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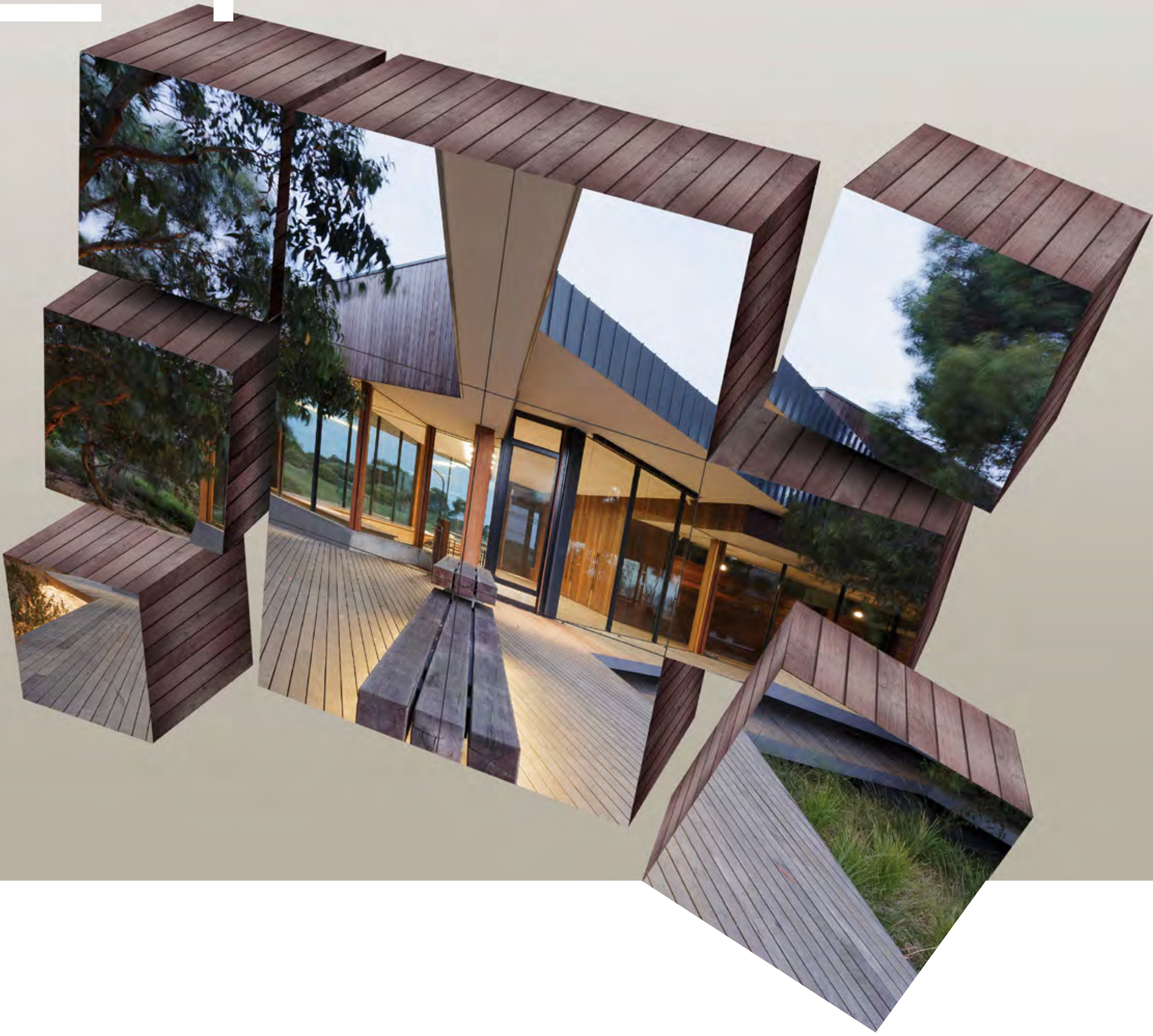

Thermal performance for timber-framed residential construction

Building comfortable and energy-efficient timber houses

Technical Design Guide issued by Forest and Wood Products Australia

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WoodSolutions is resourced by Forest and Wood Products Australia (FWPA – www.fwpa.com.au). It is a collaborative effort between FWPA members and levy payers, supported by industry bodies and technical associations.

This work is supported by funding provided to FWPA by the Commonwealth Government.

ISBN 978-1-925213-04-1

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First published: July 2015

Acknowledgments

Thanks to other staff from the Centre for Sustainable Architecture with Wood (CSAW), School of Architecture and Design, University of Tasmania for providing their insights to the publication. Colour diagrams were drawn by Stephanie Green from CSAW

Photographs and other diagrams provided by authors.

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Introduction

Timber and thermal comfort in housing

Most existing houses in Australia have timber frames and new homes continue this tradition. Modern construction methods mean an increasing number of low-rise apartment buildings, traditionally constructed from masonry for fire-resistance, are also now being built with timber frames.

Designing for timber thermally

As construction technology has developed, standards of fire-resistance, acoustic separation and thermal comfort in timber buildings have improved. This Guide provides design and construction information for superior thermal comfort. Better thermal performance results in:

- more comfortable residents
- less energy use for heating and cooling
- reduced greenhouse gas emissions.

Increasing comfort

Timber-framed houses tend to be more responsive to heating and cooling than buildings with higher thermal mass. Occupants are kept comfortable by moderating internal temperatures to avoid extremes.

Comfort and energy efficiency can be maximised by avoiding unwanted heat loss or gain through the building envelope. This Guide gives solutions for achieving this with:

- appropriate building orientation and design
- insulating the building envelope well
- avoiding air infiltration

Useful information

The Guide includes:

- general and climate specific considerations
- useful references for further reading
- modelled house case studies
- principles for thermal comfort

1 Background

A house's thermal performance is its ability to provide a naturally comfortable environment all year round. To slow unwanted heat gain or loss, and so minimise the need for artificial heating or cooling, consider:

- **Insulation** - used to retard heat flows through the envelope
- **Sealing** – used to close gaps and limit air infiltration/exfiltration that would otherwise leak heat in or out of the interiors
- **Ventilation** – used to avoid heat build-up.

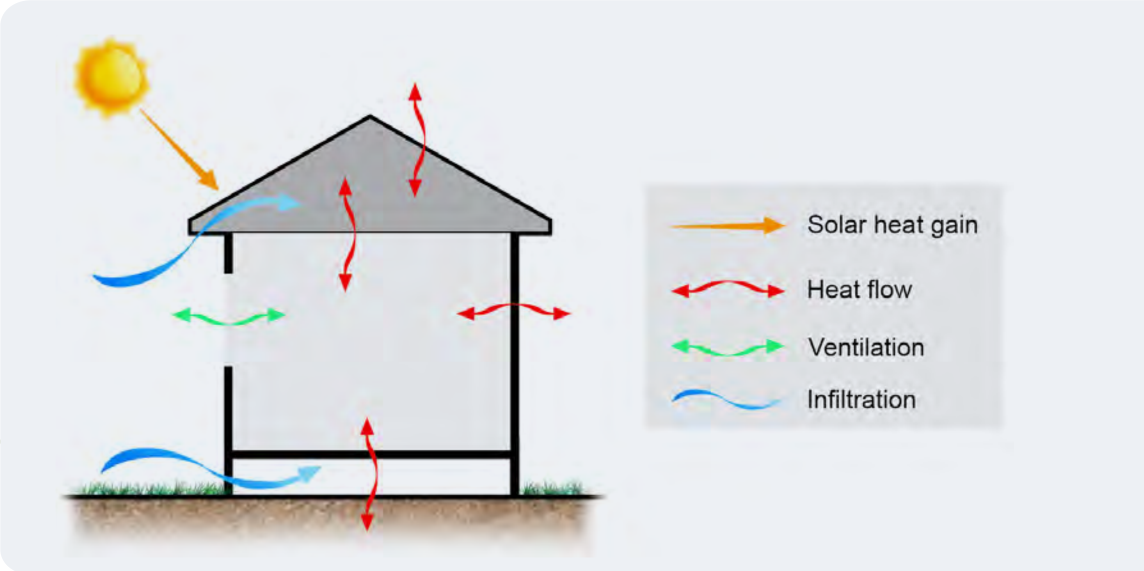


Figure 1: Energy flow in a residential building

1.1 Increasing Thermal Standards

Australia's Building Code has incrementally added controls designed to reduce energy use and greenhouse gas emissions. The National Construction Code (NCC) regulations apply to residential and most non-residential types of buildings and focus on:

- improving the thermal performance of the building envelope to reduce the amount of energy needed to heat or cool the building
- increasing the energy efficiency of fixed appliances within the building.

1.2 Purpose of this Guide

This Guide explains the principles of thermal performance and focuses on ways to enhance the performance of residential timber-framed buildings. It:

- explains principles of thermal performance for timber-framed construction
- provides strategies to optimise performance for each climate zone
- presents tips for increasing thermal performance efficiently.

The Guide focuses on detached or semi-detached dwellings but many of these principles are useful for larger timber-rich commercial and multi-residential buildings.

1.3 Designing Better Houses

To be effective, design strategies for efficient and economic thermal performance in new or renovated timber buildings must accommodate a complex interplay of factors. These include:

- **site location** - characteristics of the project's location and site, particularly its climate
- **building fit to site** - general arrangement of the building on that site
- **building planning** – planning interiors to work with natural site features such as desirable sun, shade and breezes
- **building design** - detailed design and construction of the building envelope.

These factors interact at different scales: at a site scale (e.g. climate and building orientation); at a functional scale (e.g. positioning of bedrooms and living spaces); and at an elemental scale (e.g. performance of windows, walls and floor elements).

Both general and climate specific considerations are listed a discussion of various building design elements.

Given the innate complexity of thermal performance for buildings in Australia's eight climate zones, it is difficult to provide concise design guidance. To obtain the best design results with timber-framed construction:

- use the principles and guidance in this Guide to improve both design choices and on-site construction practice
- model new house designs with thermal analysis software from an early stage in the design process
- model a number of variations to establish the most effective design features.

1.4 Using this Guide

The guide is divided into sections that address these and other key aspects of design for thermal performance:

Section 1. Background

Section 2. Codes and Standards
Includes the regulatory framework of the NCC and the various state variations, the broad working of the NCC-mandated energy rating software, and the relevant Australian Standards.

Section 3. Design Strategies
Provides general strategies for well-performing timber buildings, with suggested improvements for tuning the building's performance to match the climatic conditions of the site. Site factors are critical for the thermal performance of all forms of buildings, especially lightweight timber-rich structures.

Section 4. Planning Strategies
Outlines broad planning recommendations and discusses the potential for outdoor areas to contribute to thermal comfort and energy efficiency.

Section 5. Envelope Strategies
Discusses envelope strategies for timber-framed houses in detail. While site level factors are critical to overall performance, quality envelope performance provides the most immediate and effective means of ensuring ongoing thermal comfort. This section includes information on the control of structural moisture, the management of air infiltration and vapour movement, the requirements of insulation practice, window design, shading of the building and the potential and problems of thermal mass.

Section 6. Learning from Case Studies
Uses the lessons learnt from the computer modelling of two houses to illustrate the concepts discussed in this Guide. A range of building variations are modelled across a range of climates illustrating the how different climates require different design responses.

Section 7. Thermal Comfort and Technical Principles
Outlines key definitions and concepts of the thermal performance of lightweight buildings. These include aspects of the thermal comfort of occupants and performance of materials.

1.5 Continually Increasing Standards

Unlike more established areas of building practice, most aspects of the thermal performance of building are changing and are likely to continue to change over coming years. These include:

- **Regulatory aspects** - Thermal performance requirements have regularly increased since they were introduced in 2004. While requirements vary between Australian states, the national trend is for a continued increase in the regulated thermal performance of buildings.
- **Market expectation** - The building regulations impose accepted minimum requirements for thermal performance. The market is either accepting these minimums or requiring better-than-code performance. Given the difficulty of improving thermal performance after completion, the most cost-effective improvements are made during the design and construction process.
- **Construction practice** – New construction practices are evolving to meet increasing regulatory and market expectations.

1.6 Thermal Basics Refresher

The technical concepts involved in thermal principles are explained at the end of this Guide. Here is a summary of some basic thermal terms:

Comfort
Human thermal comfort is governed by the temperature of the surfaces that enclose us, the temperature of air within a room and the rate of airflow through a room.

Air
Buildings need to be vented to avoid a build-up of moisture, odours and carbon dioxide, and to provide fresh air for breathing. Air movement is also used to reduce heat build-up.

Moisture
In hot climates, humid air inhibits humans' ability to cool through perspiration. In hot and cold climates, condensation can lead to mould, which is hazardous to humans, and can lead to the decay of building materials.

Heat flow
Heat flows in one of three ways: radiation, conduction or convection.

Heat gain
Apart from body heat from humans and heat from equipment, the heat gain within a home can be from direct solar radiation, heat flow through the building fabric or unwanted hot air leaking into the building through gaps in the building fabric.

Solar radiation can be received through direct sunlight or indirectly through being radiated off hot surfaces around a building, such as adjacent walls or paving.

Heat loss
Heat loss in cool conditions occurs through mass conduction of the building envelope to the cooler outside air. In addition, air gaps – no matter how small – will lead to a loss of warm air.

Climate
Each climate has specific patterns of temperature, humidity and wind that need specific design responses. Exposed sites can experience magnified sun and wind effects, and sheltered sites can have microclimates that change conditions for a building. The Bureau of Meteorology website (bom.gov.au) provides local climate data on breeze direction and temperatures.

Passive vs active systems
Working with natural 'eco-services' such as the sun, wind and external air and ground temperature can maximise comfort and minimise energy use.

Passive systems work without using artificial energy and their use should be maximised. Active systems allow for a back-up when passive systems cannot maintain comfortable temperatures. A combination of passive and active technologies often creates the most effective compromise between control and energy efficiency use (such as prioritising ceiling fans over air-conditioning).

'Energy Rating'
Energy efficiency in houses can be measured in many ways, from home appliances to whole buildings. 'Energy ratings' for Australian dwellings are measured under a national system that computer models how well a building envelope will perform to keep a home's interior thermally comfortable.

2 Codes and Standards

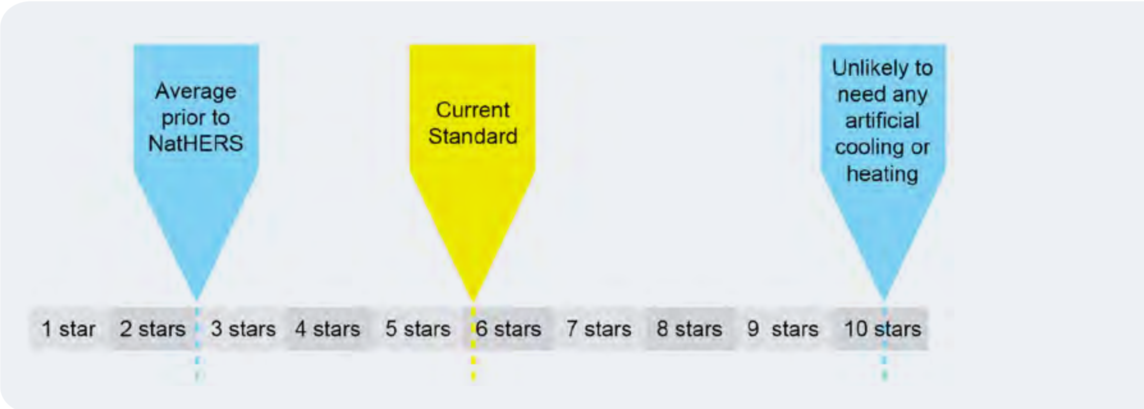
Whether it is a design for a new house or an addition or retrofit for an existing house, the proposed building needs to comply with the minimum requirements detailed in each of the following codes or referenced standards:

- National Construction Code (NCC)
- State/jurisdictional variations
- Nationwide House Energy Rating Scheme (NatHERS)
- Australian Standards (when referenced in the above documents).

2.1 National Construction Code

The NCC specifies the minimum thermal performance requirements for buildings in Australia.

Thermal performance requirements for residential construction were introduced into Australia's building regulations in 2004, with a minimum 4-star requirement on a scale of 10 stars. The minimum requirements have continued to rise since then to a 6-star requirement in most states/territories in 2012. This increased requirement for energy efficiency has been expanded to include equipment such as lighting, hot water systems and heating and cooling systems.



Meeting NCC Standards

There are two ways to meet the NCC performance requirement:

complying with the 'Deemed to Satisfy' (DTS) provisions	OR	provide an acceptable 'Alternative Solution'

While many timber houses in Australia are built to the prescribed DTS construction, house designs from bespoke designers and builders who seek alternative formats need to be assessed for compliance with the NCC. A House Energy Rating Assessor uses approved software to simulate the building's thermal performance in the local climate, and produces a comprehensive report and a house energy star rating. An example of this report is shown in Figure 2.

A number of modelling software tools are accredited under the Nationwide House Energy Rating Scheme (NatHERS) that is mandated by the NCC. See Table 1.

Energy intensity (per square metre per year)							
Location	**5.0 Stars**	**6.0 Stars**	**% Improvement**	**7.0 Stars**	**% Improvement**	**8.0 Stars**	**% Improvement**
Broome	335 MJ/m^2	285 MJ/m^2	15%	234 MJ/m^2	18%	182 MJ/m^2	22%
Brisbane	55 MJ/m^2	43 MJ/m^2	22%	34 MJ/m^2	21%	25 MJ/m^2	26%
Perth	89 MJ/m^2	70 MJ/m^2	21%	52 MJ/m^2	26%	34 MJ/m^2	35%
Hobart	202 MJ/m^2	155 MJ/m^2	23%	113 MJ/m^2	27%	71 MJ/m^2	37%

Table 1: Energy efficiency improvement per star rating
This table shows the relative Improvement per star rating for given climates.

Allowing for climate variances

Although there are 69 climate classifications used for Australia in the NatHERS software, the NCC uses eight that are based on vapour pressure, air temperature and annual heating degree days. The description for each climate type follows internationally accepted definitions.

The average 3 pm *water vapour measure* is a key factor in determining the amount of moisture in the air and whether the climate is hot and dry or hot and humid. *Heating degree days* indicates the degree to which heating would be required to be comfortable for a given climate or building. The value is calculated on the number of days in a calendar year when the day's average temperature is below 18°C.

Generally, hot climates require cooling, temperate climates require cooling and heating, and cool climates require heating. Climates 1 to 4 have a nil heating degree days, whereas climates 5 to 7 have increasing values for heating degree days.

Climate Zone	Description	Average 3pm January water vapour pressure	Average January maximum temperature	Average July mean temperature	Average annual heating degree days
1	High humidity summer, warm winter	≥ 2.1kPa	≥ 30°C		
2	Warm humid summer, mild winter	≥ 2.1kPa	≥ 30°C		
3	Hot dry summer, warm winter	< 2.1kPa	< 30°C	≥ 14°C	
4	Hot dry summer, cool winter	< 2.1kPa	≥ 30°C	< 14°C	
5	Warm temperate	< 2.1kPa	< 30°C		≤1,000
6	Mild temperate	< 2.1kPa	< 30°C		1,000 to 1,999
7	Cool temperate	< 2.1kPa	< 30°C		≥ 2,000 Other than Alpine areas
8	Alpine areas are: (a) likely to be subject to significant snowfalls (b) in New South Wales, ACT or Victoria, more than 1200 m above the Australian Height Datum; and (c) in Tasmania, more than 900 m above the Australian Height Datum				

Table 2: NCC Climate Zone Definitions.

2.2 State/Jurisdictional Variations

Many state and local government agencies have additional legislation that applies to developments within their jurisdiction, which includes requirements for solar access and other aspects of amenity.

Developers and designers must be familiar with the federal, state and local government legislation that applies to their site and the desired development. This includes jurisdictional-based variations to the NCC.

NCC implementation varies at state/territory level in response to industry, economic and energy policy. NCC Section 3.12 requirements on energy efficiency variance per jurisdiction are set out in Table 3.

