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Residential Passive Design for Temperate Climates

Gareth Cole

Figure 1: Solar passive house designed by the author
(Image: Cole, 2011)

ABSTRACT

The primary intention of passive design is to create a thermally comfortable building with reduced demand on mechanical (active) forms of heating, air conditioning and ventilation. This paper provides design practitioners with a general overview of the techniques for maximising thermal performance of a house. It will also help to explain the benefits and operation of passive solar design to clients.

About the Author

Gareth Cole has received a number of scholarships for passive solar research, including the ACI / Sisalation Scholarship and the Byera Hadley Travelling Scholarship, and has authored several books on passive solar design, including *Australian Solar Houses* and *Altering Your Home: Renovators' Options*. He has been a winner and finalist in numerous Master Builders and Housing Industry Awards, and recipient of the JJ Greenland ESD Award and the Silver and Gold medals from the Francis Greenway Society. He sat as the chair of the Australian Institute of Architects' NSW ESD Committee for two years. Gareth is a qualified member of the Australian Building Sustainability Assessors and speaks internationally on eco-smart design. Email: gareth@ecologie.com.au

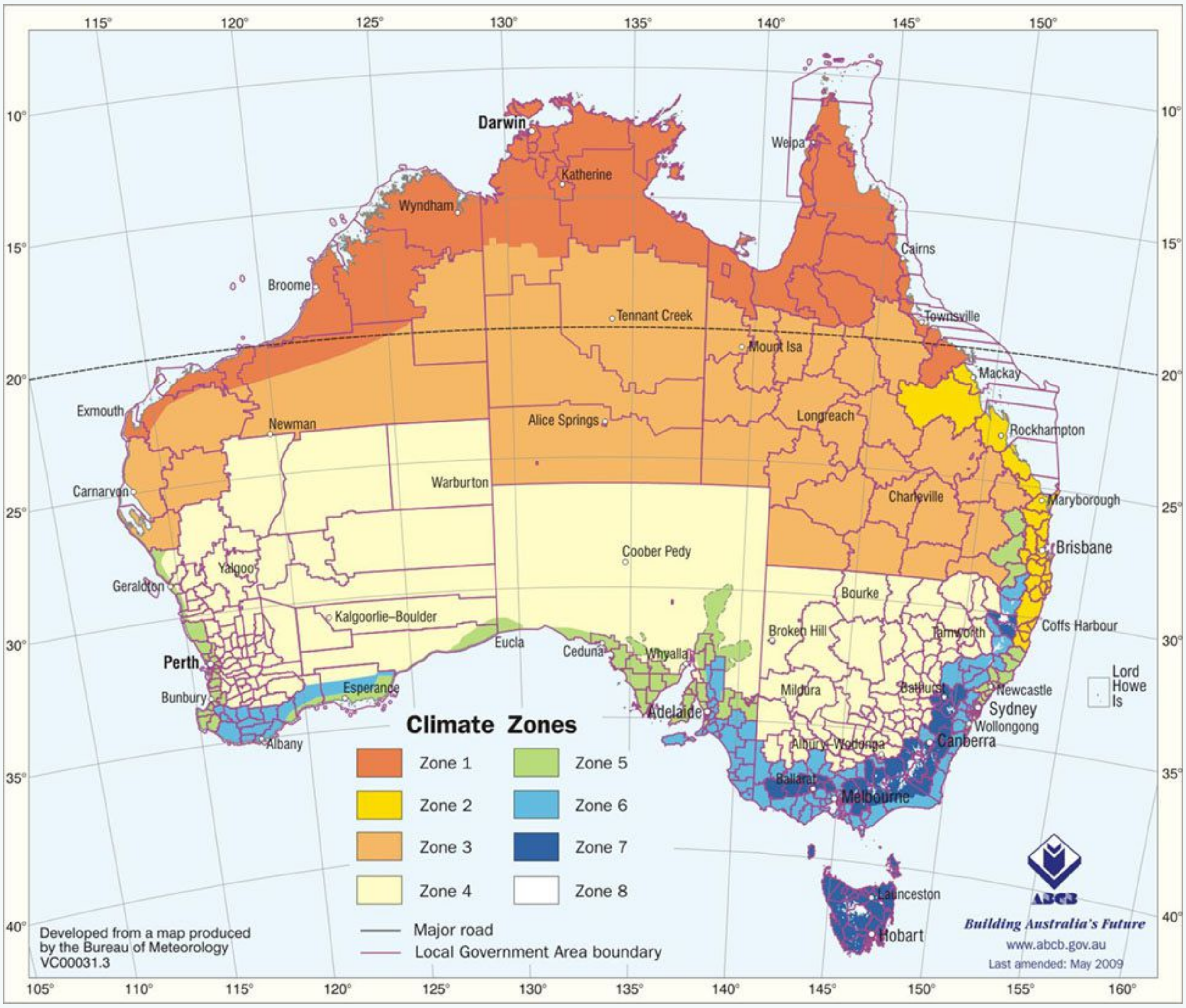

Figure 2: BCA 2010 climate zone map
(Image: www.abcb.gov.au)

Introduction

Passive design techniques are increasingly becoming a mandatory consideration for all design and specification work by residential building designers.

Within Australia there are many climatic zones, varying from hot-arid, tropical warm-humid, to cool temperate. Each of the climatic zones in Australia requires a variation in approach. This paper is directed principally at the temperate climate conditions of south-eastern Australia.

Principles

The key principles of passive design can be covered off under the following headings:

1. Orientation and House Plan Ratio
2. Building Envelope
3. Thermal Mass
4. Insulation
5. Ventilation and Zoning

To make the system work, it is imperative that all of the principles are adopted – as each depends on the others.

Orientation and House Plan Ratio

