated ceilings and walls (and floors in cool climates) while they are exposed or during re-cladding or re-roofing.
- Design additions to allow passive solar access and facilitate movement of passive heat gains to other parts of the house.
- Relocate or resize poorly orientated or oversized windows and increase the size of solar exposed north windows.
- Use high performance windows and glazing for all new windows and doors. Replace poorly performing windows where possible — glazing is normally the biggest area of heat loss in any building.
- Consider adding a solar conservatory to maximise solar gains in cool climates. Ensure the heat it traps can be distributed to thermal mass within the home during the day and that it can be sealed off from the rest of the house at night.
- Install curtains with pelmet boxes or equivalent where practicable.
- Note that cool, cold and temperate climates all require varying degrees of passive cooling.
- Use window styles that allow maximum opening area. Casement windows or louvres are most appropriate but louvres should be well sealed (they cannot be double glazed).

References and additional reading

Contact your state, territory or local government for further information on passive design considerations for your climate. www.gov.au


Your Energy Savings. www.yourenergysavings.gov.au


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