As thermal performance requirements are being continually reviewed and improved, consulting the local authority for a given project to confirm current regulatory requirements is recommended.

Victoria, Western Australia, and Australian Capital Territory
• Section 3.12 is generally adopted and a 6-Star requirement exists
Tasmania and Northern Territory
• BCA 2009 is adopted (5-star) but it is expected that 6-star provisions will soon apply.
Queensland
• Section 3.12 is generally adopted and a 6-star requirement exists. • There are options for outdoor living rooms and solar power to provide optional credits toward achieving a 6-star house. • Consult the local authority to establish the minimum star rating and optional credits that are available.
New South Wales
• The web-based BASIX building sustainability index is used in conjunction with section 3.12 of the NCC, but with broader scope, which includes water efficiency measures. • For energy efficiency, the BASIX system requires consideration of lighting, hot water system, and minimum insulation and glazing levels similar to those in the NCC, but the NCC should still be consulted to ensure compliance. • Designs that do not comply with BASIX energy efficiency requirements can use a house energy star rating to illustrate compliance with heating and cooling values designated per given postcode. • A lower star rating for timber platform floors is allowed with a concession that requires efficient heating and cooling equipment.
South Australia
• Section 3.12 is generally adopted and a 6-star requirement exists, however, some concessions apply for ratings less than this (refer to local authority). • Subject to house size and location, concessions exist for elevated timber-floor houses with a minimum 5-star rating, but these must include prescribed household solar power.

Table 3: Variations in state/territory thermal requirements.

2.3 Thermal Simulation

In the building design and approval process, the likely or theoretical passive thermal performance of the house is categorised using a star rating on a scale of 1 to 10 stars. The energy star rating results from a computer simulation of the thermal performance of the building's envelope under assumed occupancy and climatic patterns.

The simulation uses Home Energy Rating Software (HERS) to calculate the quantity of energy in megajoules per square metre that could be used to maintain thermal comfort within a house for a calendar year.

These tools are concerned with measuring heating and cooling energy loads; they do not currently assess domestic hot water, lighting or any other fixed or unfixed appliances.

The energy used to condition a home may primarily be for cooling (for example, in Broome), a combination of heating and cooling (Sydney) or primarily heating (Hobart), with milder climates generally requiring less energy for a given star rating. A rating of 10 signifying no heating or cooling should be required, see Table 4.

Star Rating	0.5	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0
	(MJ/m²/year conditioned floor area										
Launceston	895	740	513	366	272	208	160	117	74	33	1
Sydney	286	230	148	98	68	50	39	30	22	13	6
Broome	732	652	531	448	387	335	285	234	182	134	99

Table 4: Star bands for Launceston, Sydney and Broome

When designing a house or renovation, the most efficient way to compare the likely thermal performance of the design is to have varying designs evaluated by a trained assessor using Home Energy Rating Software (HERS). The HERS assessor should visit the site and model both the site and the house. The site model may include objects that provide shading, act as wind breaks and otherwise affect the house simulation.

To achieve a more practical and economic thermal performance for the house, a HERS professional should be engaged in the early stages of design, along with the architect or building designer. This will allow informed decisions to be made based on thermal efficiency and relative cost. Selecting a HERS assessor is similar to selecting any professional consultant – ensure that you are confident and at ease with their experience and communication skills prior to engagement.

2.4 Nationwide House Energy Rating Scheme (NatHERS)

NatHERS was established by the Federal Government in 1993 to develop a mechanism to measure the relative thermal performance of new housing.

The scheme is constantly under review and is periodically recalibrated, based on industry and government research activities. The Federal Government and industry use the information gained by NatHERS to inform the improvement of minimum thermal performance requirements in the NCC.

There are three accredited NatHERS software tools for completing a house energy star rating assessment (Figure 2). These provide a comprehensive report and universal certificate. All three use the same CSIRO-developed building simulation software but have distinctly different user interfaces and levels of flexibility. The three tools are:

- **AccuRate** - The AccuRate tool has been developed by CSIRO and is the most complex, as it allows for the greatest flexibility in modelling a house, but it therefore takes longer to perform a house energy rating.
- **BERS** - The BERS tool has been developed in Queensland and has a more graphical user interface than AccuRate, enabling quicker simulation times.
- **FirstRate** - is the simplest of the three tools; it was developed in Victoria with a focus on standard residential building systems and volume builders.

The NatHERS approved software tools allow a deeper exploration of non-DTS designs and use 69 postcode-based climate zones, allowing a specific climate of the house location to be considered.

AccuRate V2.0.2.13 SP1

Nationwide House Energy Rating Scheme

Project Details

Project Name:
File Name:
Postcode: **Climate Zone:** 26
Design Option: Base Design
Description: As per plans by Architect

Client Details

Client Name:
Phone: **Fax:** **Email:**
Postal Address:
Site Address:
Exposure: Suburban
Council submitted to (if known by assessor):

Assessor Details

Assessor Name: **Assessor No.**
Phone: **Fax:** **Email:**
Assessment Date: 14/07/2014 **Time:** 10:29
Project Code:
Assessor Signature:

CALCULATED ENERGY REQUIREMENTS*

Heating	Cooling (sensible)	Cooling (latent)	Total Energy	Units
143.8	5.4	0.4	149.5	MJ/m².annum

* These energy requirements have been calculated using a standard set of occupant behaviours and so do not necessarily represent the usage pattern or lifestyle of the intended occupants. They should be used solely for the purposes of rating the building. They should not be used to infer actual energy consumption or running costs. The settings used for the simulation are shown in the building data report.

AREA-ADJUSTED ENERGY REQUIREMENTS

Heating	Cooling (sensible)	Cooling (latent)	Total Energy	Units
137.7	5.2	0.3	143.2	MJ/m².annum
	Conditioned floor area		170.0 m²	

Star Rating

★★★★★★ **6.3 STARS**

Area-adjusted star band score thresholds

1 Star	2 Stars	3 Stars	4 Stars	5 Stars	6 Stars	7 Stars	8 Stars	9 Stars	10 Stars
723	498	354	262	202	155	113	71	31	0

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Figure 2: Sample of a house energy star rating report.

2.4.1 Heating and Cooling

The NatHERS-accredited software simulates the envelope of the house in a given climate and provides temperatures for each room for each hour of a full year. The simulated room data is used by the software to calculate the quantity of energy that may be required to condition rooms based on their usage type and accepted occupancy patterns. The temperature data will reveal rooms that may get too hot or too cold, and enable timely design intervention to improve the thermal comfort. This may include changing the windows, levels of insulation or room shading or an incorrect use of thermal mass. Each of these approaches can be tested in the house energy rating software.

Table 5 lists the standard room types in most houses and the times they are used. It also identifies which rooms are normally conditioned to make them thermally comfortable.

Room Type	Common Usage Patterns	Conditioned
Kitchen	6.00am to midnight	Yes
Dining Room	6.00am to midnight	Yes
Lounge Room	6.00am to midnight	Yes
Family Room	6.00am to midnight	Yes
Home Office	6.00am to midnight	Yes
Home Theatre	6.00am to midnight	Yes
Bedrooms	7 am to 9 am 6 pm to Midnight midnight to 7 am	Yes – Daytime thermostat temp. Yes – Daytime thermostat temp. Yes – Sleeping thermostat temp.
Bathroom	Random	No
Toilet	Random	No
Laundry	Random	No
Hallway	Random	No
Garage	Random	No

Table 5: NatHERS room conditioning patterns

2.4.2 Building Size

Australian houses have grown to be the biggest in the world, yet the number of people per household has either decreased, or not increased correspondingly. The size of a new house, regardless of its star rating, will play a significant role in the cost of construction, the amount of energy used for heating and cooling and lifetime maintenance and operational costs. Table 6 shows how house size affects heating and cooling energy costs.

	Conditioned Area (m^2)	Simulated Energy Use (MJ per year) and Cost					
		Launceston	Energy cost ($0.22/kWhr)	Sydney East	Energy cost ($0.22/kWhr)	Broome	Energy cost ($0.22/kWhr)
House 1	80.0	12,800	$2,816	3,120	$686.40	22,800	$5,016
House 2	150.0	24,000	$5,280	5,850	$1,287	42,750	$9,405
House 3	300.0	48,000	$10,560	11,700	$2,574	85,500	$18,810

Table 6: Energy use and building size
Possible conditioning energy use in a 6-star home relative to building scale.

Area Adjustment Factor

The Nationwide House Energy Rating Scheme encourages smaller houses through a star rating improvement via an Area Adjustment Factor (Table 7).

Location	50 m^2	150 m^2	250 m^2	350 m^2
Hobart	1.2 stars	0.3 stars	-0.4 stars	-0.8 stars
Perth	1.2	0.3	-0.3	-0.8
Brisbane	1.5	0.3	-0.4	-0.8
Darwin	1.7	0.3	-0.4	-0.8

Table 7: Encouraging smaller houses *(from NatHERS)*
Impact of house size Area Adjustment Factor on final star ratings.

Larger houses may contain more volume with fewer walls, but overall will use more energy to heat or cool than smaller houses. To create incentive for smaller houses, the NatHERS and BASIX tools provide an adjustment factor for houses smaller than 200m2.

2.5 Australian Standards

Standards establish acceptable levels of performance for many aspects of industry, manufacturing, construction and services practice. Through government guidance, Standards Australia develops and revises standards with contributions from relevant industry groups and government agencies. The NCC references many standards relevant to the construction and thermal performance of housing. Some Standards relevant to this Guide are:

- AS 1288 Glass in buildings - Selection and installation
- AS/NZS 1680 Interior lighting
- AS 1684 Residential timber-framed construction
- AS 2047 Windows in buildings – selection and installation
- AS 3660 Protection of buildings from subterranean termites
- AS 3959 Construction of buildings in bushfire-prone areas
- AS 3999 Thermal insulation of dwellings – bulk insulation – installation requirements
- AS/NZS 4859 Materials for the thermal insulation of buildings

Other relevant standards of practice include the Australian Building Codes Board's Protocol for House Energy rating Software.

Figure 3: High performing social housing
Hopkins Street Affordable Housing Project is a multi-residential timber framed building with a 7.3-8.1 star rating. Source: Xsquared Architects, Photographer: Ray Joyce

3

Design Strategies

Strategies for the efficient design for thermal performance in timber-rich buildings must address the:

- characteristics of the site

Strategies for the efficient design for thermal performance in timber-rich buildings must address the:

- characteristics of the site
- general arrangement of the building and its surrounding landscape
- detailed design and construction of the building envelope

3.1 Establishing Performance Level

The star rating required under the NCC has increased over time, and is currently at 6 stars for most states/territories, although this varies from state to state as noted in Section 2. While the NCC provides a minimum standard, some owners may want higher performance. Any improvements in thermal performance will:

- give greater comfort for occupants
- save energy, as less will be required for heating and cooling
- deliver savings for the life of the house (50 years on average)
- be cheaper if designed in before construction, rather than added later.

Establishing best value

Better thermal performance offers residents significant energy savings for the life of the building, but improvements need to be balanced between insulation, infiltration control, glazing and thermal mass to gain the best value. Generally, it is easier and more economical to invest in:

- higher levels of insulation
- better-quality building wrapping (building paper, sarking, etc)
- better-performing windows
- more-efficient heating/cooling equipment.

The cost effectiveness of better-than-code enhancements will vary according to climate and also by builder – depending on how experienced they are with the chosen construction technologies. House Energy Rating simulation should be used to assess the thermal impact of each improvement. Research has found that increasing the thermal resistance value to the amounts shown in Table 8 can provide a significant benefit. However, the value of increasing insulation will vary subject to climate.

Location of Insulation	R-Value
Sub-floor – Platform floors	Up to R4.0
Sub-floor – Concrete Slab-on-ground	Up to R3.0
Walls	Up to R6.0
Ceiling	Up to R8.0

Table 8: Potential increased levels of thermal insulation.

3.2 Designing for Climate

A dwelling designed to respond well to climate can produce more comfort and liveability, and minimise the energy needed for additional comfort control.

Balancing internal and external conditions

Buildings tend to be warmer than their surrounding environment, due to their intrinsic enclosure and the heat generated by occupants and equipment. Designing for efficient thermal performance of most buildings requires limiting the amount of unwanted heat loss/gain through the building envelope (the floor, external walls and roof structure).

Timber buildings are more responsive

Conventional timber-clad and timber-framed buildings generally have lower thermal capacity than masonry buildings and, as a result, are more responsive to changes in external temperature. Compared to 'heavier' buildings, lightweight buildings:

- tend to cool down and heat up faster
- can be easier to heat and cool down
- can be less reliant on orientation for adequate performance.

Working with climate

To optimise comfort, it is important to control how much external temperature, solar radiation, breeze and humidity enters the building. This will need to be specific for a given climate. It means controlling:

- ***Solar heat*** – catching sun for heating and shading from the sun to keep cool.
- ***Air movement*** – opening up for cooling in non-conditioned space and closing down to contain heat.
- ***Heat gain/loss through envelope*** – using insulation to slow heat transfer and high quality, climate-specific building wrap to stop unwanted air leakage.
- ***Windows size and orientation*** – to control heat loss in winter and overheating in summer, as well as ventilation.

General strategic approaches for lightweight building are summarised in the sections below.

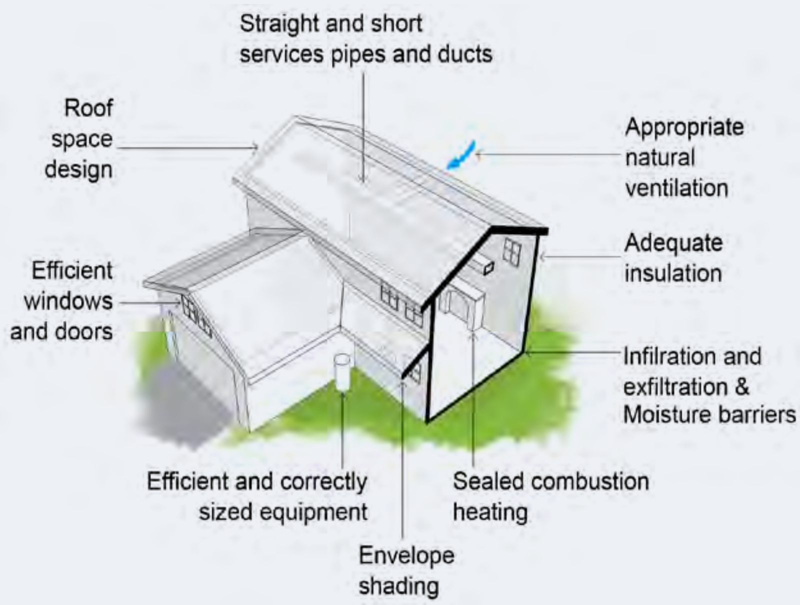


Figure 4: Key strategies in design and construction.

3.3 Designing for Sun

Passive solar gain is radiant energy from the sun that enters a building directly through glazed openings or indirectly by conduction through the envelope. Once inside, the energy heats up the air and thermal mass within a house. This can be exploited where artificial heating would otherwise be needed, although interiors can overheat in warm weather or with too much glazing.

Solar heat gain can be controlled with careful use of room planning, appropriate placement of glazing and shading. Eaves and other shading on the north can be designed to allow welcome lower altitude winter sun while cutting out unwanted higher summer sun.

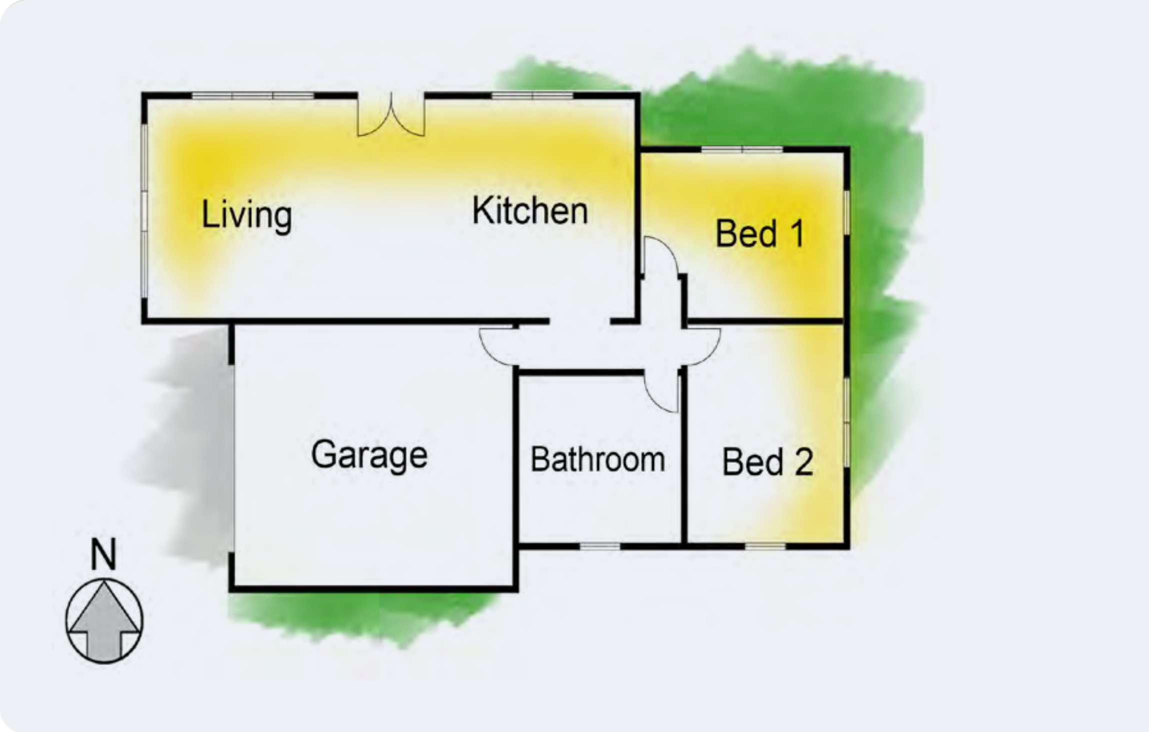


Figure 5: Plan for solar warmth.
Use room orientation, as well as window size and location to utilise sun in a cool climate.

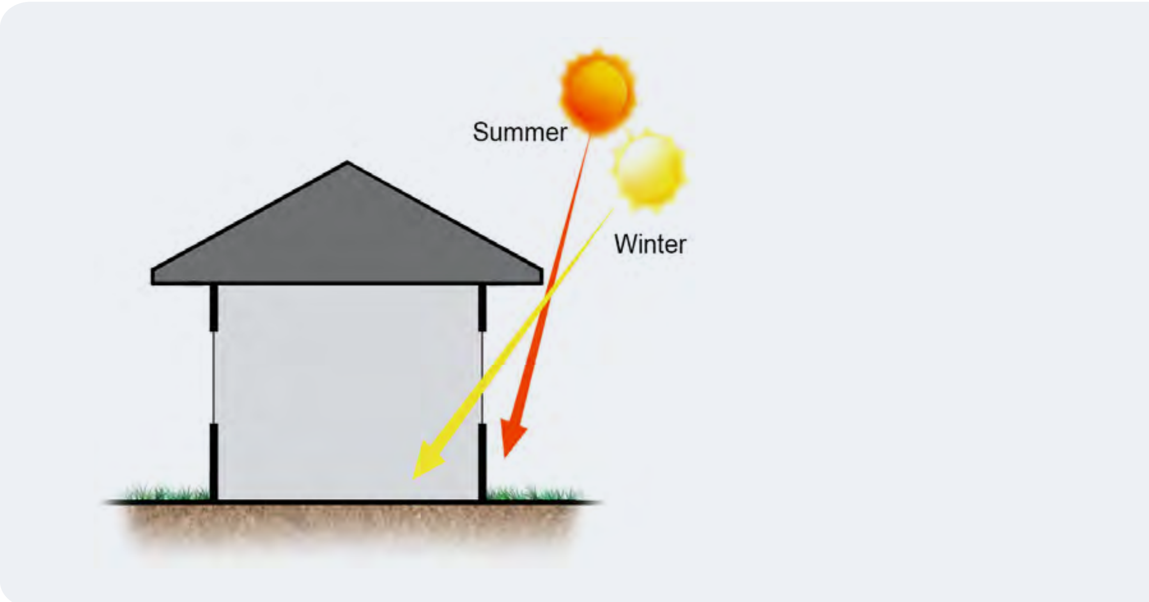


Figure 6: Control solar radiation.
Eaves and overhangs offer seasonal control of sun.