The single most important aspect of passive design is facing the building towards the sun. The design layout must take into account the direction of sunrise and sunset in midsummer and midwinter and the angle of the midday sun for both solstices. In summer, when combined with the correct eaves overhang, it will minimise sun penetration into the north glass wall, and in winter it will maximise it.

A passive house should have a ratio of approximately 2:1 length to depth (east-west axis to north-south axis). This provides the added advantage of assisting with cross ventilation, as the house will have minimal rooms in the north-south direction, allowing for better cross flow (especially as most cool summer breezes on the east coast of Australia come from the northeast, east to southeast).

For location-specific climate data including prevailing wind directions, go to www.bom.gov.au/climate/data/. Base your search on 'Monthly Climate Statistics'.

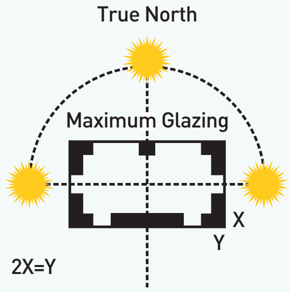

Figure 3: House plan ratio

Site Analysis

The best method to determine whether a site is suitable for passive solar design is by performing a site analysis. Most councils now ask for a site analysis to be presented at the development application stage. It pays to do the planning work up front as there are many considerations that need to be taken into account, including wind direction at different times of year, desirable views and undesirable views, sources of noise, connection of the house to outdoor activities, and the best places to plant deciduous and evergreen trees.

When obtaining a survey plan from a registered surveyor, it is important to request the direction of true and magnetic north to be shown on the plan, as true north (or solar north) and magnetic north are not the same. The direction of true north varies over time. Currently true north is generally accepted as between 11.5° and 12.5° west of magnetic north.

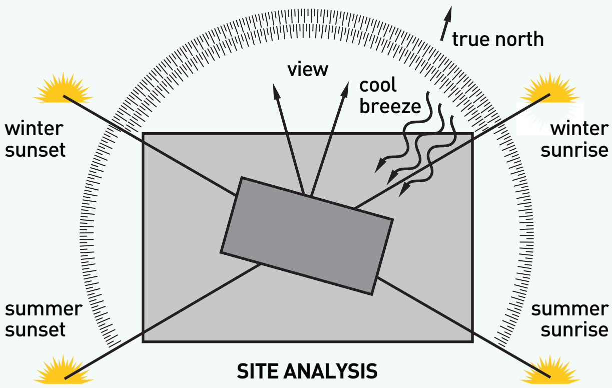

Figure 4: Simple site analysis for a Sydney house

Ideally, the siting of the house should be orientated so the long side of the house is at 90° to true north, with living rooms arranged along the northern face. A deviation from north by 15° west or 20° east of true north is considered acceptable.