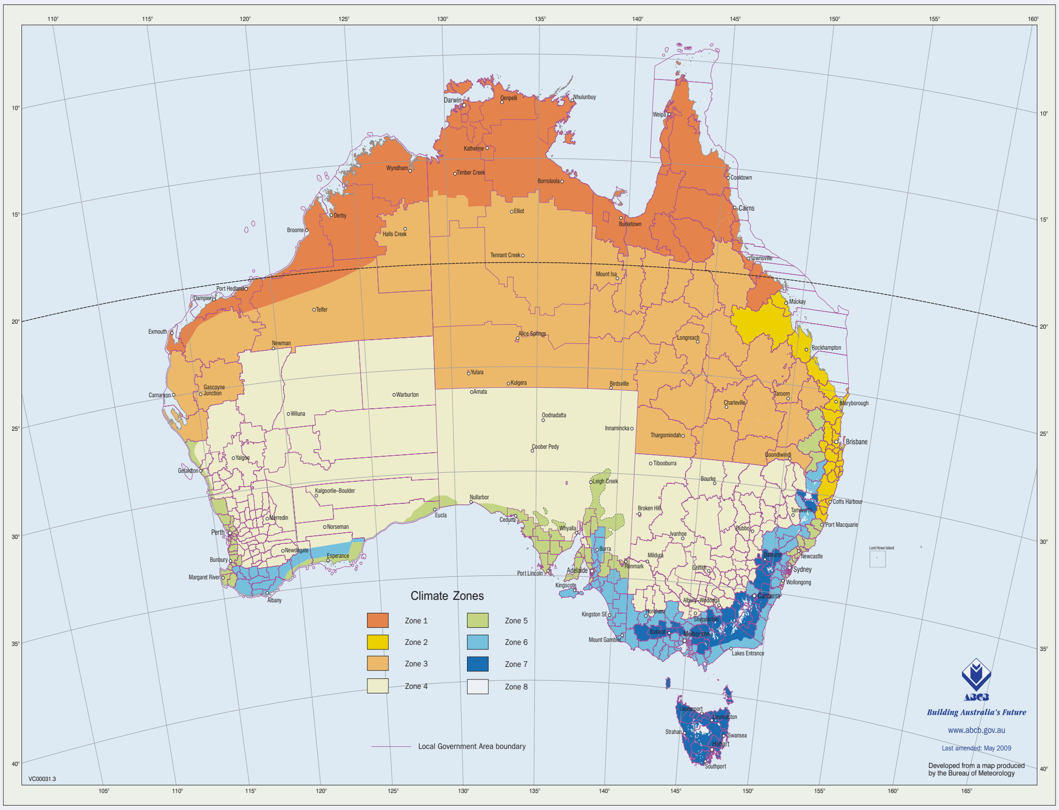


Figure 7: NCC climate map 2009.
Source: Australian Building Codes Board (ABCB) www.abcb.gov.au

3.4.1 Hot and Humid (NCC Climate Zone 1 and 2)

In hot and humid climates – focus on shading and maximising natural ventilation to non-conditioned spaces – both day and night.

Hot and humid climates have intense solar radiation and high rainfall. The intense direct and reflected energy in these climates places considerable thermal load on buildings. Shading the building envelope is very important. The consistently high temperatures create the need for cooling, while the high humidity limits the human body's ability to cool itself by perspiration.

The main focus of building for comfort in hot and humid climates is providing the capacity to open up the building to maximise ventilation, when the air temperature is suitable, while also maximising shading to limit solar gain.

Generally, designing a house for hot and humid climates should:

- limit unwanted heat gain (solar, conduction and infiltration)
- capture available cooling breezes day and night in a secure and weatherproof way
- provide internal spaces that can be efficiently conditioned
- allow good flow from internal to more comfortable outdoor spaces (day and night)
- avoid moisture build-up which can be a hazard to humans and the building.

3.4.2 Hot and Dry (NCC Climate Zone 3 and 4)

In hot and dry climates – focus on good shading to limit sun, and insulate for both hot days and cooler nights.

Hot and dry climates have intense solar radiation and low rainfall. In contrast to more humid climates, nights in hot and dry climates can be very cool. These extremes in day-to-night temperature place considerable thermal loads on a building.

There is little rain in this climate type but it can be brief and intense when it does occur.

Generally, designing a house for hot and dry climates should:

- limit unwanted heat gain (from direct sunlight, conduction through the envelope and air infiltration)
- capture available cooling breezes
- provide internal living spaces that can be efficiently conditioned
- allow good flow from internal to more comfortable outdoor spaces (day and night)
- provide water and moisture barriers to protect the building fabric and insulation.

3.4.3 Temperate (NCC Climate Zones 5 and 6)

In temperate climates – focus on capturing winter sun and insulate to keep winter warmth in, and summer heat out.

Temperate climates experience more moderate aspects of the conditions in hot and cool climates. The aim is to keep the heat in the building during winter and out of the building during summer.

Generally, designing a house for temperate climates should:

- capture winter sun
- limit unwanted heat gain/loss (sunlight, conduction and infiltration)
- shade to exclude unwanted summer solar radiation
- use natural ventilation to remove unwanted hot air.

3.4.4 Cool Temperate and Cold Climates (NCC Climate Zone 7 and 8)

In cooler climates – focus on capturing winter sun and keeping warmth in.

Timber houses in cool temperate and cool climates can require heating 8-12 months of the year. Summers are often mild and, if the house is adequately shaded and insulated, natural ventilation should provide most of the required cooling.

Due to high levels of heat, moisture vapour from house interiors can be forced into the building envelope by vapour pressure. This can be mitigated by correct and careful selection of sub-floor, external wall and roof space building wraps.

Generally, designing a house for cool temperate and cold climates should:

- exploit solar gain during colder months
- provide internal spaces that can be efficiently conditioned
- limit avoidable heat losses particularly through infiltration and exfiltration
- have access to wind-shielded sunny outdoor spaces
- pay special attention to avoiding moisture problems in the structure by using vapour breathable building wraps.

4

Planning Strategies

The thermal performance of new timber houses is influenced by the site's characteristics, the general arrangement of the building and its surrounding landscape and the detailed design and construction of the building envelope. This section deals with the larger-scale aspects of site and building orientation.

Section 5 deals with more detailed aspects of envelope detail and arrangement.

Design and planning strategies discussed in this section are:

- planning and site selection
- building orientation
- room and zone planning
- natural ventilation
- outdoor spaces and landscaping.

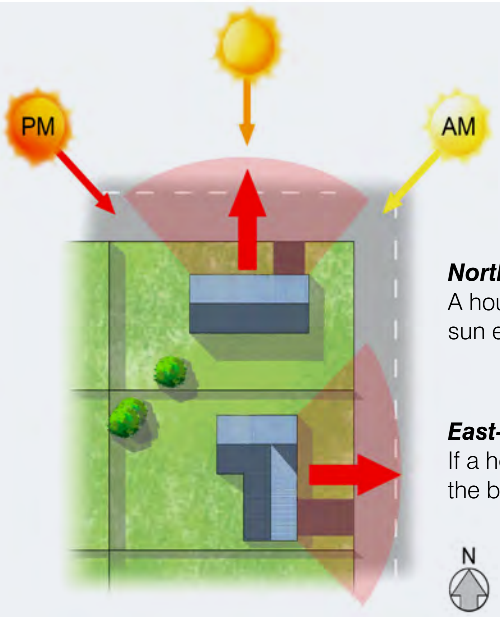
4.1 Planning and Site Selection

Selecting the right site for a house project can have a significant impact on the quality of living and thermal performance of the house.

A house's thermal performance needs to be considered when deciding on the land, the position of the house on the land, and the position and type of landscaping around the house. Each will affect the house's thermal performance and durability for its entire lifetime. In Australia, this is 50 years or more on average.

Consider the following in site selection:

- ***Solar radiation*** – access to direct solar radiation, especially in temperate and cooler climates.
- ***Breeze*** – access to prevailing breezes (especially in warm and hot climates) that can come from different directions in the morning and evening.
- ***Adjacent landscape*** – topography, vegetation and adjoining buildings can block sun and breezes which could bring benefits or be a hindrance, depending on the climate. These factors can also create a microclimate that can affect comfort.
- ***Site shape and orientation*** – house planning can be limited by the way a block sits relevant to the street and the northern sun.



North-south running block.
A house design running east-west allows good northern sun exposure to half the house.

East-west running block.
If a house is to face the street rather than run the length of the block, maximising solar control can be more difficult.

Figure 8: maximising solar control.

4.2 Site Master Planning

Before a house can be designed or planned in detail, a master plan for the site has to be developed. A master plan should balance the major functional and architectural requirements of the house, including characteristics that influence thermal performance. These include:

- ***Orientation*** – orientate the house to capture beneficial sun and breezes.
- ***Landscaping*** – add landscaping to improve the site's microclimate.

4.2.1 House Location and Orientation

Siting a house is inevitably influenced by the views, and location of street frontages and neighbouring buildings. However, a house's orientation with respect to solar radiation, shading, breezes and room-usage patterns has significant impact on its thermal performance. Research has shown that correct house orientation can save up to 60% of lifetime heating and cooling costs.

General considerations:

- ***Siting*** - locate the house to capture available cooling breezes, especially in warmer climates.
- ***Layout*** - position living spaces where they will benefit from solar heat gain when heating is needed and where solar gain can be minimised when cooling is required.
- ***Maximise daylight*** - use natural daylight to limit the need for energy-consuming electrical lighting. In some countries, regulations mandate no place within a room is to be more than 6 metres from an opening window.
- ***Passive solar heating*** - use solar heat for warmth wherever possible.
- ***Natural shade*** - use natural shade wherever possible and avoid exposure to the afternoon sun.
- ***Indoor-outdoor living*** - couple living areas with shaded outdoor spaces for summer.
- ***Capturing cooling breezes*** - allow the capture of breezes to provide an efficient and natural way to cool buildings and occupants in all climates.
- ***Eastern morning sun*** - use for warmth on cold mornings when appropriate.
- ***Northern sun*** - control exposure to the northern sun for the best orientation for solar heating.
- ***Western afternoon sun*** - limit this exposure; it is undesirable in most climate zones.
- ***Controlled shade*** - carefully design shading to allow warming sun in cooler months while excluding it during warmer months.

Climate specific considerations:

<table>
<tr><th>Zones 1 and 2
Hot and humid</th><th>Zones 3 and 4
Hot and dry</th><th>Zones 5 and 6
Temperate</th><th>Zones 7 and 8
Cool temperate and cold climates</th></tr>
<tr><td colspan="2">• Orientation - position the house to make the most of cooling breezes and shade it from unwanted solar radiation.
• Breeze - focus on capturing breeze for living spaces in the afternoon and evening.
• Western sun - limit exposure to western sunlight. It is difficult to control throughout the year due to its low altitude and overheating of western facades can render the house uncomfortably hot well into the night.
• Southern aspect - use the southern aspect to create well-ventilated internal or external spaces on the south side of the building. These can make useful cool refuges.</td><td colspan="2">• Orientation - position the house to promote use of solar passive design principles.
• Layout - position living spaces to the north for winter sun.
• Cold winds - block cold winds that will generate drafts inside the house. These drafts are a problem for efficient thermal performance in temperate and cool climates. Protection from cold winds by vegetation or built screens is desirable.
• Eastern sun - use morning sun to provide warmth and physiological benefits.
• Southern aspect - avoid using this aspect for habitable spaces as it generally gets no exposure to sunlight.</td></tr>
<tr><td>• Eastern sun – give thought to this exposure – early summer sun can cause overheating.</td><td>• Solar passive design –orientate the house to assist solar passive design principles.
• Eastern sun – consider making use of the eastern sun – it may be wanted on winter mornings.</td><td>• Northern sun – position living spaces to the north but with access to cooling breezes, especially in summer.</td><td>• Northern sun – position living spaces to the north and spaces likely to be used in the morning to the north or east.
•Avoid cold winds – limit exposure to cold winter winds.</td></tr>
</table>

Further resources*: Window Energy Rating System (WERS) - for details about How To Select Windows (www.wers.net/werscontent/how-to-select-windows)*

Your Home Technical Manual - for details about Passive Cooling (www.YourHome.gov.au/technical/fs46.html)

4.2.2 Landscaping

Plants, screens and other landscaping items are a key component of the site master plan as they improve the thermal performance, privacy and comfort of a house.

General considerations:

- ***Visual amenity*** - landscaping can be used to balance views with privacy.
- ***Shade*** - trees and shrubs can be used to limit direct sun on the building.
- ***Wind control*** - trees can direct wind and breezes.
- ***Foliage*** - as well as shade, plants can provide cooler microclimates through evapotranspiration from leaves.
- ***Seasonal sun*** -careful location, spacing and selection of deciduous and non-deciduous plants allow the timing and extent of shading and wind moderation to be controlled.
- ***Targeted shade*** - small, contained trees and landscape screens with or without associated climbing plants can provide focused shade on specific openings, elements or areas.
- ***Trellises*** - climbing plants over timber or wire screens are effective in controlling exposure to the western sun.
- ***Risk*** - having landscape elements close to the house for amenity reasons needs to be balanced with risk from bushfire, high winds or cyclonic conditions.

Climate specific considerations:

<table>
<tr><th>Zones 1 and 2
Hot and humid</th><th>Zones 3 and 4
Hot and dry</th><th>Zones 5 and 6
Temperate</th><th>Zones 7 and 8
Cool temperate and cold climates</th></tr>
<tr><td colspan="2">• Tall trees - can be used to block solar radiation from the walls, windows, roof and surrounding ground and still allow breezes.
• Lower trees - shaded ground and paving radiate less heat into the house and can provide a more comfortable microclimate around the perimeter of the house.
• Screens - shrubs grown close to the house provide additional shading and privacy.
• Vines - climbing plants over timber or wire screens are effective in controlling exposure to the western sun.</td><td colspan="2" rowspan="2">• Cold winds - use trees or built screens to block undesirable cold winds that can cause drafts inside the house.
• Winter courtyards - shrubs can be used to provide outdoor spaces that are sheltered from cool breezes.
• Seasonal sun - deciduous trees can provide shade in summer but permit additional solar gain when the leaves fall in colder months.
• Winter sun - ensure winter solar access is maintained</td></tr>
<tr><td>• Breeze – note morning and afternoon cooling breezes can come from different directions.</td><td>• Increasing humidity - vegetation can improve comfort by increasing humidity.</td></tr>
</table>

Further resources*: Your Home Technical Manual – for details about Shading (www.yourhome.gov.au/passive-design/shading)*

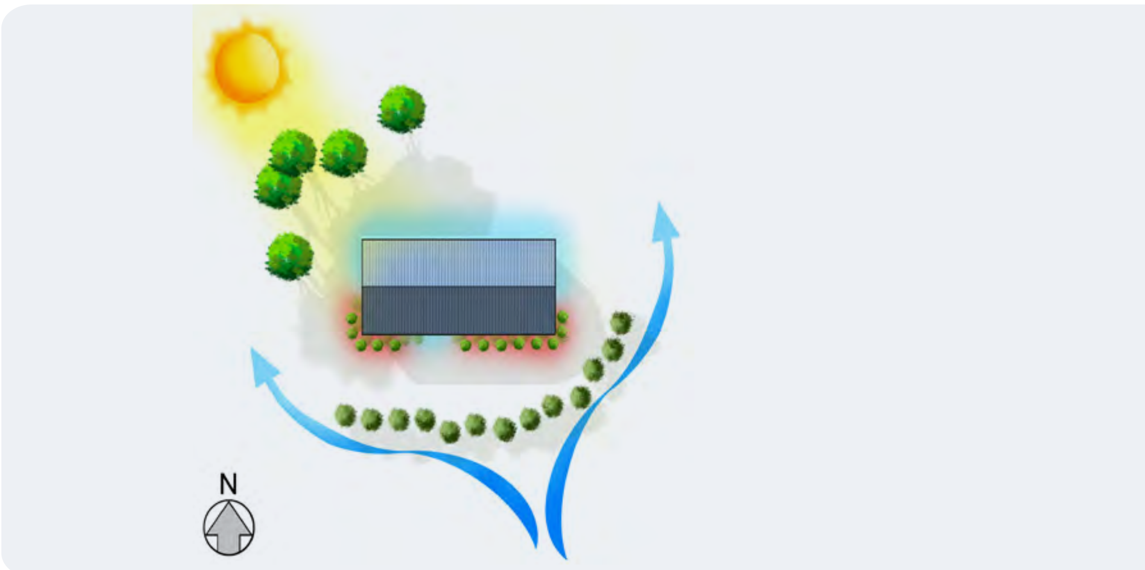


Figure 9: Divert cold winds. *Trees can divert unwanted hot and cold winds*

Figure 10: Blocking western summer sun. *Trellises with climbing plants can be used to shield western façades. (Photo: Gregory Nolan)*

Figure 11: Creating cooler microclimates. *Plants integrated into decks and screens. (Courtesy of CplusC Architectural Workshop)*

4.2.3 Internal Conditioned Spaces

Internal spaces in the house can be grouped into zones based on their function, common usage pattern and the likelihood that they will be conditioned. Zoning rooms helps clarify which ones need to be thermally comfortable and at what time of day. Prioritising the thermal comfort of rooms in this way allows planning that will incorporate the site sun and breezes – maximising comfort, while minimising the energy usage.

Although individual families will live differently, NatHERS provides assumptions for how rooms are used. These assumptions provide a good guide to design.

Maximise passive systems to minimise energy use

4.2.4 Passive vs Active Systems

Buildings can be heated or cooled by passive or active means, or a mixture of the two. Using well-placed windows to bring in winter sun for warmth or summer breezes for cooling are considered passive methods. The use of mechanised equipment to provide heating and/or cooling is considered an active system.

4.2.5 Containing Conditioned Spaces

Modern houses tend to have living, dining and kitchen spaces effectively joined together into one open-plan space. The increased volume of these combined spaces and connected hallways can significantly increase the volume of air requiring conditioning to expected levels of thermal comfort. There are two cautionary aspects to room volumes. In hotter climates, having a larger volume can keep the warmer surfaces of the walls and ceiling further away from the room occupants, making the room feel cooler. In temperate and cool climates, where the inside walls should not be as warm, smaller volumes significantly affect the energy needed to heat and cool a home.

Dividing spaces with doors that control air movement can increase comfort and save energy. Common room and zone concepts include:

- ***Living space*** - are critical thermal comfort areas and need maximum comfort so they should be contained with separation from entries, halls and other spaces.
- ***Dining rooms*** - often connect to living rooms and kitchens for function but are often used for short periods.
- ***Kitchens*** - need more venting to exhaust odours and heat from cooking and so can remove conditioned air from interiors as well.
- ***Hallways***- can be used as breezeways in summer, but there is generally little need for conditioning.
- ***Bedrooms*** - avoid overheating in bedrooms from western summer sun, although in cooler climates an eastern aspect can provide welcome morning warmth. The conditioning focus is afternoons and overnight, with acoustic and visual privacy being a high concern. Note that most people sleep with bedroom doors closed, which can prevent cross ventilation if there are not multiple windows.
- ***Bathrooms*** - the use period is short and ventilation needs to be high to remove excess moisture from the house. Heat loss through bathrooms is exacerbated through the common practice of leaving doors to bedrooms or hallways open.
- ***Home office*** - positioning these areas to the north in most climates can maximise daytime comfort and light.
- ***Auxiliary spaces*** - comfort in non-habitable rooms such as laundries, pantries and other storage spaces is less of a concern, so these spaces are frequently placed to the south.
- ***Garages*** - as these are not considered habitable, they can be positioned to block undesirable aspects such as the summer afternoon sun.

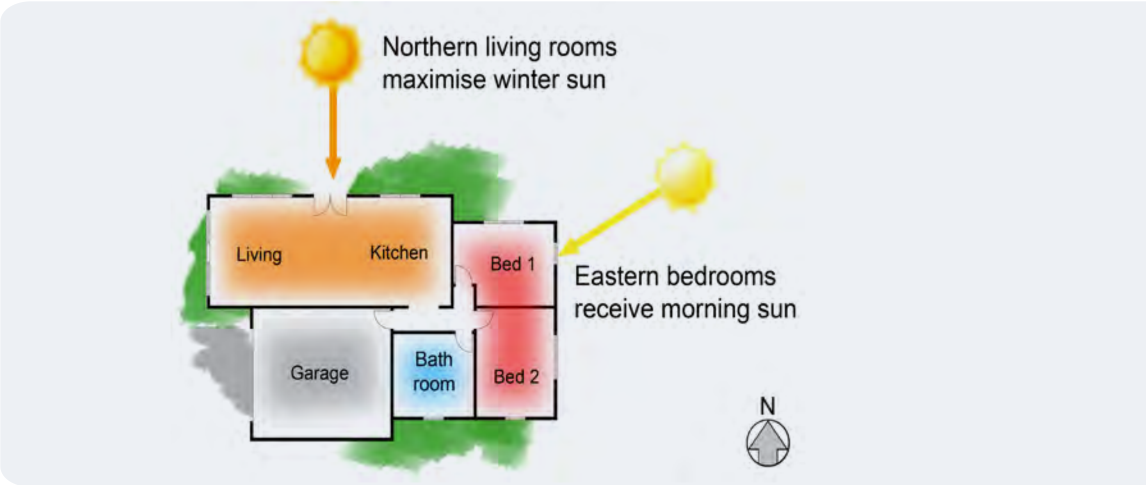


Figure 12: Orientation for non-tropical dwellings. *Appropriately orientated and zoned timber house south of the Tropic of Capricorn.*

4.2.6 Outdoor Spaces

Australia's climates are generally mild, which promotes outdoor activities. Well-designed outdoor spaces can extend living areas and provide relief from thermally uncomfortable houses. Multiple outdoor spaces can be positioned to suit different seasons and can include living rooms, decks, verandas, pergolas or garden areas for eating and relaxing.

General considerations:

- ***For hot weather*** - focus on maximising shade and capturing predominant breezes.
- ***For cooler weather*** - focus on capturing sun while sheltering from cool breezes.
- ***Rain protection*** - aside from protecting furniture, rain protection is unlikely to be required in cooler weather when spaces won't be used if there is no sun, as opposed to hotter climates, where outdoor spaces might be used in wet or dry weather.
- ***Fans*** - some climates will benefit from adding fans to outdoor living spaces.
- ***Protection*** - consider security and protection from insects, dust and wind-blown rain when designing for outdoor living.

Climate specific considerations:

Zones 1 and 2 *Hot and humid*	**Zones 3 and 4** *Hot and dry*	**Zones 5 and 6** *Temperate*	**Zones 7 and 8** *Cool temperate and cold climates*
• ***Shaded spaces*** – consider providing in hot climates for summer. • ***Separate sunny spaces*** – can provide options during winter.		• ***Catch sun –*** in cooler climates, a sheltered space to capture the sun is invaluable. • ***Wind shelter*** – winter spaces need to be in the sun and protected from cold winds or drafts.	
• ***Warm-nights*** – Consider extended night-time use of outdoor spaces.	•***Cooler nights*** – nights tend to be noticeably cooler in drier climates.	• ***Shade*** – daytime summer temperatures can still be extreme and require shade.	• ***Limited shade*** – the need for shade might be limited during a short summer.

Further resources*: Your Home Technical Manual – for details about Passive Cooling (www.YourHome.gov.au/technical/fs46.html)*

Figure 13: Screened outdoor space. *If rain protected, these spaces can function as outdoor rooms in warmer climates. (Courtesy of CplusC Architectural Workshop)*

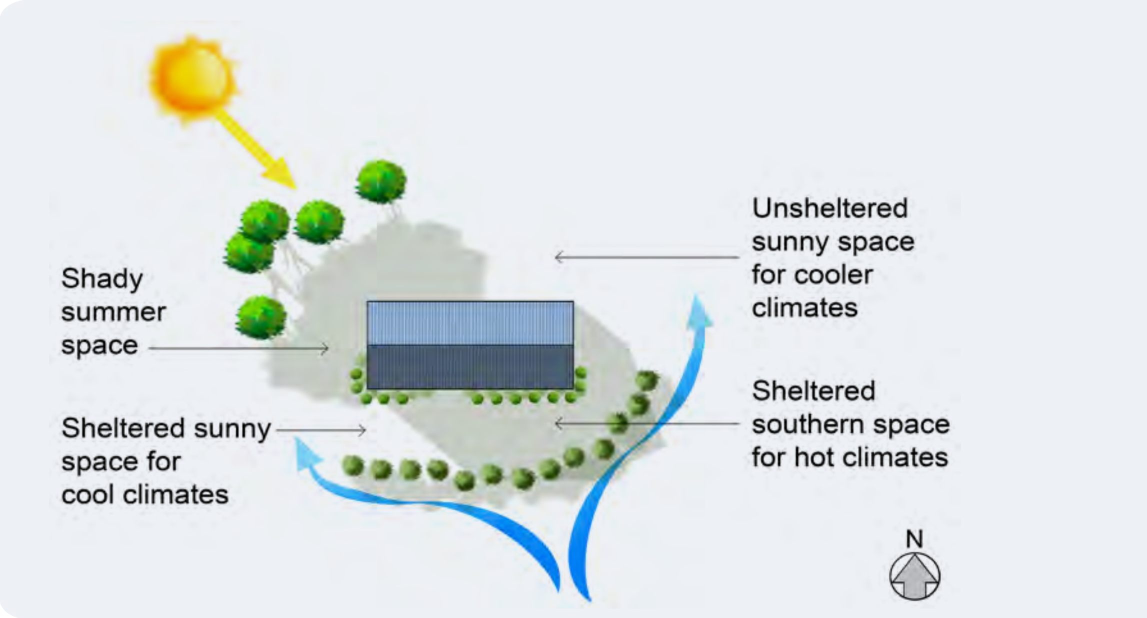


Figure 14: Design for outdoor living.

4.2.7 Natural Ventilation

All houses require ventilation to remove stale, polluted and oxygen-depleted air. Natural ventilation can be used to provide passive cooling. Additional active systems such as fans can be used to enhance this natural effect at low cost. Air movement is generated by a change of air pressure, which can be generated by wind pressure, or rising hot air as it expands.

Ventilation rates

There are minimum levels of ventilation required to maintain a healthy internal environment. Internationally, it is accepted that a house should have 0.25 air changes per hour (ACH). To provide the potential for natural ventilation, the NCC establishes a minimum requirement for openings in habitable room of not less than 5% (1/20) of the room's floor area. Although such openings may allow for convection to exhaust warm and polluted air, minimal openings do little to guarantee comfort.

For natural ventilation to work effectively without active means, a building's external openings need to be exposed to differential air pressures. Openings on the windward face of a building are subject to a positive air pressure; openings on the leeward side of the building will be subject to a negative air pressure. If the building's depth does not provide too much resistance, airflow will be generated between windows exposed to differential air pressures.

General considerations:

- ***Natural ventilation*** - encourages physiological cooling, removes unwanted stale and hot air and gets rid of heat that may have built up in the internal building fabric.
- ***Stack ventilation*** - paired low and high openings allow fresh air to be drawn in at a low height and hotter stale air to rise and flow out higher openings (Figure 17).
- ***Cross-ventilation*** - even slight breezes can create airflow through a building when it has opposing openings of adequate size, but this doesn't work when multiple windows are placed in the same wall (Figure 18).
- ***Single-loaded corridors*** - plans with rooms only to one side of a hallway provide greater potential for cross ventilation than 'double loaded' hallways.
- ***Double-loaded corridors*** - plans with rooms both sides of a corridor provide more compact planning, although free air movement is more inhibited, especially when opposing rooms rely on their doors as well as windows being open to gain cross ventilation (see Figure 16).
- ***Windows type*** - different types of windows allow different opening areas and each offers additional benefits: double-hung windows can aid stack ventilation, awning windows can be left open during rain, and casement windows 'catch' the breeze, even if it is moving parallel to the wall surface.
- ***Privacy and security*** - most people sleep with bedroom doors shut – restricting the possibility for cross ventilation unless alternate air paths have been allowed for.

Climate specific considerations:

Zones 1 and 2 ***Hot and humid***	**Zones 3 and 4** ***Hot and dry***	**Zones 5 and 6** ***Temperate***	**Zones 7 and 8** ***Cool temperate and cold climates***
• ***Stack ventilation*** – high-level windows can provide more secure venting of heat, particularly overnight. • ***Air-tightness*** – Air-tight construction is important to minimise unwanted heat gain.		• ***Air-tightness*** – Air-tight construction is important to minimise heat-loss.	
• ***Evening ventilation*** - continued ventilation is required for comfort in evening. • ***Low windows*** - Ensure low-level openings to promote the entry of cooler outdoor air.	• ***Evening ventilation*** - evening temperatures can be much cooler and thus less ventilation is required.	• ***Warm breezes*** - warm breezes in winter can help remove the chill from cool rooms.	• ***Avoid drafts*** – consider providing for ventilation but avoiding drafts.

Further resources*: Window Energy Rating System (WERS) – for details about How To Select Windows (www.wers.net/werscontent/how-to-select-windows)*

Your Home Technical Manual – for details about Passive Cooling (www.YourHome.gov.au/technical/fs46.html)

Ventilation of buildings

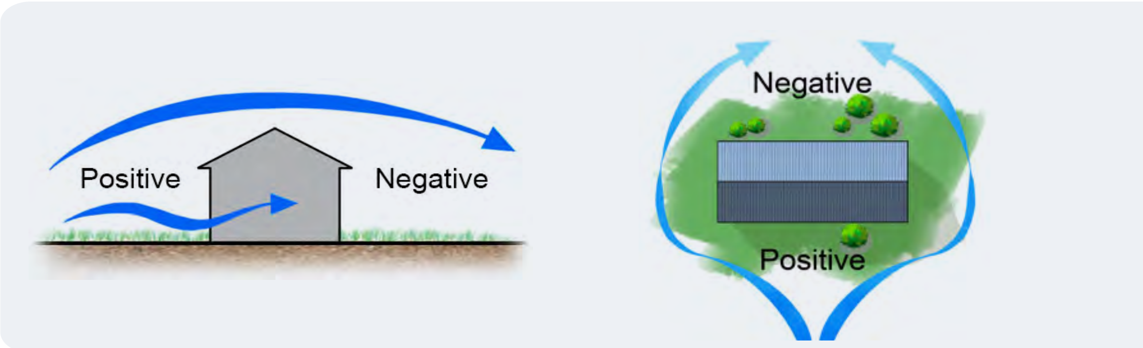
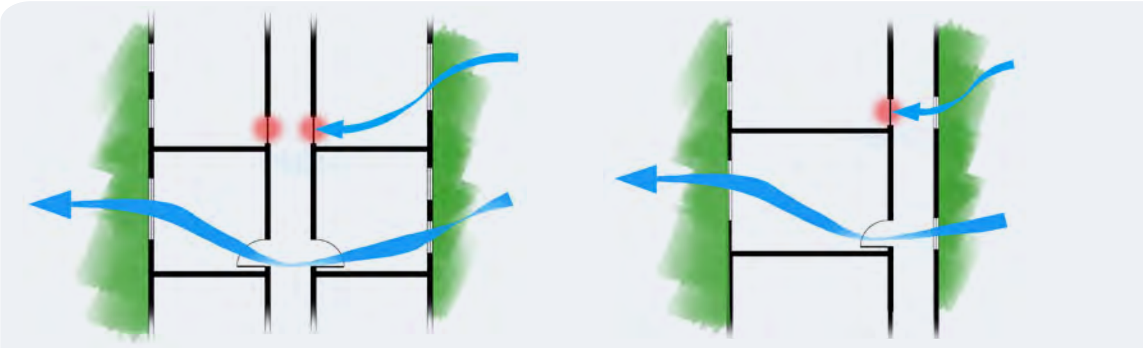


Figure 15: Wind pressures on buildings.
Wind creates differential air pressures on the windward and leeward sides of the house.



Double-loaded hallways limit cross ventilation - consider roof windows.

Single-loaded hallways increase the potential for cross ventilation.

Figure 16: Narrow buildings allow greater ventilation.

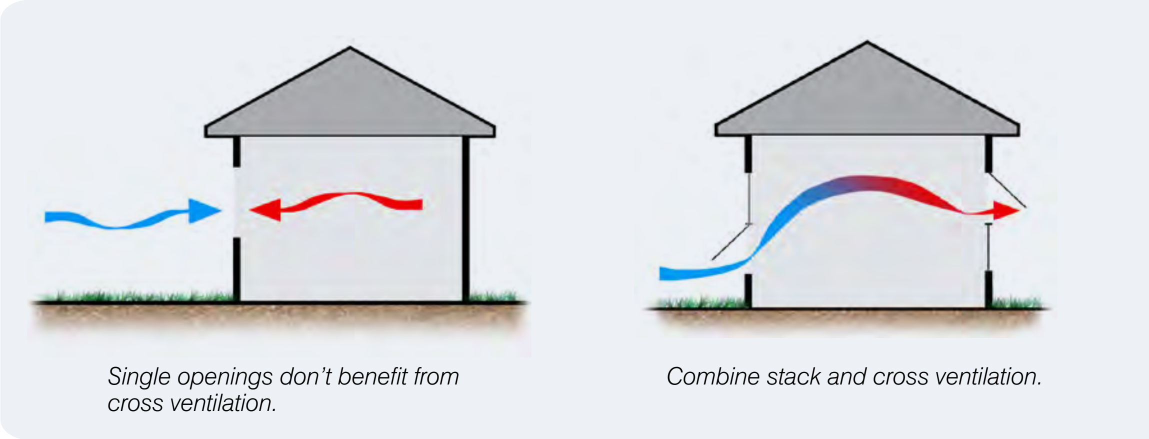


Figure 17: Number of openings.

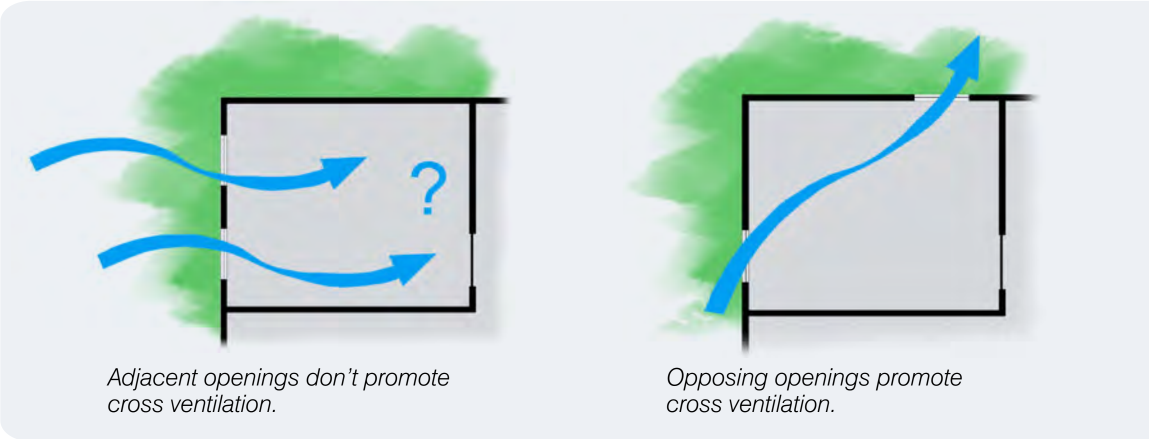


Figure 18: Location of openings.

5 Envelope Strategies

The thermal performance of a building is determined by the amount of moisture, air and heat passing through the envelope. The envelope of a house consists of its floor, walls, windows, ceiling and roof. This section covers the critical control of moisture, air and heat through the envelope. It discusses:

- structural moisture control
- control of infiltration, exfiltration and vapour through the wall systems
- thermal insulation
- the performance of window and doors
- eaves and external shading
- thermal mass
- conditioning and other equipment and services.

Balancing insulation

The thermal performance of the envelope involves the balance between the levels of insulation, the area of glazing and the amount of thermal mass. The simplest way to determine an economic balance of these elements is to test variations through thermal modelling.

Heat and moisture control

The external and internal climatic variables that affect the thermal performance of the house envelope include:

- ***Solar radiation*** - including direct radiation from the sun and indirect radiation from surrounding objects and the ground heated by the sun.
- ***Conductive heat gain*** - the conductive effect from internal and external air and material temperatures and the temperature of external surfaces such as adjacent ground temperature.
- ***Convected heat gain*** - the convective effect from internal and external air movement.
- ***Air movement*** - unwanted heat loss or gain from uncontrolled air infiltration and exfiltration.

A natural material such as timber needs to breathe

Roofs play a key role in protecting buildings from the penetration of rain and heat. Depending on thermal insulation, they can protect ceilings from significant heat gain but, just as importantly, they can shade walls to limit solar heat gain from direct sun.

5.1 Structural moisture control

The control and management of moisture within the built fabric must be considered for all climates, based on two principles:

- ***Moisture exclusion*** - the capacity for the envelope to prevent unwanted moisture entering the building from the rain and ground.
- ***Moisture vapour*** - the capacity for the envelope materials to allow or block the flow of water vapour through the building envelope, subject to climate and heating and cooling systems.

The roof and walls must resist moisture from rain, snow and other precipitation; the walls or the sub-floor structure must resist moisture from the ground. The NCC lists minimum performance standards.

General considerations for ground and storm water

- ***Site falls*** - the site should be graded away from the building for a minimum of 1 m (ideally 3 m) and landscaped to direct surface and sub-surface moisture away from the building.
- ***Drains*** - drains should be provided on the uphill side of the building to minimise ground water near the building.
- ***Under floors*** - the ground beneath platform floors should be above adjacent ground and graded to prevent ponding.

General considerations for sub-floors, walls and roof

- ***Flashings*** - breaks in external wall cladding systems caused by joins, windows, doors and other penetrations should have lapped flashings to direct water to the exterior surface.
- ***Moisture control*** - high quality moisture barriers that stop moisture moving from behind the cladding system to the inner structure should be applied to walls and roofs. A high quality of wall wrap installation will also minimise air infiltration and exfiltration.
- ***Cladding*** -pre-primed timber cladding should be installed with an air space between the cladding boards/panels and the wall wrap.

Climate specific considerations:

Zones 1 and 2 *Hot and humid*	**Zones 3 and 4** *Hot and dry*	**Zones 5 and 6** *Temperate*	**Zones 7 and 8** *Cool temperate and cold climates*
• ***Moisture and vapour protection*** - a high quality building wrap that is water and vapour impermeable.	• ***Moisture protection*** - a high quality building wrap that is water impermeable but may be vapour permeable.		
• ***Drafts*** - a high-quality installation of a good building wrap system will also help in vapour management and provide a significant control of unwanted hot and cold drafts within the home.			