Eave Overhangs

Sun angles in winter and summer will determine the width of eave overhangs. Draw a line from the highest point of the summer sun to the lowest point of the window, then design the eave overhang so its shadow-casting edge cuts out the maximum possible summer sun while still permitting the maximum possible midwinter sun.

The rule of thumb for determining an eave overhang for a full-height window is to divide the height of the wall by an average of between 3 and 4. For half-height windows, the rule of thumb is to divide the height of the wall by between 4.3 and 5.

For a 2.4m wall with a full-height window, dividing the wall height by 2.5 gives a 960mm overhang, while dividing it by 4 gives a 600mm overhang.

The latitude of the site is crucial. At a latitude of 35° south (Sydney), at noon in midsummer the sun's altitude is at an altitude of 76°, while in midwinter it is at an altitude of 32°. In Hobart (35° south) the midsummer sun is at altitude of 68° and the midwinter sun is 24°. Excluding summer sun is a more 'burning' issue in Sydney than it is in Hobart, hence the overhang for a 2.4m wall with a full-height window in Sydney

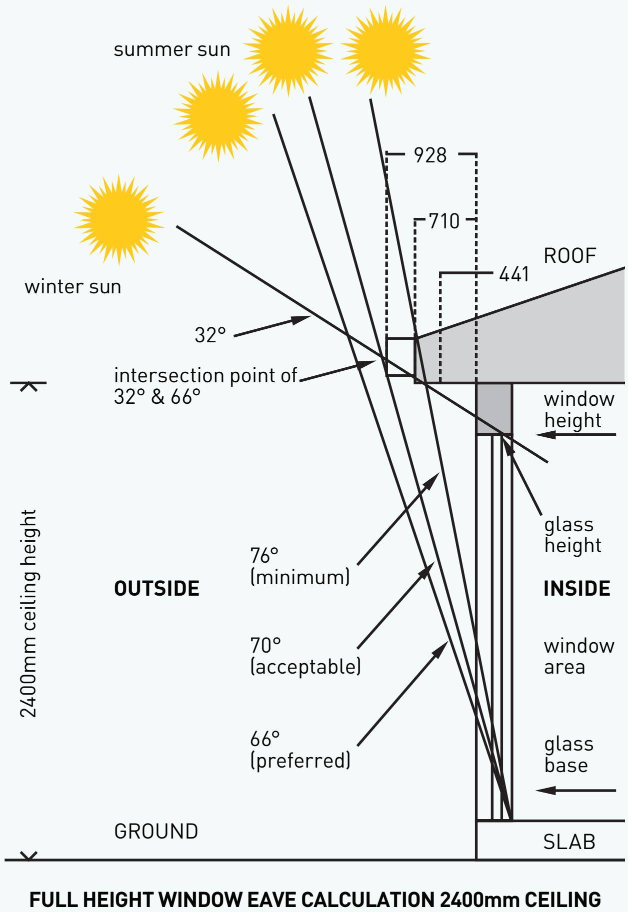

Figure 5a: Eave overhang calculations, latitude 35° south (Sydney)

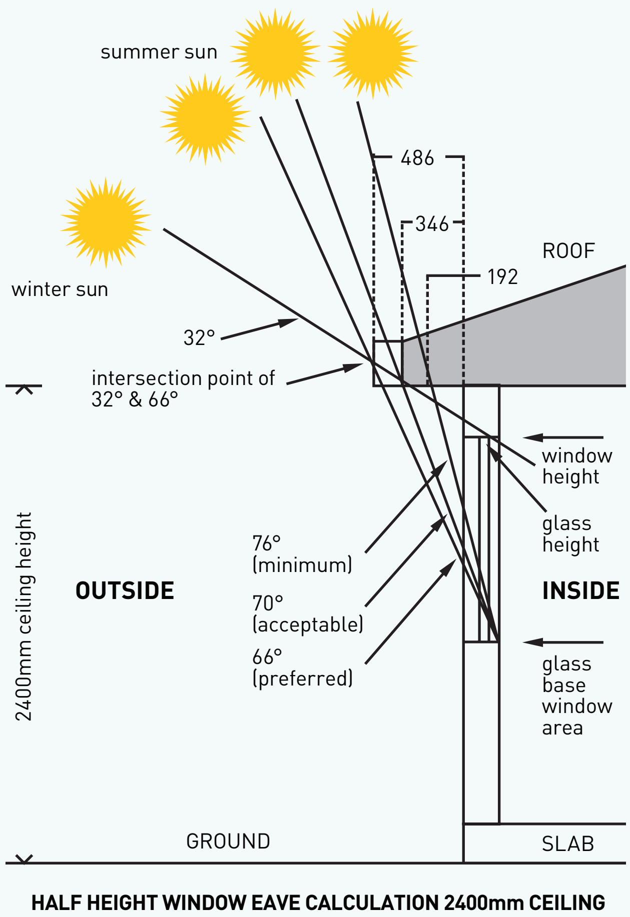

Figure 5b: Eave overhang calculations, latitude 35° south (Sydney)

should be as close as possible to 960mm; in Hobart it can afford to be as little as 600mm.

Internal Planning

Rooms with maximum daytime use – such as living, dining and kitchen – should be placed on the northern side of the building so that they are kept warm during the winter months. Glazing to this north wall should be maximised, preferably full-height glass doors and windows; bearing in mind that in climates with cool to cold winters, such as Melbourne and Hobart's, double glazing may be necessary to reduce heat loss.

Flooring to northern rooms should be tiled or polished concrete (for thermal mass), with an ideal floor to glass ratio of 2:1. (Note that if the floor covering is low mass – e.g. carpet or timber – then the glass to floor area ratio needs to be revised downwards or the rooms will overheat in winter.)

Rooms that are used for short periods of time during the day – e.g. bathroom, laundry and bedrooms – can be set to the southern side.

Window Placement and Shading

The following is provided as a guide:

North glass - maximise, with correct eaves overhang

South glass - minimise, but allow sufficient openings to facilitate breeze paths

East and west glass - avoid or minimise, with only small windows where necessary. Provide full external shading

Building Envelope

The overall shape, fabric, and dimensions of a building in both plan and elevation can have a dramatic effect on its thermal performance. A well designed passive house will achieve optimal performance in a given climate zone through its building envelope. A properly designed building must: vary its shape to take advantage of the prevailing hot or cooling winds; work with the type, style and height of vegetation and topography; and respond to solar access of its site. Each site is unique, and the house needs to be designed to cater to its site's particular characteristics (such as sun and wind shadows).

For high wind areas, the pitch of the roof can be critical: a steeper roof pitch – i.e. 25 to 35º – will assist in holding the roof down in high winds. The floor plan should also be articulated to minimise wind shadowing to adjacent sites.

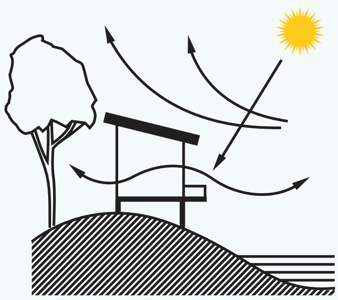

Figure 6: Building envelope

Colours

Light colours will reflect heat, whereas dark colours will absorb it. However, very light colours on the outside of a building can provide discomfort to other buildings and their occupants. Glare and flaring from a white roof can have a devastating effect on adjacent buildings. For this reason, many councils will not approve white, off-white and silver roofs.

For climates that have a high summer temperature, light coloured walls and roofs may be used to enhance the solar effectiveness of the building. Dark colours, combined with high thermal mass materials, are best used on internal floors and walls in north-facing rooms.

Landscaping

Landscaping may be used to enhance solar gain and give protection from cold winds in winter, and to give shade and funnel cooling breezes into the house in summer.

Planting evergreen trees to the east and west of a house can protect against cold winds in winter and, if placed correctly, will focus cool breezes into the house in summer. Deciduous trees to the north will allow sun penetration to the building in winter, while providing extra shading in summer.