***Further resources**:*

Your Home Technical Manual – for details about Insulation (www.YourHome.gov.au/technical/fs48.html)

Insulation Council of Australia and New Zealand Insulation Handbook (www.icanz.org.au/wp-content/uploads/import/pdf/17132_ICANZ_HANDBOOK.pdf)

Australian Standards – As NZS 4200.1-1994 Pliable Building Membranes and Underlays Materials

General considerations for roofs

- ***Sarking*** – install high-quality reflective sarking to help control inward-bound moisture and reduce unwanted heat radiation from the roofing material.
- ***Ventilation*** – ensure the roof space is well ventilated to remove unwanted heat and moisture.
- ***Ducting vents through roof*** – do not duct bathroom and kitchen ventilation into the roof space.
- ***Gutters*** – roofs should be guttered, and any run-off from un-guttered roofs should be at directed at least 1 m away from walls.
- ***Shading*** – a well-designed roof can also provide shading to the walls and rooms below

Climate specific considerations:

Zones 1 and 2 *Hot and humid*	**Zones 3 and 4** *Hot and dry*	**Zones 5 and 6** *Temperate*	**Zones 7 and 8** *Cool temperate and cold climates*
• ***Ventilate roof space*** – provide high levels of ventilation to allow unwanted hot air and moisture to leave. • ***Bushfire*** – consult your local authority about the type of meshes that can be used to allow roof space ventilation but stop ashes and cinders from entering.			

***Further resources**:*

Your Home Technical Manual – for details about Insulation (www.YourHome.gov.au/technical/fs48.html)

Insulation Council of Australia and New Zealand Insulation Handbook (www.icanz.org.au/wp-content/uploads/import/pdf/17132_ICANZ_HANDBOOK.pdf)

5.2 Vapour management

Controlling the movement of vapour through the external skin of the home is an important function of the building envelope. Significant damage can occur to the built fabric if the movement of vapour is not managed. In this context, the problem is called 'vapour pressure'. Good construction will have three opportunities to manage vapour pressure and the subsequent movement of vapour into and through building elements. These are:

- ***External cladding system*** – The cladding system should not touch the building wrap. Ideally, the cladding system is fixed to battens, which provide a vapour zone between the cladding and the building wrap. This type of construction can also reduce the chances of damaging the building wrap and is suitable for all climate types.
- ***Building wrap systems*** – Building wrap systems vary depending on climate type. In a hot and humid climate, vapour wants to migrate into the house, while in a cool climate the water vapour generally wants to migrate out of the house. The temperate and hot and dry climates can provide a more complex situation as the water vapour will want to migrate inward in hotter periods and outward during cooler periods. This can be a daily or seasonal pattern. In some climates, an additional building wrap on the inside of the timber framing may be advantageous.
- ***Internal linings*** – All lining materials have intrinsic vapour permeability properties. Most timber products, plasterboard and some paints are vapour permeable, allowing vapour to penetrate the internal skin and allowing it to pass through to the permeable insulation and timber framing.

Special notes on building wraps:

- Building wraps come with a wide range of properties, from a non-permeable moisture barrier to a permeable moisture barrier.
- Generally, a permeable (breathable) system should be used for houses in a climate where heating is used.
- Additionally, the building wrap can provide significant infiltration control. In this case there must be no holes in the product.
- A good-quality product that is resistant to external moisture and provides good infiltration control can be vapour permeable, even if it has no visible holes.
- Manufacturers provide a range of products and they should be consulted to establish the minimum and best product for a particular house relative to its climate and the heating and/or cooling systems intended to be installed.

Vapour impermeable	Vapour semi-impermeable	Vapour semi-permeable	Vapour permeable
Polyethylene Vinyl Glass Aluminium foil Sheet metal Foil-faced insulation	Oil-based paints Some vinyl wall coverings Extruded polystyrene Paper-faced bulk insulation	Plywood Particleboard Expanded polystyrene Most plastic paints	Unpainted paper-faced plasterboard Unpainted plaster Bulk insulation such as rock-wool, glass-wool and polyester Cellulose insulation Timber Clay bricks Concrete blocks

Table 5: Building materials and vapour permeability.

Wrap well: more air gaps = more energy loss

Climate specific considerations – showing vapour travel direction:

Zones 1 and 2 *Hot and humid*	**Zones 3 and 4** *Hot and dry*	**Zones 5 and 6** *Temperate*	**Zones 7 and 8** *Cool temperate and cold climates*
• ***Refrigerated A/C*** – this creates dryer internal conditions, therefore adopt impermeable wrap to avoid moister ingress	• ***Cooling system*** – if evaporative cooling is used adopt a vapour permeable system	• ***Vapour reversal*** – adopt a vapour permeable system in this climate due to frequent reversal of vapour pressure	• ***Walls*** – generally can be permeable • ***Ceilings*** – constant vapour migration into roof spaces can cause rapid decay of structure. Application-specific permeability requirements should be confirmed with wrap manufacturers
General direction of vapour flow			
• inward	• both directions	• both directions	• both directions
When heating is in use			
• N/A	• outward	• outward	• outward
Refrigerated air-conditioning			
• inward	• inward	• inward	• inward
Evaporative cooler			
• N/A	• outward	• outward	• outward
Be sure to consult a suitable manufacturer about the building wrap system for your house in your climate with your heating and/or cooling system.			

***Further resources**:*
ABCB Condensation in Buildings: www.abcb.gov.au/en/education-events-resources/publications/abcb-handbooks

5.3 Air-tightness

Air movement through the building envelope reduces the thermal performance of all buildings and is particularly important in lightweight timber-framed buildings. Unwanted infiltration of hot or cold air can lead to more pollutants, dust, moisture and noise within the house and an increased need to use heating and cooling equipment to maintain thermal comfort. Similarly, points of unwanted air exfiltration can become locations for excessive condensation and diminish thermal comfort and energy efficiency. While other countries have regulations and tools that mandate a level of airtight construction for buildings, Australian jurisdictions currently do not. The NatHERS-accredited House Energy Rating Software programs currently use the default infiltration rates specified within NatHERS, and therefore cannot show the benefits of tighter construction.

Increasing air-tightness to save energy

Good airtight construction avoids uncontrolled infiltration and exfiltration. When paired with well-designed controlled ventilation, this will provide a healthier home in most climates.

Although the air-tightness of most buildings is never known, tests conducted on typical Australian houses suggest they are not very airtight with a rating on average at 1.72 air changes per hour (ACH), varying from 0.4 to 3.67 ACH. Generally, Europe and the UK have a stronger focus on energy conservation and have standards on air-tightness. By comparison, the voluntary Passivhaus standard for Europe is producing construction that is about six times more airtight at 0.25 to 0.3 ACH.

Air-tightness and internal lining

Air leaking from a building interior into a wall or ceiling structure not only loses heating or cooling energy from the interior, but can also carry moisture as discussed above. To limit this, the internal linings can be constructed to provide a secondary airtight skin to retard air movement leakage. Well-installed floor, wall and ceiling lining will further reduce air leakage. Take care in lining detailing and construction at the ceiling-to-wall and wall-to-floor junctions, which are common points for leakage in Australian homes.

Measuring air-tightness

The infiltration and exfiltration in a house can be measured by a blower door test. This test, which has been in use internationally for the past decade, has become an economical method of testing houses for unwanted air leakage (Figure 28). It consists of a fan temporarily sealed into an external doorway. The fan depressurises and pressurises the house to pre-set levels – mimicking the pressure differential that a house experiences from wind.

This test allows easy location of areas with unwanted air leakage during construction. With the blower door operating, a small smoke-producing device can clearly indicate significant leakage points. If this test occurs before the external cladding is installed, leaks can be easily repaired. If it is delayed until the commissioning of the building, repairs – if possible – will be much more difficult and expensive.

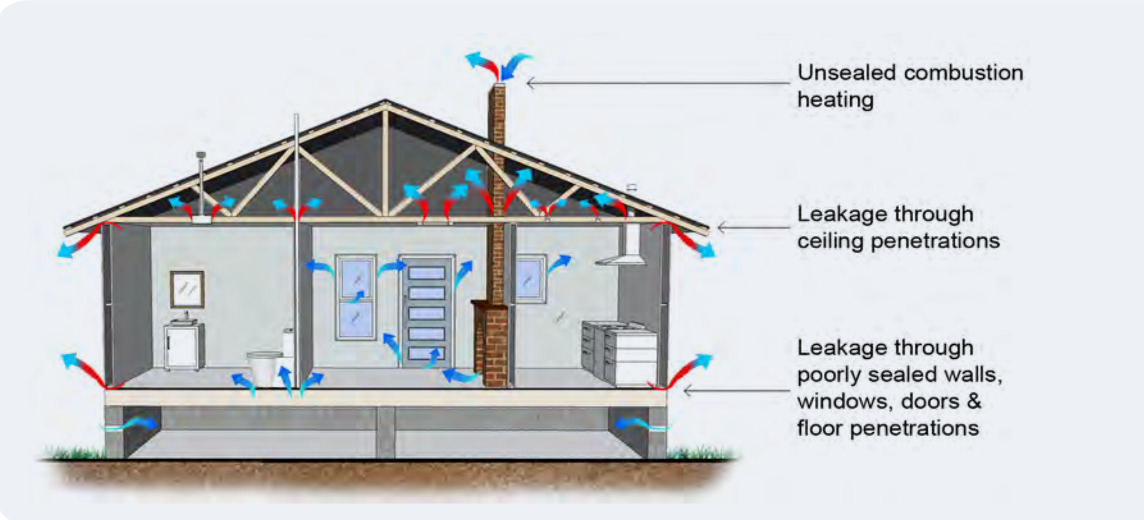


Figure 19: Air leakage. *Common locations of air leakage in house construction.*

General considerations:

- ***Continuous linings*** - provide continuous sheet wall, floor and ceiling linings that are appropriately installed and sealed at corners and joints.
- ***Tapped joints*** - install high quality building wraps to walls, floors and ceilings with lapped and taped joints (Figure 21).
- ***Wrap extent*** - extend the building paper without breaks between the sub-floor and the ceiling space (Figures 26 and 27).
- ***Seal wall framing to floor*** - apply weatherproof sealant between bottom plate of the external wall frames and the floor they sit on.
- ***Downlights*** - reduce downlight penetrations through the ceiling where possible and use proprietary hoods with low wattage fittings to reduce heat build-up and allow insulation to safely abut fitting. Each downlight can 'leak' 1 litre per second of warmed or cooled air out of the room, and has the potential for wind pressure to force 1 litre per second of hot air from the roof space into the rooms below.
- ***Service penetrations*** - carefully seal all plumbing and electrical service penetrations with caulk, wrap or tape where they penetrate the floor, wall and ceiling lining. This includes pipes, conduits, waste water pipes, bathtubs, showers, electrical fittings and electrical circuit boards.
- ***Conditioned spaces*** - wrap and fully insulate the walls and roofs between unconditioned and conditioned spaces.
- ***Seal window and doors*** - wrap, tape, seal and weatherproof door and window penetrations in the external envelope and those to conditioned spaces (Figure 25 and WoodSolutions Design Guide 10: Timber Windows and Doors).
- ***Lining to frame joints*** - internal lining material must be sealed to the timber framing at the top and bottom plates, corners, junctions with the ceiling and at all openings and penetrations.

- ***Internal lining joints*** – all corners and joints in plasterboard sheet should be taped before finishing and painting; if timber lining is used, joints should be taped and sealed behind trims.
- ***Additional wall wrap*** – for wallboards or cladding that is not in a sheet form, additional building wrap can be installed on the internal side of the timber frame before lining (Figure 27).
- ***Floor lining*** – floorboards should be installed over a particleboard substrate or, alternatively, a fitted floor can be used, with wrap installed over the bearers and under the floor joists. If the wrap is installed under the floor joists, it must be fully taped and sealed on all sides to the external wall wrap.
- ***Sealants*** – spray-in foam insulation products can also act as an air sealer, providing extra infiltration and exfiltration control. Fibreglass, polyester, cellulose and wool insulation products do provide good bulk insulation but do not have useful air-sealing properties. However, timber products like plywood, strand-board and high-density fibreboard can be used in conjunction with these products to provide excellent air sealing assemblies.

Advanced practice

- ***Above ceilings*** – Consider installing a vapour-permeable building wrap between ceiling battens and the roof trusses, particularly if the selected ceiling is not a sheet material that can be well sealed (Figure 26).

Climate specific considerations:

Zones 1 and 2 ***Hot and humid***	**Zones 3 and 4** ***Hot and dry***	**Zones 5 and 6** ***Temperate***	**Zones 7 and 8** ***Cool temperate and cold climates***
• ***Inward heat*** – seal to avoid heat gain.	• ***Daily variable heat*** – seal to avoid day/night heat loss and gain cycle.	• ***Seasonal variable heat*** – seal to avoid seasonal heat loss / heat gain cycle.	• ***Outward heat*** – seal to avoid heat loss.

Further resources:
Window Energy Rating System (WERS) – for details about How To Select Windows (www.wers.net/werscontent/how-to-select-windows)

Your Home Technical Manual – for details about Passive Cooling (www.YourHome.gov.au/technical/fs46.html)

Avoiding air leakage.

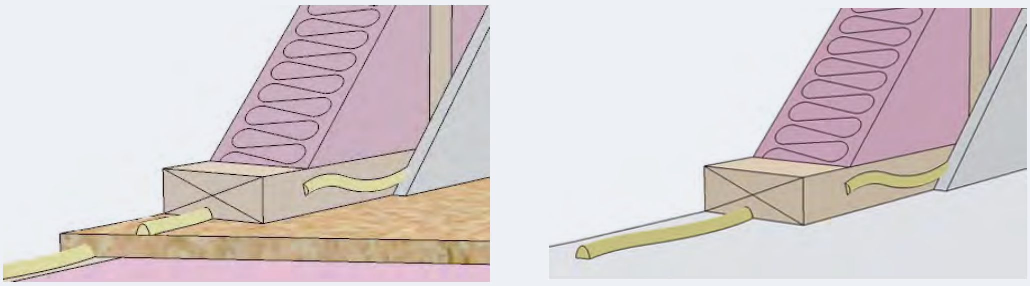


Figure 20: Sealing wall to floor. *Apply weatherproof sealant between the bottom plate and flooring.*

Figure 21: Tape joints. *Building wrap covers all walls and is overlapped and taped.* Photo: Mark Dewsbury

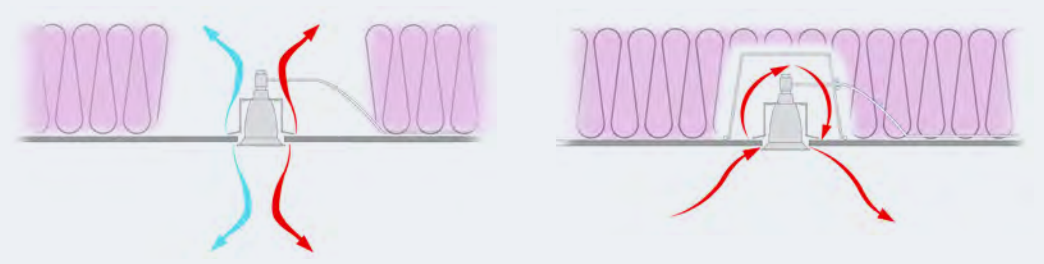


Figure 22: Seal downlights. *Beware unwanted air movement through vented downlights.*

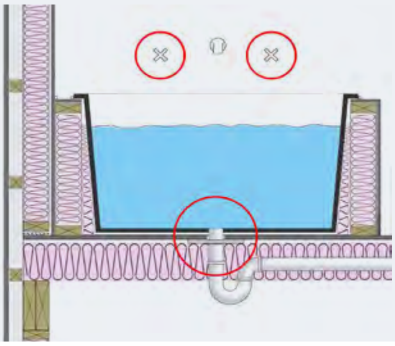


Figure 23: Seal penetrations.
Carefully seal all services penetrations.

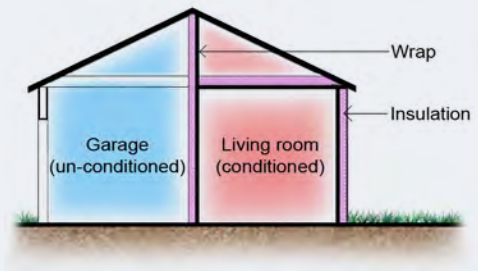


Figure 24: Separate conditioned zones.
Use wrap and insulation between conditioned and unconditioned spaces.

Wrap used to seal envelope.

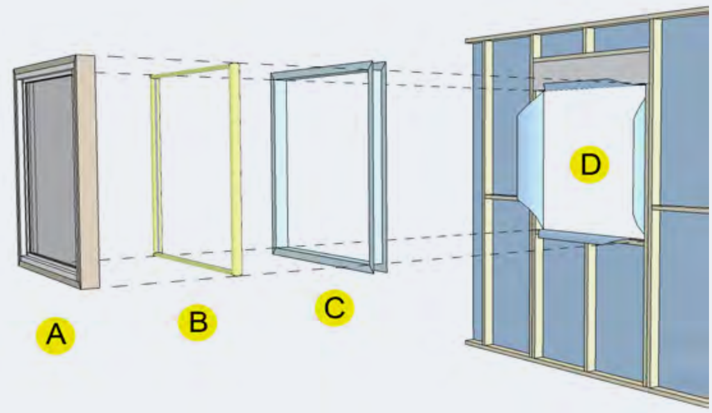


Figure 25: Seal wall openings. *Installation of doors and windows into a well-wrapped wall*

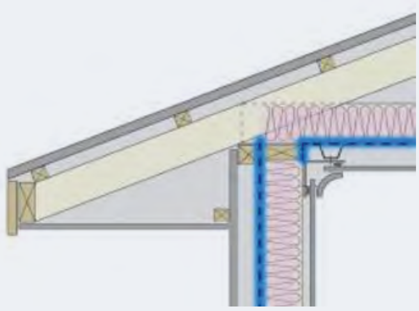


Figure 26: Seal ceilings to walls.
Continuous seal created by fixing to wall plate.

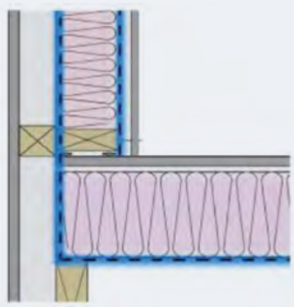


Figure 27: Seal walls to floors.
Continuous seal created by fixing to wall plate.

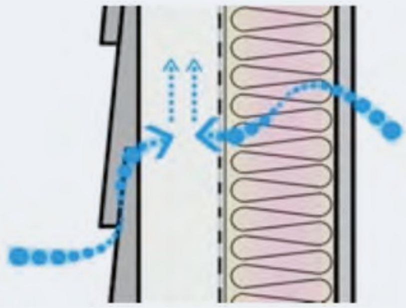


Figure 28: Blower door testing.
A fan temporarily sealed in an external door allows for airtightness to be measured. Photo: Mark Dewsbury

Figure 29: Cavity behind external cladding.
Battening cladding off of studwork promotes vapour diffusion.

5.3.1 Moisture and Vapour Management inside the Cladding

Venting moisture from walls

In all climate types, it is desirable to establish an air cavity between the exterior cladding system and the building wrap (as shown in Figure 23). This gap provides a zone for moisture moving from the exterior inwards to evaporate and for vapour moving from the interior outwards to diffuse. It also limits 'thermal bridging' or conduction of heat between the cladding and the wall frame and insulation.

Venting moisture from roof spaces

Reflective sarking is usually installed under sheet metal and tile roofing systems to reflect unwanted heat away from the roof space and to prevent any moisture that comes through the roofing material from entering the roof space. Sarking is generally installed in continuous, overlapped and/or taped lengths and is impermeable to moisture vapour.

Any vapour that enters the roof space from the house or other sources can become trapped and condense on the underside of the sarking or other cooler surfaces such as metal ductwork. If this moisture is allowed to build up, it will be retained by the materials in the roof structure (such as timber, plasterboard and insulation) and will eventually lead to their decay.

To counteract this possible problem, it is important to adequately ventilate the roof space and avoid extra vapour loads from bathroom or kitchen ceiling exhausts. Simple actions such as keeping the ridgeline unwrapped or providing vents in gables in combination with eave vents will, in most cases, provide adequate ventilation to remove this excessively hot and at times very moist air.