If strategically placed, fern gardens, pools, ponds and water features can mitigate warm summer winds and, through evaporation, cool and condition the air as it moves into the house.

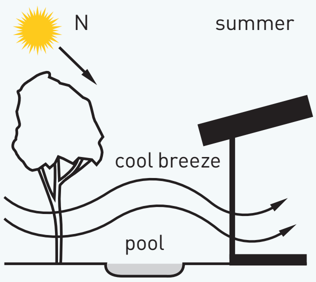

Figure 7: Landscaping

Attached Glass House

Glass houses or sun spaces attached to the house are best placed on the northern side. They should be avoided on the east, west or south sides. Properly designed and used, this system can provide a heating source for the house in winter and act as a cooling source for the house in summer.

In winter, open the door or windows that connect the glass house to the residence. The heat generated in the glasshouse will reradiate into the house during the day. But be sure to close off the openings in the evening as the glass house will cool down quickly.

In summer, allow the glass house to heat up, then with the use of roof windows, allow the glass house to exhaust its hot air. At the same time, by a small opening to the residence (say, a sliding door opened by about 150mm) allow the glass house to draw air from the residence. This is called the chimney effect. If the replacement air into the residence is drawn from a densely planted, moist southern garden it will draw the cool air through the house.

A glass house can also provide an extra living space in winter, and can double as a place for plant propagation.

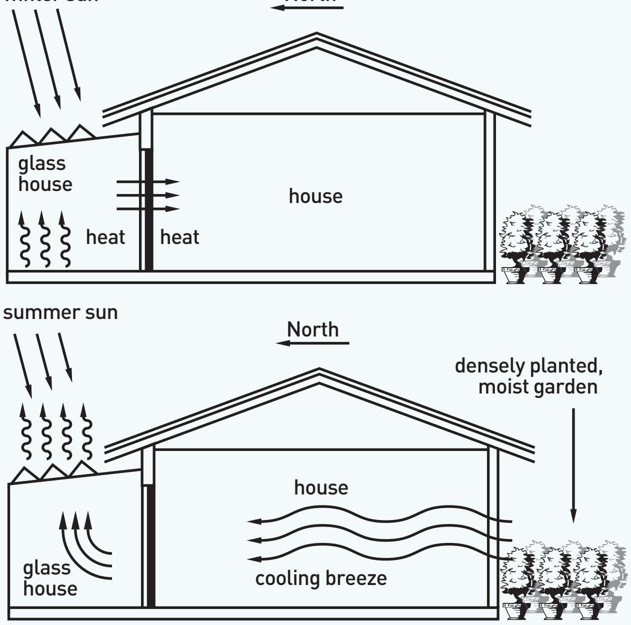

Figure 8: Glass house, winter and summer

External Shading Devices

If correctly designed, in accordance with the correct sun angle for the building's latitude, pergolas and other external sun shading devices will mitigate the summer sun while still allowing penetration of winter sun.

External fixed or adjustable louvres with 85 to 100 per cent shading to any east and west glazing will minimise overheating of the rooms associated with these windows in summer. External louvres should also be provided for clerestory windows and skylights.

Thermal Mass

Thermal mass materials, e.g. concrete, tiles and stone, are heavy and dense. Thermal mass represents the ability of a material to store heat. It provides the building with thermal inertia, sometimes called the 'thermal flywheel effect'.

Thermal mass is a ideal for temperate and hot arid climates, where it can even out daytime and nighttime temperature differences. Thermal mass building materials can store heat for as long as eight to 10 hours.

In building terms, high thermal mass materials include concrete, mud or brick floors in the horizontal plane; and brick, mud brick and rammed earth in the vertical plane.

The denser the material the greater its thermal mass. So a compressed fibro lining is a better choice thermally than plasterboard, because it is denser. Similarly, dry pressed bricks perform better than

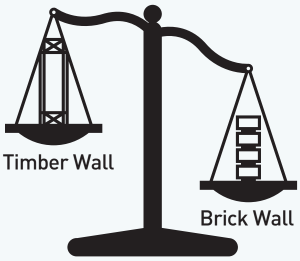

Figure 9: Thermal mass materials

extruded bricks (the former weigh around 1600 kg/m^3, whereas the latter may be only 400 kg/m^3).

Where to Place Thermal Mass

As a general rule, thermal mass is only of thermal benefit when located inside the house. Thermal mass is best placed in the north-facing rooms, where the winter sun can penetrate the glazing and heat the floor or walls. The thermal mass will store the sun's heat during the day, and release it into the living spaces at night.

Conversely, in summer, assuming the northern glazing is properly shaded, excess environmental heat entering the house will be absorbed into the thermal mass, allowing the air in the space to remain cool during the hottest part of the day. At night, any heat gain in the room during the day can be purged through cross-flow ventilation.

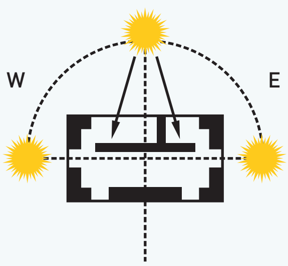

Figure 10: Locating thermal mass

Insulation

Thermal Insulation reduces the rate that heat can flow through walls, roof and floors. The amount of heat lost in winter and heat gained in summer to internal spaces will be dramatically reduced by installing the correct level of insulation in the correct way.

There are two main types of thermal insulation: bulk insulation, such as rock wool, fibreglass, wool and expanded plastics; and reflective insulation such as foil laminates, known as sarking or foil wrap.

R-Value

R-value (resistance value) is a measure of the thermal resistance of an insulation product – that is, its ability to slow down heat flow (either heat escaping from the house in winter, or coming into the house in summer). It is expressed as the thickness of the material divided by its thermal conductivity. The higher the R-value the more effective the insulation.

All thermal insulation carries a manufacturer's statement as to its R-value.

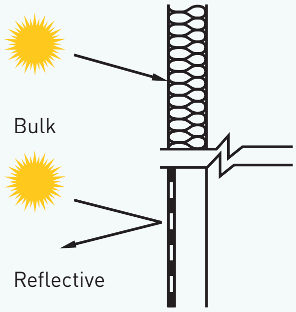

Figure 11: Insulation types

Where to Place Insulation

All areas of the building envelope should be insulated against the entry of heat and cold. The areas requiring consideration are the floors, walls, roof, ceiling, doors and windows. If they are not all insulated correctly and holistically, then the 'insulation chain' is broken and the building's thermal performance will be affected. It will fail at its weakest link. As water always flows downhill, so heat will always rise or flow towards the coldest leak point in a room: a fire place without dampers, an uninsulated cornice – even electrical power points.

Floors

Different floor types require different treatments.

- Timber suspended floor: insulate in between joists to prevent heat loss in winter with R 2.7
- Concrete slab on ground: insulate to the slab edges to prevent heat loss in winter
- Concrete and AAC slab, suspended: insulate under the slab with R2.7 as well as the slab edge

Walls

Caution: Do not compress insulation batts. E.g. purchasing a 180mm-thick insulation batt with an R-value of R3.5 and installing it in a stud frame wall that is 90mm thick will reduce its insulation value by half. Note that insulation now on the market allows for R2.5 to be installed within a 90 mm stud frame.

Step 1: Install reflective foil to all external walls and ensure that all windows and doors are fully taped so there is no air loss where the foil meets the window or door frames. In a two-storey house, wrap the reflective foil down around the floor and above to the next floor, taking the foil up to and over the walls at the top ceiling level. Ensure that all joints are well lapped and taped and any holes or penetrations are very well taped up and sealed.

Step 2: Install bulk insulation to all external walls, ensuring that all gaps are filled, and use the foil wrap externally as a backing. Remember: no joint or gap is too small for heat to pass through, so ensure it is filled with insulation.

Foil and batt insulation installed correctly in a stud wall can raise its R-value to R3.

Roof and Ceiling

Roofs should be insulated with reflective insulation (R1.5) to prevent heat gain into the roof space. R3.5 batts above the ceiling lining will insulate satisfactorily against heat loss in winter and some heat gain in summer. However batts as high as R 6 are now available at not much extra cost. Installed correctly, these will provide very high levels of insulation on the upper side of the building, greatly minimising heat loss in winter and heat gain in summer.