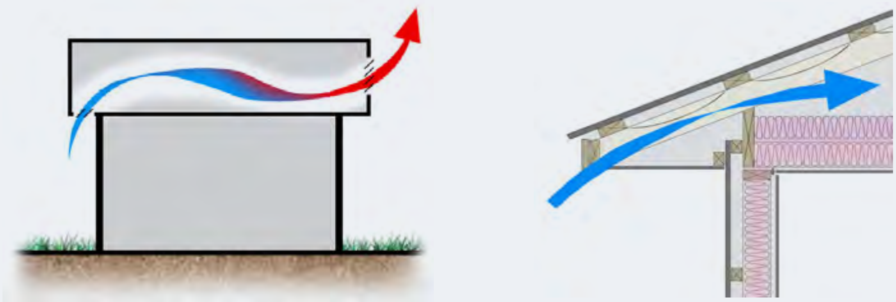


Figure 30: Ventilate roof spaces. *Ensure the attic or cathedral roof space is ventilated.*

Moisture management on service ducts and units

In most climate types, condensation can form in or on surfaces –such as ductwork and pipes for centralised heating and cooling equipment and hot water services – when moisture-laden air comes into contact with these significantly cooler surfaces. Insulating ducts and pipes will deter this.

General considerations:

- ***Sarking*** - install high-quality reflective sarking to help control inward-bound moisture and reduce unwanted radiant heat from the roofing material.
- ***Vent roof space*** - place sufficient vents in both eaves and gables to allow a cross-flow of air through the roof space.
- ***Insulate ceilings*** - use ceiling batts to provide a thermal barrier between the ventilated roof space and the house interior.
- ***Vent exhausts to exterior*** - vent bathroom and kitchen exhausts to the building exterior rather than into the roof space to avoid adding unnecessary moisture.

Zones 1 and 2 ***Hot and humid***	**Zones 3 and 4** ***Hot and dry***	**Zones 5 and 6** ***Temperate***	**Zones 7 and 8** ***Cool temperate and cold climates***
• ***Non-breathable vapour barriers*** – control inward-bound vapour pressure.	• ***Breathable vapour barriers*** – control inward or outward-bound vapour pressure.	• ***Breathable vapour barriers*** – control inward or outward-bound vapour pressure.	

Further resources:

Your Home Technical Manual – for details about Insulation (www.YourHome.gov.au/technical/fs48.html)

Insulation Council of Australia and New Zealand Insulation Handbook (www.icanz.org.au/wp-content/uploads/import/pdf/17132_ICANZ_HANDBOOK.pdf)

ABCB Condensation in Buildings: www.abcb.gov.au/en/education-events-resources/publications/abcb-handbooks

Australian Standards – As NZS 4200.1-1994 Pliable Building Membranes and Underlays Materials

Wood Solutions: R-values for Timber-framed Building Elements R-values for Timber-framed Building Elements

5.4 Thermal Insulation

The air temperature of the interior of a building will tend toward equalising with that of the outside. A building's envelope provides the most obvious line to resist this flow of heat energy by installing thermal insulation.

Although many common building materials resist the flow of heat, materials are termed 'insulation' when they are designed to resist heat flow.

Gaps in insulation installation create what are effectively holes in the thermal envelope. Beyond the obvious thermal holes created by glazing, insulation of the building envelope and across a building element should be continuous, without breaks at edges, corners and junctions.

5.4.1 Common Insulation Products

Formats

Thermal insulation comes in a variety of materials and formats that are often designed to work in specific locations. Various formats include:

- ***Blown-in*** - blown-in fibrous elements.
- ***Foam-in-place*** - spray-on expanding foams.
- ***Rigid*** - extruded polystyrene foam board.
- ***Bulk*** - matted fibrous known as 'blanket' when in continuous rolls or 'batts' if cut into individual panels designed to fit within timber framing.
- ***Reflective*** - foil blankets or individual panels.
- ***Composites*** - reflective materials bonded onto fibrous or cellular materials.

Bulk insulation for ceilings is often quite flexible while bulk wall insulation products are stiffened so that they don't settle over time. Insulation for sub-floors may also be stiffened to avoid sagging. As some products are designed for specific applications, they may not be interchangeable. For example, if a roof insulation product is used in a wall, it may eventually compress and settle into the bottom of the wall frame, leaving uninsulated areas at the top of the wall.

Size

Most insulation products offer sizes that relate to traditional timber construction.

- ***Individual batts*** – 430 mm or 580 mm widths to fit between 450 mm or 600 mm wall stud framing.
- ***Roll-out blanket*** – 900 mm or 1200 mm to fit timber truss common rafter or truss spacing.

Function

There is a range of bulk and reflective insulation products to reduce the heat flow through the building fabric. Of the three types of heat transfer, insulation can resist two:

- ***Conduction:***
  - bulk insulation products slow the flow of heat through the fabric
  - often resisted by materials of low conductivity, and can abut surfaces
  - frequently containing air pockets which slow heat transfer.
- ***Radiation:***
  - reflective insulation reflects radiant heat back in the direction it came from
  - generally can be quite conductive so, to work effectively, an unvented air gap between building elements and the reflective surface is required
  - if an air cavity is vented, air movement across the gap can transfer heat and compromise insulation (Figure 32).

Gaps and ill-fitting insulation = thermal holes

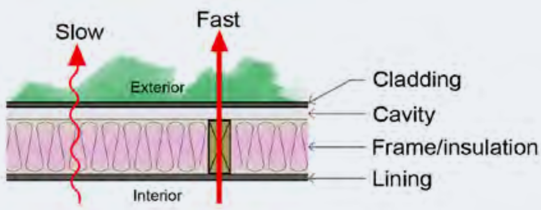


Figure 31: Avoiding conducted heat loss.
Bulk insulation reduces heat flow significantly over that of timber framing elements.

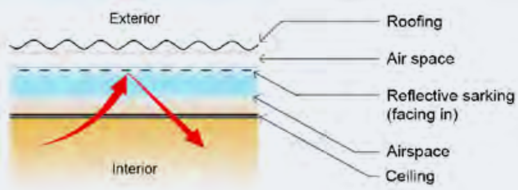
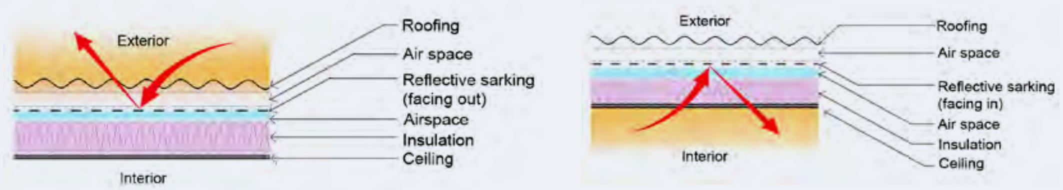


Figure 32: Avoiding radiant heat loss.
Isolate materials to create still air cavity and utilise reflective foil to control heat.



Reflecting heat up *Reflecting heat down*

Figure 33: Diagram of reflective insulation.

Rating insulation performance

As the purpose of insulation is to resist the flow of heat, it is the product's thermal resistance or 'R-value' that is used to rate its effectiveness as an insulation product. When selecting an insulation product, be sure that the quoted R-value is for the product only and not that of a typical construction system. This can confuse designers, builders and retailers into thinking that the product has a higher R-value than it physically does.

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Useful insulation values

Material	Thermal Resistance R-value (m2.k)/W
Glass-wool (7 kg/m^3)	R 1.754
Glass-wool (12 kg/m^3)	R 2.273
Mineral-wool (37 kg/m^3)	R 2.500
Polyester (8 kg/m^3)	R 1.587
Polyester (16 kg/m^3)	R 2.222
Lamb's wool (16 kg/m^3)	R 2.222
Expanded polystyrene	R 2.564
Extruded polystyrene	R 3.571
Spray-in-place foam	R 3.571

Table 9: Thermal resistance values (R-value) for 100 mm of insulation products.

Material Depth/Thickness	R-value
57 mm	1.0
114 mm	2.0
171 mm	3.0
228 mm	4.0
285 mm	5.0
342 mm	6.0
399 mm	7.0
456 mm	8.0

Table 10: Glass-wool insulation thickness (these can vary between products).

Material	Thickness mm	Thermal Conductivity W/(m K) – 1m	Thermal Resistance R-value (m.k)/W
General fabric materials			
Aluminium	90	221.000	0.000
Steel	90	45.300	0.002
Glass	4	1.000	0.004
Paper Faced Plasterboard	10	0.160	0.063
Clay Brick Extruded	110	0.614	0.179
Timber – Hardwood	90	0.176	0.523
Timber – Softwood	90	0.110	0.818
Insulation products			
Glass Wool Insulation	90	0.044	2.045
Expanded Polystyrene	90	0.039	2.308

Installation

- ***Make continuous*** – if a rigid or foil product is used, all joints should be lapped and/or tapped.
- ***Full cove***r – coverage should be consistent and well fitted into corners and around penetrations.
- ***Avoid bridging*** – avoid thermal bridging where possible by avoiding the amount or the extent of non-insulation materials which are able to conduct heat through the envelope – see the discussion on 'framing factor' below.
- ***Don't compress*** – while insulation needs to fit snugly, compressing bulk insulation removes the air pockets that provide its insulation property and diminishing its R-value.
- ***Moisture*** – cold surfaces can lead to condensation wherever they are, so insulation type and its ability to transfer vapour are important considerations to confirm with product manufacturers.

Insulation types.

Bulk (batts and blankets)

Bulk insulation in batts and blankets is the most common form of insulation in the sub-floors, walls and ceilings of Australian houses. The batts are made of glass wool, mineral wool, lamb's wool or polyester fibres. Considerations:

- ***Flexile*** – batts and blankets systems are flexible and sized to fit snugly between framing.
- ***High density*** – for best results, use high-density unfaced batts.
- ***Innovation*** – newer products are becoming available that are denser and manufactured from recycled or more sustainable materials.

Unstiffened

- ***Benefit*** – low cost, most common product with the strongest installation knowledge base. Skill level required to install is low. Quick to install.
- ***Liability*** – does not prevent air leakage, requires appropriately sized cavities for installation, and is not suitable for vertical installation (e.g. in walls).

Stiffened

- ***Benefit*** – relatively low cost, ideal for walls and sub-floors, and easy to install.
- ***Liability*** – does not prevent air leakage, and is only available in a limited range of sizes targeted for use in walls and ceilings.

Glass-wool bulk insulation batts.

Photo: Mark Dewsbury

Blow-in

Insulation products can also be blown into place. Common blown-in or loose-fill products include glass wool, mineral wool, lamb's wool and cellulose insulation. These products are generally not acceptable for new buildings as the quality of installation and possible settling of material will significantly affect the thermal resistance value. Considerations:

- ***Retrofits*** – useful in retrofit projects where access is restricted.
- ***Spray*** – some products can be sprayed into existing framed walls, where it dries and sets within the wall. To be effective, these systems require wall frames with minimal cross and diagonal members.
- ***Resist air movement*** – some blown-in products offer resistance to air movement.
- ***Benefit*** – good for top-up and retrofitting.
- ***Liability*** – consistency of application hard to control, therefore not supported by codes.

Blow-in insulation.

Photo: Joe Timi, CSR Bradford

Foamed-in-place

Foam-in-place insulation products are common overseas and of growing availability in Australia. Installed by a certified applicator, they generally provide very high insulation performance.

- ***Tight-spaces*** – ideal for spaces that are small or have limited access (like sub-floors and cathedral ceilings), which are often not insulated correctly.
- ***Seal gaps well*** – by expanding into small voids this form offers excellent infiltration control.
- ***Benefit*** – expanding foams are very flexible, very good insulators and stop airflow well.
- ***Liability*** – generally the most expensive option.

Sprayed-in-place wall insulation

Photo: Mark Dewsbury

Sprayed-in-place wall insulation

Photo: Mark Dewsbury

Rigid insulation

Extruded and expanded polystyrene products are a lightweight rigid insulation most commonly available in sheet form. Other natural fibrous board products are also available. Rigid insulation may be used in conjunction with other insulation types to further improve sub-floor, wall, ceiling and roof insulation. As this product comes as a rigid panel, it is better to apply it to outside of a timber frame (sub-floor, walls and roof), rather than trying to fit it between timber members.

- ***Acoustic*** – provide good thermal and acoustic insulation.
- ***Foil options*** –some products are faced with a reflective wrap (foil-board).
- ***Applied finishes*** – available with surface ready for the application of external render.
- ***Over-laid*** – may be laid across framing and in addition to other insulation types.
- ***Beware vapour*** – foil-surfaced board is vapour impermeable and if used on external wall can trap moisture in the wall.
- ***Termites*** – sheets in contact with the ground should be treated for termite resistance.
- ***Benefit*** – Good insulator, easily screw fixed to the structure and if overlaid and taped – reduces infiltration.
- ***Liability*** – difficult to install between framing due to variability of framing members and all joins require taping.

Extruded polystyrene over-cladding a timber-framed wall before external cladding is fixed.

Photo: Mark Dewsbury

Reflective sub-floor insulation

Reflective insulation has been used in Australia for more than 40 years, commonly for roof sarking. Reflective wall wraps are also used widely as well as growing range of concertina batt and composite products.

- ***Compact*** – reflective insulation is lightweight, and requires little volume to be effective.
- ***Limit conduction*** – reflective foils are often quite heat conductive, so it is important to have them adjoining air cavities.
- ***Avoid air movement*** – any air movement will significantly reduce or even negate the system's insulation value so it is important joints are taped and cavities well sealed to provide a 'still air space'.
- ***Hot climates*** – useful for limiting heat gain of the envelope by reflecting heat out.
- ***Benefit*** – Low cost.
- ***Liability*** – requires a lengthy installation process to ensure an airtight/taped installation. If still air spaces are not achieved, the product does not provide the marketed levels of insulation.

Reflective sub-floor insulation.

Photo: Mark Dewsbury

5.4.2 Sub-floor Insulation

In climates where the outside air and ground temperatures are significantly different to the temperature required inside a house, sub-floor insulation may be needed to reduce the heat gain or heat loss through the floor. There are three main residential sub-floor construction types in Australia, each with specific thermal characteristics and insulation approaches:

- platform-floor with an unenclosed-perimeter
- platform-floor with an enclosed-perimeter
- concrete slab-on-ground.

Figure 34: Sub-floor enclosure types.

Timber platform floors

Both the insulation of a suspended floor and its enclosure affect thermal performance. Unenclosed sub-floors provide the best ventilation for timber floors and allow for easier visual inspection for termites and other problems; however, this air movement brings the potential for greater thermal losses. In some climate types, enclosing the sub-floor can make it up to 30% more thermally effective.

Enclosed platform floors are shielded from hot or cold wind and heat radiating from the surrounding ground. Also, the air in the enclosed sub-floor space can act as a thermal buffer between the ground and the floor of the inhabited rooms. It is important that enclosing walls contain appropriate vents to remove evaporating ground moisture and internal building vapour that can escape through the floor, and to ensure that footings, substructure and insulation materials remain dry.

When walls and ceilings are insulated up to 50% of heat loss can come from an uninsulated platform floor

The specification and installation quality of sub-floor insulation is a critical factor in the performance of timber-framed, platform-floored houses. Regardless of the level of sub-floor enclosure, the level of insulation in the floor will eventually govern the rate of heat loss or gain through the platform floor. In a house with insulated walls and ceilings but an uninsulated platform floor, up to 50% of heat loss or gain in the building can be through the floor.

Products available to insulate a platform timber floor include polystyrene sheets, glass and mineral wool batts, foam-in-place and reflective insulation. Products can be used individually or combined to insulate both the sub-floor space and the floor.

As standards for platform-floors insulation increase, so do the number of available products. While the NCC may require as little as R1.0 sub-floor insulation, most floor-joist systems can easily accommodate a dense R3.0 or high-rated insulation batt. As access to the sub-floor can be difficult after construction, it is preferable to install better-than-code levels of insulation during construction. Advice should be sought from manufacturers regarding specification.

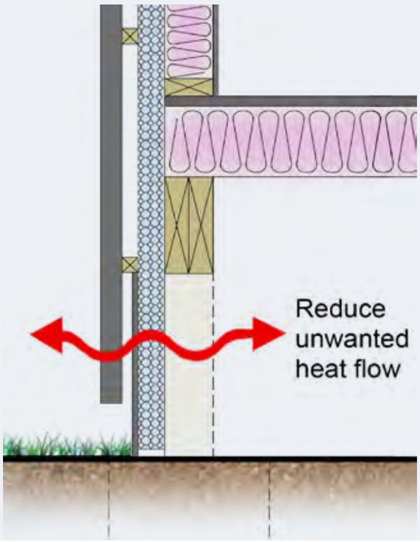


Figure 35: Insulation of sub-floor walls. *Continue insulation to ground in accordance with manufacturer's detailing.*

Concrete slabs

Concrete slab-on-ground floors do not have a sub-floor zone and generally have a moisture barrier system installed under the slab and around its edges to prevent ground moisture penetration.

There are three methods for insulating slab-on-ground floors:

- slab edge
- underslab insulation
- waffle-pod concrete slabs.

Figure 36: Board under slab and slab edge insulation. *Slab edge insulation is suitable for most climates. Photo: Mark Dewsbury*

Figure 37: Underslab waffle-pods. *Underslab insulation is suitable for cooler climates. Photo: Mark Dewsbury*

In both concrete slab-on-ground types, the solid polystyrene products provide the thermal insulation. While providing underslab insulation, a polystyrene waffle-pod is largely designed as a void form or sacrificial formwork with as little as 20 mm of solid polystyrene in the top surface.

Overseas research has found that underslab insulation up to R3.0 is cost effective (approximately equivalent of 120 mm thick expanded polystyrene). When Australian house designs were subjected to thermal simulations, 6-star designs that included 50 mm to 75 mm of expanded polystyrene as sub-floor insulation achieved an increased energy ratings of up to 8.0 stars.

However, the use of sub-floor insulation on a concrete slab-on-ground floor in temperate climates needs to be carefully considered in the context of the house design, its heating and cooling requirements and the temperature of the ground. The sub-floor insulation may provide a significant benefit in winter but may allow the house to overheat in summer. By having the design modelled by a House Energy Rating assessor, the heating and cooling requirements can be evaluated and used to inform the right approach to concrete slab-on-ground sub-floor insulation.

5.4.3 Wall Insulation

The external walls of a house are the second most critical area of potential heat loss or gain after the glazed opening in the envelope. A range of factors can significantly improve the effectiveness of wall insulation. These include:

- correct installation
- separating unconditioned and conditioned rooms.
- reducing the external wall ‘framing factor’ (discussed below)
- over-cladding the wall frame with insulation.

Installation

Most wall insulation products are designed to fit between the wall framing of 450 mm and 600 mm standard wall-framing systems, the most common being bulk insulation batts. As mentioned above, when selecting a bulk batt product look for ‘stiffened’ batts, as these products have a stiffened face to reduce the chance of the batt crumpling and compressing within the wall. Before cladding, insulation in walls should be inspected to ensure there should be no gaps in the insulation (Figures 38 to 41).

Figure 38: Correctly installed wall batts insulation. *Photo: Mark Dewsbury*

Figure 39: Lack of insulation in corners. *Photo: Mark Dewsbury*

Figure 40: Batt insulation removed for installation of services. *Photo: Mark Dewsbury*

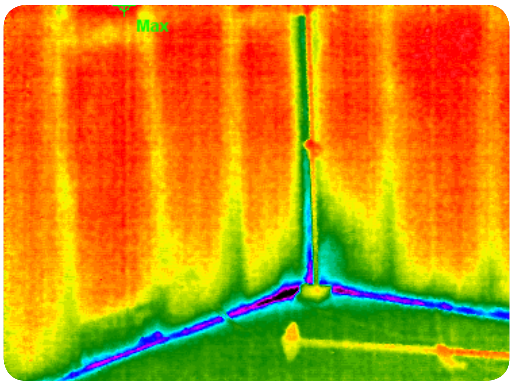


Figure 41: Heat leakage. *This infra-red image of a wall-floor junction with blue tones indicating heat-leakage from this warmed space. Photo: Mark Dewsbury*

Separating unconditioned and conditioned rooms

Most houses limit heating and cooling to 'habitable' rooms with garages and utility rooms wisely excluded. Installing insulation in walls between unconditioned and conditioned rooms can significantly improve the thermal performance of a house.