Wherever possible, do not use recessed downlights (particularly halogen downlights) in the ceiling as these will make a 'Swiss cheese' out of your ceiling insulation.

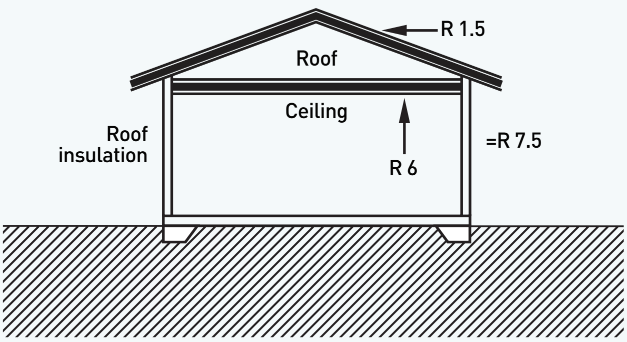

Figure 12: Roof insulation

Ventilation and Zoning

The ventilation of a house is of importance year round. For basic health reasons, such as preventing mould build-up and removing airborne toxins and smells, a house needs to breathe. Also of course, ventilation enables internal surfaces in the house to cool down in summer.

The ventilation of a room is measured in air changes: the movement of a volume of air in or out of a space in a specified time period. The ventilation of a good building should give about 12 to 18 complete air changes per hour. Many Australian homes have unwanted air changes of 25 to 30 air changes per hour.

This may have a small benefit in summer, but presents a very negative effect in winter. In the first place, such a house needs to be better sealed; then the house's ventilation needs to be brought under the occupants' control with windows and doors that can be opened and closed to provide ventilation when and as required.

Ventilation for Summer

Windows should be positioned to facilitate maximum cross-flow ventilation by the prevailing cooling summer breezes, and operable windows must be aligned in an approximately straight line to facilitate breeze paths. For instance, in Sydney cooling breezes are generally from the northeast, hence windows and openings through the house should be orientated to the north and northeast.

The choice of window type can also assist here. Casement windows may be used to act as 'wind catchers', and some studies have shown that external louvres can help funnel winds into the house, adding extra wind speed or cooling effect into the house.

Breeze paths through the house should be kept clear of obstructions, to help facilitate and encourage air flow for nighttime cooling. Ideally, the windward opening should be smaller than the leeward opening.

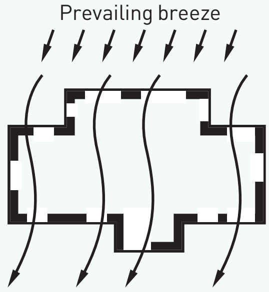

Figure 13: Summer ventilation

Zoning for Winter

Where facilitation of cooling breezes is critical during summer, zoning and sealing are equally vital during winter. The building must provide for sufficient ventilation, while at the same time being correctly zoned to allow the building to be compartmentalised in winter. When planning the zoning of a house, group together similar activity rooms: for example, bedrooms in one zone, living rooms in another, and wet rooms in another.

The house needs to be zoned so that those rooms requiring heating can be heated without having to lose heat to unused rooms or large spaces, thus reducing the effectiveness of the heat source. Living spaces should be protected by zoned airlocks to the outside of the house, such as a main front entry passage and a sealable rear exit such as a laundry.

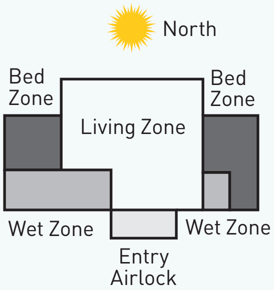

Figure 14: Winter zoning

Sealing

To prevent unwanted ventilation (draughts) it is vital is that the entire house be carefully sealed during construction. Wrap up the internal skin of the external walls of the house with reflective foil and lap and tape up around all windows and doors, ensuring that there are no tears or holes in the wrap.

External doors and windows and zoning doors need to be able to be sealed off with tight fitting seals to all four sides. The opening element of all doors and windows should have gaskets (preferably rubber) to ensure a good air seal to all four sides when closed.