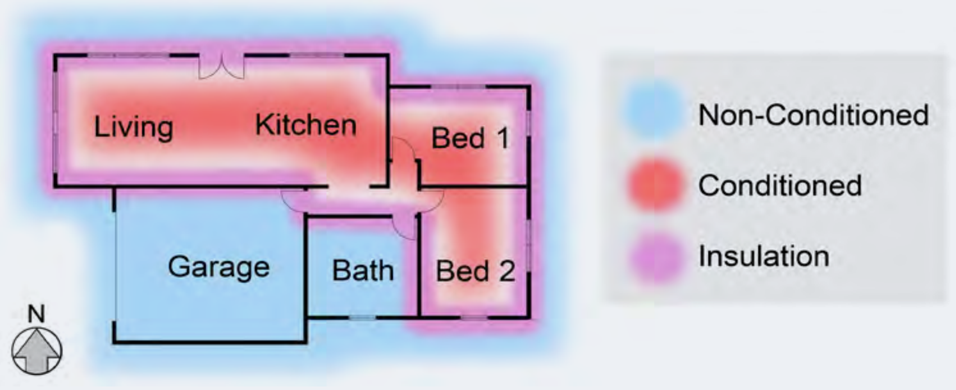


Figure 42: Separate conditioned rooms. *Insulate internal as well as external walls to contain heating and cooling.*

5.5 Thermal Bridging

Areas or components with lower thermal insulation value break the insulation continuity and are known as thermal bridges; these areas will suffer the most unwanted heat loss or heat gain. For example, gaps in the installation of insulation or a highly conductive member within a wall such as a steel lintel will provide this. The installation of services is common source of thermal bridging.

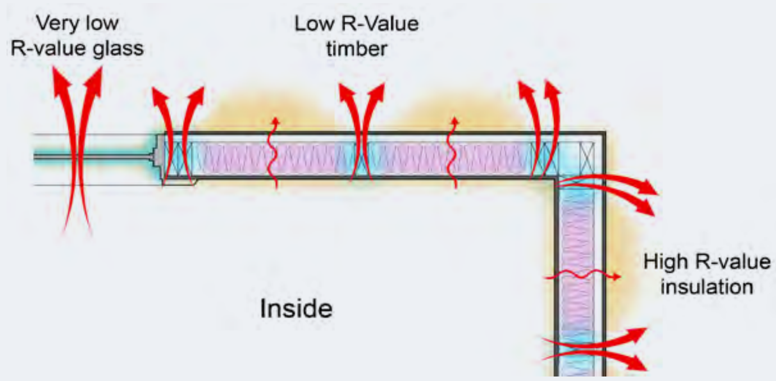


Figure 43: Timber-framed wall. *Conventional timber framing with insulated cavities will still give some thermal bridging.*

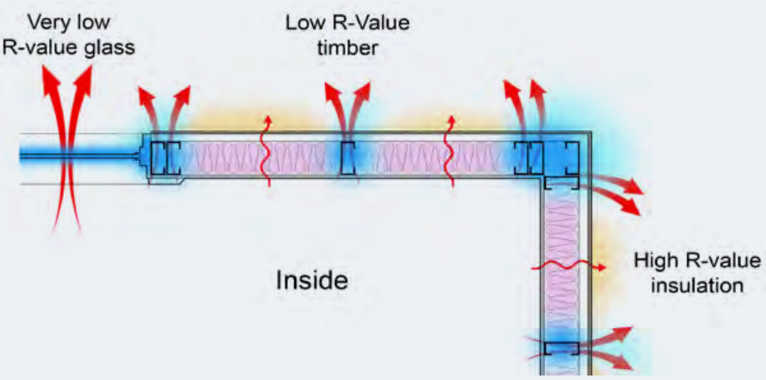


Figure 44: Steel-framed wall. *Due to the substantively higher conductivity of steel thermal 'breaks' are now required in some jurisdictions.*

Reducing the framing factor in wall framing

As the timber frame has less thermal resistance than the surrounding insulation, each framing element in the external envelope conducts more heat than the surrounding insulation. The R-value of softwood timber wall framing (R0.818) and that of wall insulation (R2.0) are significantly different. These weak points in the insulation layers are called thermal bridges and their effect is shown in the infrared images in Figure 41.

In framed systems, such as a timber-frame wall, the area of timber in the frame relative to the area of insulation is called the 'framing factor'. Generally, if the amount of insulation in wall is the same, a wall with a high framing factor will have a lower average thermal resistance than a wall with a low framing factor.

In Australia, framing factors range from 25% to as high as 40%, limiting the portion of the wall area that can contain insulation. At both the design and construction stages, a framing factor of 20 to 25% should be aimed for. Providing timber framing with studs at 600 mm centres as opposed to 450 mm centres will give a lower framing factor, and allow for increased area of insulation. Additional non-required framing elements should be limited wherever possible.

Practices that limit thermal bridging through the wall frame:

- ***Limit noggings*** – to one row where possible, and in a flat rather than vertical format.
- ***Avoid double top plates*** – by aligning roof and wall framing.
- ***Reduce corner studs*** – where permitted by standards by using plaster fixing cleats.
- ***Cover steel beams*** – avoid high levels of thermal bridging by allowing lintels, etc., to be fully encased in insulation.
- ***Insulate face of beams*** – keep lintels to the outside face of the wall frame and maximise the internal wall space that can be insulated.

Reducing thermal bridging.

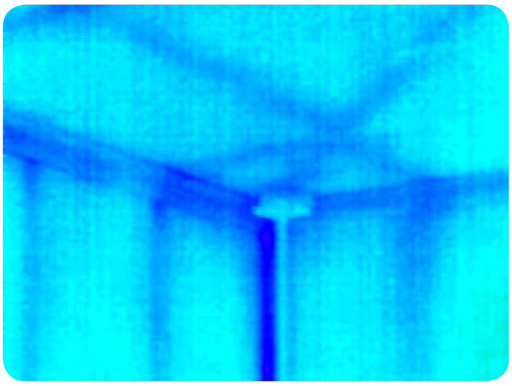


Figure 45: Thermal bridging.
Infra-red image of wall-ceiling junction with darker tones indicating thermal bridging created by timber framing. Photo: Mark Dewsbury

Figure 46: Thermal bridging.
Beware high conducting elements that breach wall insulation. Photo: Mark Dewsbury

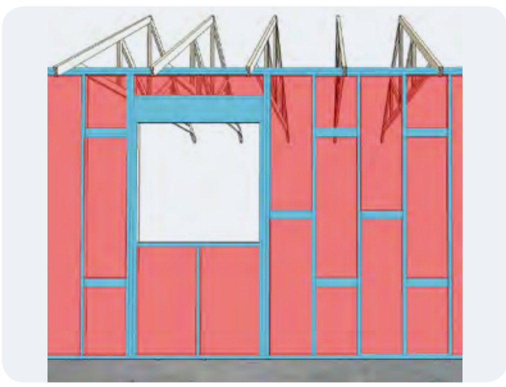


Figure 47: Excessive framing.
Wall with multiple noggings and a high framing factor. Unaligned wall and roof structure as requires a double top plate.

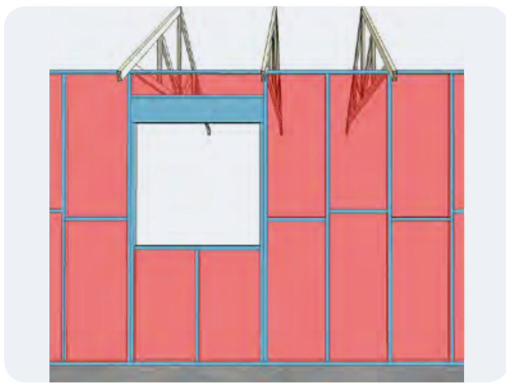


Figure 48: Efficient framing.
Aligned wall and roof structure requiring a single top plate and combined with single on-edge noggins result in a much lower framing factor.

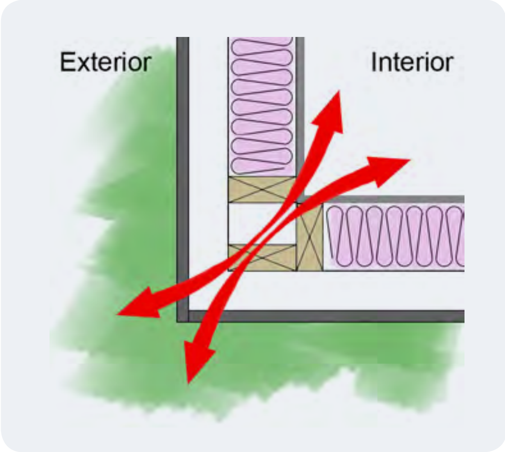


Figure 49: Standard corner framing
Conventional framing often results in uninsulated corners.

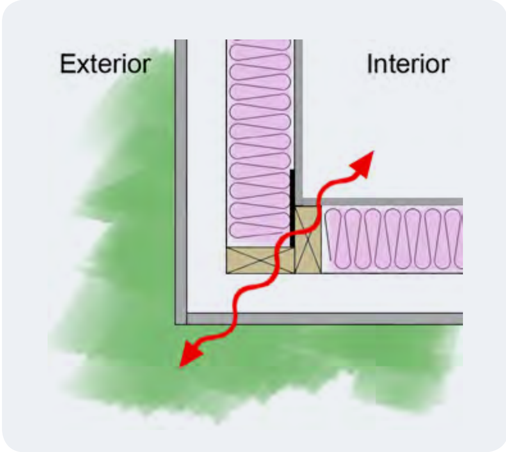


Figure 50: Minimised corner framing
Proprietary fixings minimise studwork and promote effective insulation.

Advanced framing

Advanced framing methods can reduce the framing factor to 9%; their details are available from the US Department of Energy and various European research groups, including the Passivhaus Institute. Advanced framing methods are beyond the standard forms of timber-framed construction detailed in the NCC and AS1684 Residential Timber-framed Construction and their use in design in Australia needs separate engineering certification.

Over-cladding the wall frame to increase insulation levels

To create more space for in-wall insulation, some builders and designers are moving to wider timber frames. However, the increased cost of this may not produce the results sought as it does not eliminate thermal bridging nor reduce the framing factor. It is much more thermally efficient to use standard studs, over-clad the frame with a sheet insulation product and install batt insulation between the studs in the frame. This method has several benefits as it:

- ***reduces thermal bridging*** – by providing insulation between the wall framing and cladding
- ***improves infiltration control*** – by adding an additional barrier and with few joints
- ***increases insulation*** – by allowing levels significantly above current code requirements.

Insulation products such as polystyrene sheets can be applied continuously to the face of timber-framed wall to significantly reduce thermal bridging from the frame. This can be done by including the insulation as a layer within the wall assembly or using the insulating element as the external cladding. With either method, it is critical that the construction detail allows for any moisture to be drained from walls, without creating ventilated cavities.

Over-clad rigid insulation systems.

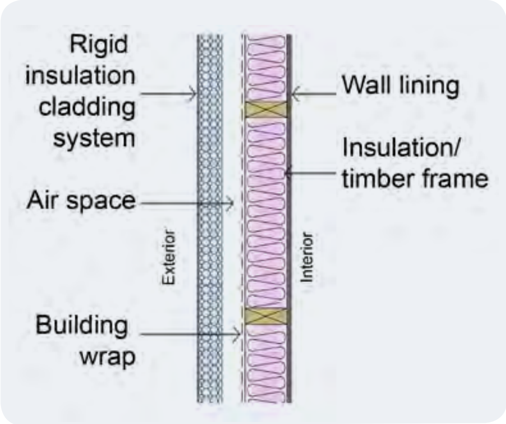


Figure 51: Over-cladding as external cladding.
A still air cavity and wall wrap between the over-cladding and frame enhance insulation.

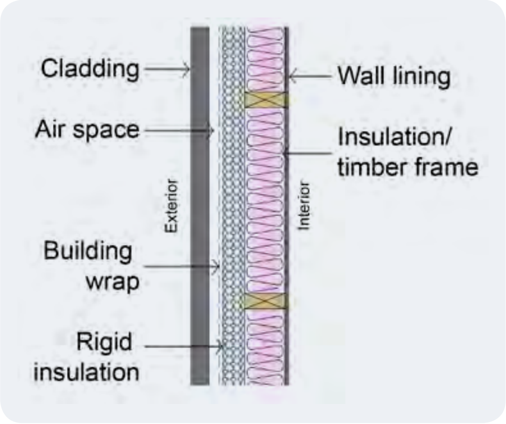


Figure 52: Over-cladding as a layer in the wall assembly.
Battening conventional cladding off of over-clad insulation board enhances insulation.

Figure 53: Rigid insulations as external cladding.
Solid insulated panel with sheet-metal faces and polystyrene core. Photo: Mark Dewsbury

Figure 54: Traditional cladding over rigid board insulation.
Timber ship-lapped boards over polystyrene board. Photo: Mark Dewsbury

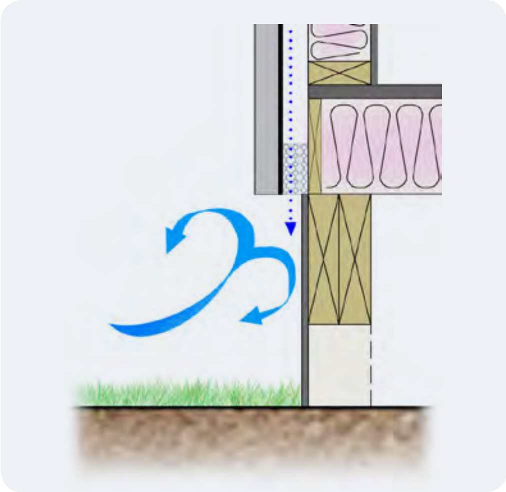


Figure 55: Closed cavity drainage.
Cavity with a closed cell foam product that stops airflow but allows moisture to drain.

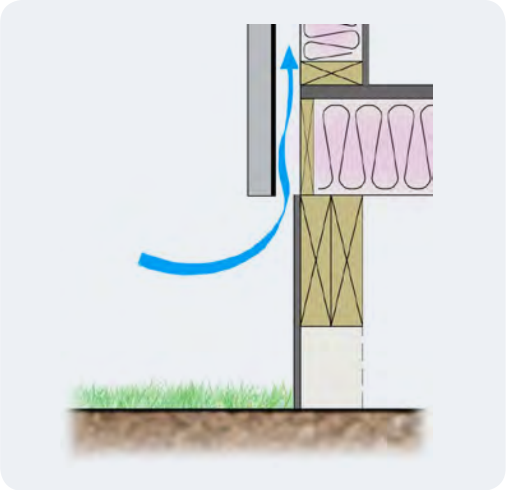


Figure 56: Beware 'chimney' effect.
Open cavities can allow air-movement that compromises thermal performance.

5.5.1 Ceiling Insulation

As hot air rises, ceilings can be the most important element to insulate. While convection can allow heat to rise into the roof space in cool weather, in hot weather, hot ceilings can radiate heat down into building interiors.

Like wall framing, ceiling framing allows some thermal bridging. This can be overcome by applying a second layer of bulk insulation. This is a method of covering the top of exposed framing (Figure 58).

- ***Limit and seal penetrations*** – skylights, ceiling vents and manholes to the roof space can act as flues to bring heat through ceilings. (The NCC includes strict limits on skylight use.)
- ***Manholes*** – access points between the house and the roof space should be weather-stripped and have insulation attached (Figure 60).
- ***Better lighting*** – many common downlights are vented and generate so much heat as to require insulation to be setback from fittings. Using unvented fittings that generate less heat (such as LED) can allow for uninterrupted coverage by ceiling insulation.
- ***Edge treatment*** – provide adequate depth for ceiling insulation to be installed where roofs meet ceilings and provide edge baffles to protect the outer perimeter of the ceiling insulation.

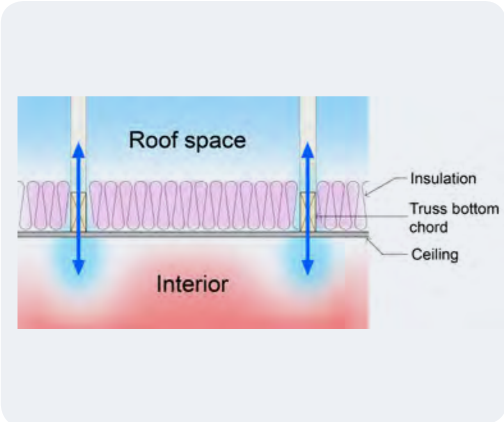


Figure 57: Typical thermal bridging at ceiling.
With ceiling joists exposed to roof space.

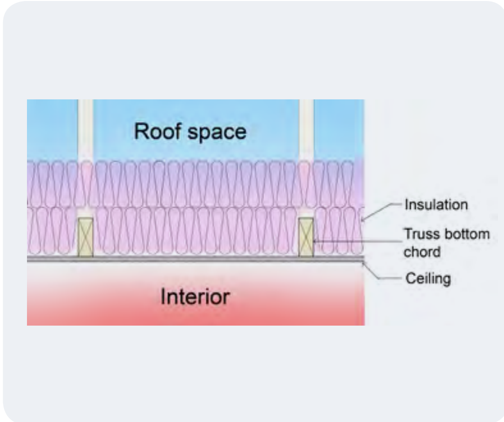


Figure 58: Overcoming thermal bridging.
Insulation applied in a second layer to over joists.

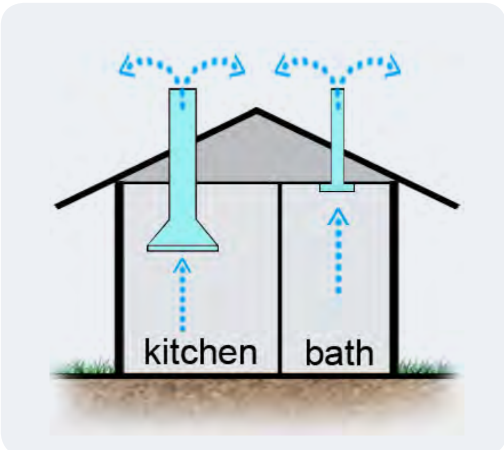


Figure 59: Bathroom and kitchen exhaust.
These must be vented outside the roof space.

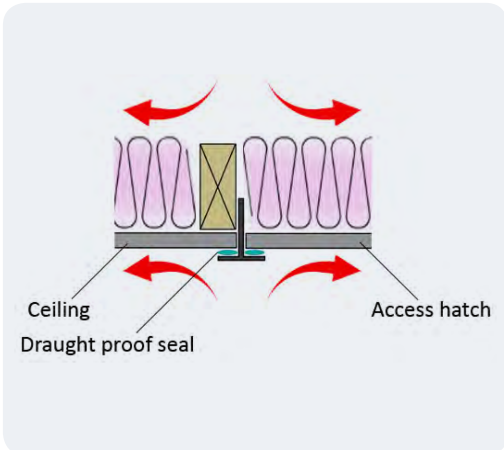


Figure 60: Access hatch.
High-density foam seal between a prefabricated insert and the ceiling.

5.5.2 Roof Insulation

The roof encloses a complex thermal zone of the house that offers a buffer between the atmosphere and solar radiation and a building's interior. It requires both adequate ventilation and careful detailing to control heat flow into and out of the space.

- ***Adequately ventilate*** - use vents in eaves and higher up in the roof to allow heat and any build-up of moisture to escape.
- ***Reflective sarking*** - reflect solar radiation back into the atmosphere limiting overheating of the roof space.
- ***Cathedral ceiling*** - as these allow no roof space to be vented, adopt a detail that allows for a ventilated cavity between the insulation and sarking and another between the sarking and roof covering.