Windows

As glass is relatively transparent to heat gain and heat loss, consideration needs to be given to the glass type, window frame and the way the insulation envelopes the building and continues around the window. Wall insulation should butt into all door and window frames.

The four main types of glazing used in house design are clear glass, low-e (low emissivity) glass, tinted glass and double glazing.

Broadly, most windows frames fall into the categories of timber or aluminium. The consideration here is that timber is a good insulator, however is more difficult to seal as the timber can warp, shrink and split. Aluminium has a much higher heat transference but is easier to insulate. It is also good in bush fire prone areas. Furthermore, some aluminium frames now come with 'thermal breaks' which separate the external skin from the internal frame and minimise any heat bridging, though these are costlier than standard frames.

Window Standards

Always consider the glazing and frame as being part of the same unit: both must perform if the unit is to perform. There are two factors to consider when determining the appropriate standard of window. They are the window's U-Value and its SHGC. The U-value is the term for the thermal coefficient of heat transfer. Basically the lower the U-value the better. For example 3mm glass has a U-value of 6, while good double glazing is about 2.7. SHGC is the Solar Heat Gain Coefficient. A lower SHGC is good for colder climates and a higher SHGC is good for warmer climates.

Skylights and areas of glass that are difficult to curtain should be double glazed. Double glazing is also advisable in north-facing windows in southern climates (e.g. Melbourne and Tasmania) and south-facing room windows in habitable rooms.

The choice on which type of window to select are best made using programs like BERS (Building Energy Rating Scheme), which can simulate the thermal performance of a building.

Curtains and Pelmets

It is difficult and costly to obtain residential glazing with a U-value of less than 2, and hence there needs to be some consideration given to extra insulation to the window. This is best achieved with internal curtains and pelmets. The curtain needs to be two layers on two separate tracks, and needs to be of heavy enough material to ensure an air space from the glass to the liner, and again from the liner to the decorative curtain.

Moreover, none of this will work effectively unless there is a pelmet over the top of the tracks. The pelmet ensures that heat does not rise and cascade over the top of the curtain and down the front of the glass.

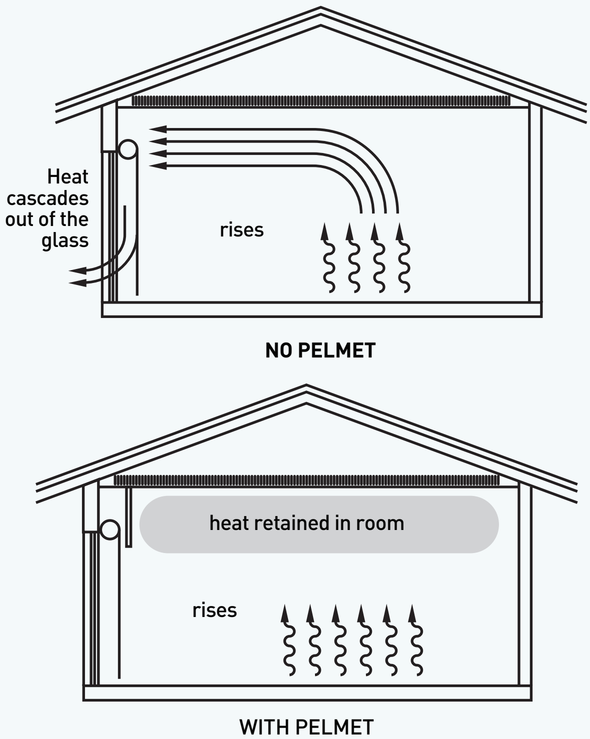

Figure 15: Curtains with/without pelmet

Conclusion

When designing, treat passive solar design principles in a holistic manner from the outset of the design process – each design element depends on the the others for its effectiveness, and should not be considered in isolation.

For passive solar design to work, it is imperative that the occupants understand the concepts involved so that they may actively ensure their own comfort: for example, knowing when to open and close windows for ventilation and night purging. A passive house requires active occupants.

Further Reading

EDG 65 AH, 'Thermal Mass and Insulation for Temperate Climates'

EDG TEC 2, 'Natural Ventilation in Passive Design'

Your Home Technical Manual, www.yourhome.gov.au