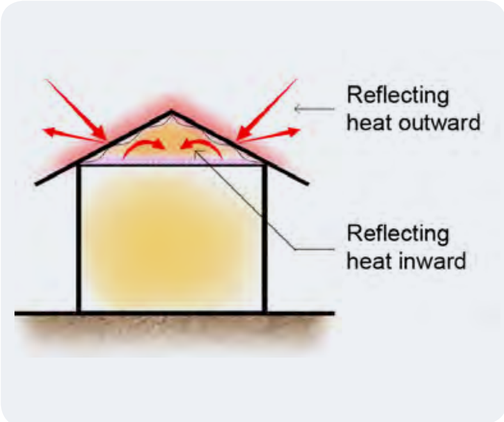


Figure 61: Reflective insulation in the roof
Reflecting internal and external heat.

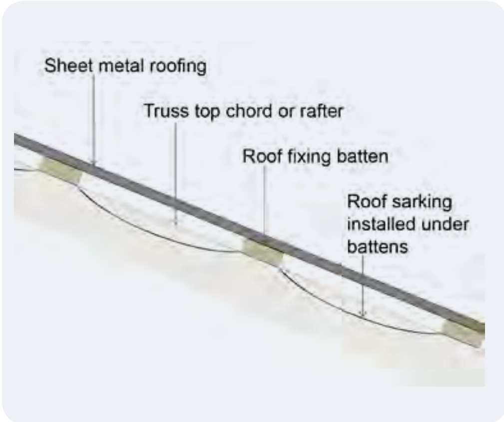


Figure 62: Alternate roof sarking detail.
Sarking under rather over battens allows condensation to form outside the roof space rather than inside it.

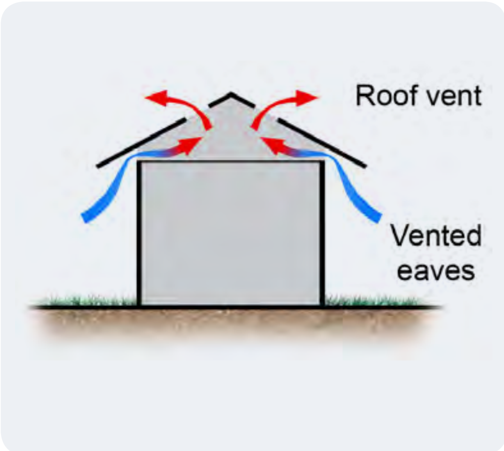


Figure 63: Vent attic roofs.
Having multiple vents to roof space allows airflow.

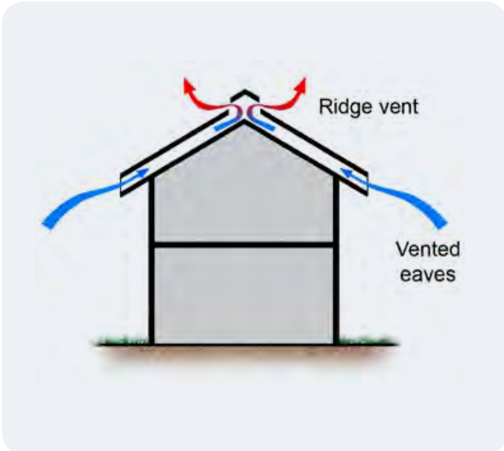


Figure 64: Vent cathedral roofs.
Special detailing is needed to allow vapour to escape.

5.5.3 Tips for Thermal Insulation per Climate Zone

General considerations:

- ***Floors*** – in conditioned rooms use sub-floor insulation to reduce heat gain or loss through the floor.
- ***Walls*** – high levels of wall insulation reduce heat flow through external walls, especially for spaces likely to be conditioned.
- ***Ceilings*** – high levels of bulk ceiling insulation reduce heat flow down from hot roof spaces into the habitable zones and keep conditioned air cool, and the reverse is achieved in cooler weather.
- ***Conditioned spaces*** – consider additional insulation for conditioned spaces.

Climate specific considerations:

<table>
<tr><th>Zones 1 and 2
Hot and humid</th><th>Zones 3 and 4
Hot and dry</th><th>Zones 5 and 6
Temperate</th><th>Zones 7 and 8
Cool temperate and cold climates</th></tr>
<tr><td colspan="4">• Vent roof – a well-ventilated roof space can dump the hot air out of the building zone, reducing conductive gain through the insulation and ceiling into the room below.
• Increased insulation –installing R6.0 ceiling insulation will provide significant benefit in all climates.</td></tr>
<tr><td colspan="2">• Reflect heat out – well-installed reflective sarking will significantly reduce the temperature in the roof space.</td><td colspan="2">• Reflect heat in – well-installed reflective sarking will reflect unwanted summer heat up and wanted winter heat back down toward the ceiling.</td></tr>
<tr><td>• If unshaded – if walls are un-shaded, install greater than code wall insulation to reduce conductive gains.
• Sub-floor – subject to the outside air and ground temperatures, sub-floor insulation can reduce heat gain through the floor.</td><td colspan="2">• Low mass cladding – good lightweight, low mass external cladding with a good level of wall insulation will reduce heat flow in on hot days and heat flow out on cool nights.
• Platform floors – good quality sub-floor insulation to reduce heat flow inward during summer and heat flow outward during winter.</td><td>• More insulation – In cool climates, installing greater-than-code floor, wall and ceiling insulation will provide long-term benefit.
• Sub-floor insulation – use to reduce heat loss to the sub-floor space or ground.
• Unenclosed sub-floor – increase the insulation level in the floor to achieve at least the same performance as an enclosed insulated sub-floor.</td></tr>
</table>

Further resources:

Your Home Technical Manual – for details about Insulation (www.YourHome.gov.au/technical/fs48.html)

Insulation Council of Australia and New Zealand Insulation Handbook (www.icanz.org.au/wp-content/uploads/import/pdf/17132_ICANZ_HANDBOOK.pdf)

ABCB Condensation in Buildings: www.abcb.gov.au/en/education-events-resources/publications/abcb-handbooks

Australian Standards – As NZS 4200.1-1994 Pliable Building Membranes and Underlays Materials

Wood Solutions: R-values for Timber-framed Building Elements R-values for Timber-framed Building Elements

5.6 Windows

While glazed doors and windows are key components in the design of houses, they are often the parts of the external envelope that allow the greatest heat loss and gain. Careful window selection and detailing is essential if the target thermal performance is to be attained. Key thermal performance factors include:

- ***size*** – the larger the window, the bigger the impact
- ***thermal conductivity*** – of both the glass and frame
- ***solar heat*** – the Solar Heat Gain Co-efficient (SHGC) or degree of solar heat admitted
- ***air tightness*** – the air infiltration rate.

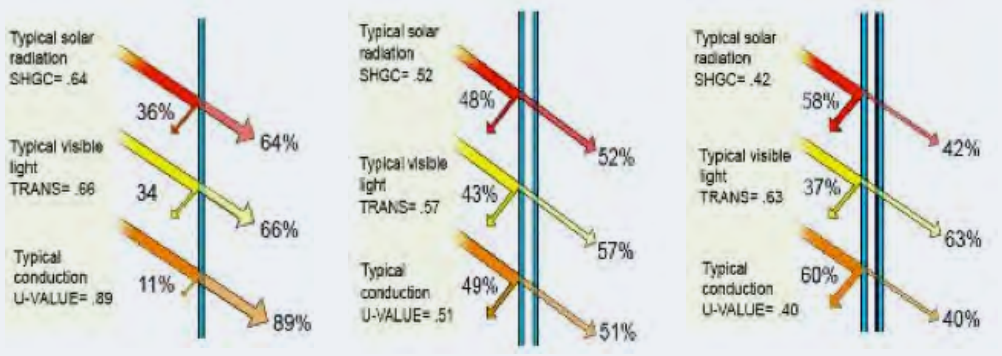
Research has shown that glazing has a significant impact on thermal performance of housing once it exceeds about 12% of floor area. More glazing can mean more heat load from admitted sun, and its low R-value offers poor resistance to heat transfer.

Thermal conductivity

Heat flows through windows by radiant, conductive and convective means. Conducted heat loss/gain comes from both the conductivity of the frame and the glazing. The aim in design is to reduce heat flow by selecting windows with lower conductivity.

Figures 65, 66 and 67 show the differential heat flows through various window components. Double glazing cavities are sometimes filled with argon or other gases, as they are less conductive than air.

Heat flow through windows.



Clear Single Glazed *Clear Double Glazed* *Low E Double Glazed (low-emissivity emits less heat)*

Figure 65: Heat flow through glazing.

Frame Type	Conductivity Value
Aluminium	8.0 – 12.0
Thermally broken aluminium	1.9- 3.5
UPVC	2.0 – 4.0
Timber – aluminium composite	2.5 – 10.0
Timber	2.0 – 3.0

Figure 66: Conductivity values for different frame types

Window Part	Material	Conductivity Value	SHGC	% of window
Window Frame	Meranti (35 mm thick)	2.23	n/a	18
Glazing	4 Clear / 12 Argon gas/ 4 Clear	2.56	0.74	82
Glazed Unit Total Values		2.50	0.62	

Figure 67: Thermal performance calculations for a double-glazed timber window
WoodSolutions Design Guide 10: Timber Windows and Doors provides additional detail on thermal performance, durability and maintenance requirements for timber windows.

Solar heat gain co-efficient

The Solar Heat Gain Co-efficient (SHGC) is the value given to the amount of solar radiation that passes through a glazing system, which will heat-up the building interior. A SHGC of 1.0 indicates that 100% of the solar radiation will travel through to the inside of the glass, dependent on the type of glass, and any films that may be applied to the glass to reduce glare or the R-Value. Where the sun's warmth is sought, a window with a high SHGC and a low U-Value is needed. Where solar heat gain is undesirable a window with a low SHGC and a low U-value is needed.

Window airtightness

Air infiltration for windows is a measure of the amount of air that may leak through a window assembly, between the frame and sashes when the window is closed. To limit unwanted heat transfer through infiltration and exfiltration, windows with a low infiltration rate should be selected.

Historically, windows and other glazed units that slide tended to have a higher infiltration rate than units that are hinged. However, many manufacturers have significantly improved the infiltration properties of their window systems.

Window performance

The national Window Energy Rating Scheme (WERS) lists the thermal properties of a wide range of windows. The WERS website, www.wers.net, provides an extensive report on the relative thermal performance of windows and doors, listed by frame type, glazing type and their particular manufacturers.

Use this information when choosing windows for a new building or renovation and model the impact on thermal performance for a given climate and shading in House Energy Rating software. Some examples of double-glazed units from the WERS website are shown below. Each manufacturer must list a description on their window assessment information for any acronyms and letters that are used to describe the glass and air-gap types. The stars illustrate the window system's relative benefit for climates that require cooling or heating. Other key information includes the amount of daylight that passes through a window (Tvw).

Under the WERS window rating scheme mentioned below, air infiltration ratings are measured up to a maximum rate of 5 litres per second. Untested windows or windows which exceed this are rated at 5.0 litre per second.

Double-glazed, timber-framed casement unit					**Total Window**			
Glazing	Cooling stars	Heating star	Cool %	Heat %	Uw	SHGC	Tvw	Al L/s.m^2
4Gry/6/4Clr	★★★★	★★★★★★	59%	64%	2.9	0.38	0.34	0.12
4Gry/12Ar/4Clr	★★★★	★★★★★★☆	59%	70%	2.5	0.41	0.39	0.12
4Clr/6/4Clr	★★★	★★★★★★☆	49%	71%	2.9	0.51	0.55	0.12
3Clr/8/3Clr	★★★	★★★★★★★	49%	73%	2.8	0.53	0.56	0.12
4Gry/12Ar/4EA	★★★★☆	★★★★★★★	64%	74%	2.0	0.37	0.36	0.12
4Clr/6/4EA	★★★☆	★★★★★★★	54%	74%	2.5	0.47	0.51	0.12
4Clr/12Ar/4Clr	★★★☆	★★★★★★★	51%	75%	2.5	0.51	0.55	0.12
4Clr/12Ar/4EA	★★★★	★★★★★★★☆	56%	80%	2.0	0.48	0.51	0.12

Table 11: Thermal performance window example from www.wers.net

Uw *whole-window U-value*
SHGCw *whole-window solar heat gain coefficient*
Tvis *whole-window visible transmittance*
Uw *whole-window U-value*
AI *air infiltration rate at positive inward pressure difference of 75 Pa*

The glazing description 4Gry/6/4clr is a descriptor for the glazing system. In this case, it refers to a 4 mm glass panel with a grey film applied, a 6 mm air-gap and a sheet of 4 mm clear glass.

The 4Clr/6/4Clr and 4Gry/6/4Clr glass types have a SHGC of 0.51 and 0.38 respectively. This indicates that the 4Gry/6/4Clr window stops 13% more radiant heat flow through the glass, making this glazed unit good for un-shaded windows in hot and temperate climates. But this same glazing type is less suitable for climates that require heating. It has a heating stars value of 6 stars while the 4Clr has a heating stars rating of 6.5 stars.

General considerations:

• ***Thermal holes*** – windows and glazed doors allow heat through as they create virtual holes in the thermal envelope of a house.

• ***Size and orientation*** – maximise size for breeze and light penetration and minimise to limit unwanted heat loss/gain.

• ***Position*** – windows placed well can bring ventilation, cooling cross ventilation and warming winter sun. Poorly placed, they can cause heat gain/loss and other issues with noise, dust, security, etc.

• ***Window type*** – consider the best style of window for the application (casement windows catch breezes better, awning windows protect from rain, etc.

• ***Frame conductivity*** – select frames with a low conductivity

• ***Glazing conductivity*** – select glazing with a low conductivity such as laminated glass or double-glazed units to reduce unwanted heat gain or loss in all climate zones.

• ***Daylight*** – consider the light transmittance level of glazing to avoid overly dark interiors.

• ***Solar heat*** – for unshaded windows in hot climates, select low SHGC glazing to reduce unwanted solar heat gain.

• ***Seals*** – high-quality seals limit air, dust and moisture penetration.

Climate specific considerations:

<table>
<tr><th>Zones 1 and 2
Hot and humid</th><th>Zones 3 and 4
Hot and dry</th><th>Zones 5 and 6
Temperate</th><th>Zones 7 and 8
Cool temperate and cold climates</th></tr>
<tr><td colspan="3">• Un-shaded – un-shaded windows require a low SHGC to reduce unwanted solar heat gain and maybe a lower visible light transmission to reduce glare.
• Open area – select windows with a high opening percentage to promote natural ventilation and passive house operation.</td><td>• Seasonally shaded glazing – select high SHGC to maximise winter solar heat gain.</td></tr>
<tr><td>• Ventilation – select windows and doors that allow maximum quantity and control of ventilation.</td><td colspan="3">• Conductivity – select windows with a low U-value to reduce heat flow inward and outward as seasons change.</td></tr>
<tr><td>• Better sealing windows – will help limit unwanted hot drafts</td><td>• Shade – ensure windows are seasonally shaded to maximise passive solar opportunities.</td><td colspan="2">• Better sealing windows – will help limit unwanted cold drafts.</td></tr>
</table>

Further resources:

Window Energy Rating System (WERS) – for details about How To Select Windows (www.wers.net/werscontent/how-to-select-windows)

Your Home Technical Manual – for details about Passive Cooling (www.YourHome.gov.au/technical/fs46.html)

Wood Solutions Guide: 10 Timber windows and doors – a comprehensive guide to designing and specifying timber windows and doors

5.7 Eaves and External Shading

Direct midday sun gives the equivalent of about 1000 Watts of heat, which is similar to a single-bar electric radiant heater every square metre. In cold weather, gaining this heat through windows and on external walls is welcome but, otherwise, shade is important to a building's thermal performance for all climate types and building orientations. Shading walls is critical in hotter climates for most – if not all – times of the year.

External devices such as roof eaves, awnings, verandas, pergolas and established trees can all be used for shade; however, internal shading devices do little to reduce heat gain. Blinds and curtains can be used to block light and glare, but as they block the sun inside of the glass line, solar heat is already within the room's interior.

Working with seasonal sun

Below the Tropic of Capricorn, the sun's angle to the ground (altitude) is lower on a winter's midday than midday in summer, and it is possible to design roof overhangs and awnings to allow winter sun to penetrate northern windows and yet block northern summer sun. Correspondingly, during the longer days of summer, the sun rises south of east and sets south of west (Figure 68).

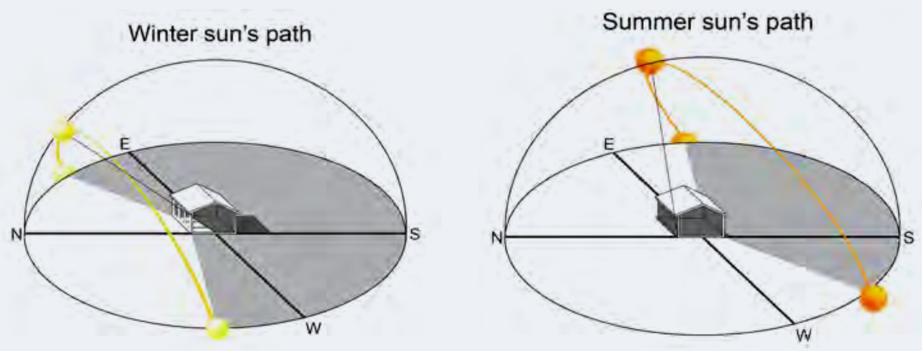


Figure 68: Seasonal sun paths. *Warm House Cool House 1995*

A simple rule of thumb to calculate the midday sun altitude angle for the winter and summer solstices in your location is:

Summer: 90 + 23 – given Latitude, e.g. Sydney: summer 90 + 23 – 34 = 79°

Winter: 90 – 23 – given Latitude e.g. Sydney: winter 90 – 23 – 34 = 33°

The angle of the sun to north is called 'azimuth'. For a given location it is possible to calculate the sun azimuth at any time of the year. However, there are many websites and apps that provide sun angle calculators and most computer-aided drafting software packages now allow buildings to be modelled showing sun paths and shading patterns. Using these tools, the shading of a house can be designed specifically for its climate and location. Figure 73 illustrates how sun angles vary from season to season in the cities listed.

5.7.1 Tips for Envelope Shading per Climate Zone

General considerations:

- ***Customise per site*** – shade the house to suit the climate type and orientation using fixed and operable shading as well as deciduous trees.
- ***Customise per facade*** – consider each facade individually and shade to exclude unwanted solar heat gain.
- ***Wanted sun*** – the welcome winter midday sun in the higher latitudes comes at a lower altitude than that of summer.
- ***Unwanted sun*** – the later afternoon summer sun comes from the west at low altitudes, which allows it to come in below eaves and awnings.
- ***Devices*** – provide large eaves, exterior window shades, verandas and pergolas, especially to the west façade.
- ***Seasonal*** – all external walls and windows should be shaded during the hotter months of the year but the shading should allow for passive solar gain during cooler months.
- ***Trees*** – plant deciduous or open evergreen trees to improve natural shading of the site, house, and outdoor spaces.

Climate specific considerations:

Zones 1 and 2 *Hot and humid*	**Zones 3 and 4** *Hot and dry*	**Zones 5 and 6** *Temperate*	**Zones 7 and 8** *Cool temperate and cold climates*
• ***Shade walls*** – fully shade all the external walls all year. • ***Evergreen trees*** –provide year-round shading to house and surrounds.	• ***Deciduous trees*** – these provide shade in summer but drop leaves to allow winter sun		
	• ***Shade windows and walls*** – fully shade all the external walls and windows during the hotter months (i.e. November to February). • ***Windows*** – allow the warming sun to provide free heating through windows during winter.		• ***Windows*** – shade northern windows in summer but allow direct winter sunshine. • ***Evergreen*** – avoid the use of evergreen trees to the north and east facades

Further resources:
Your Home Technical Manual – for details about Shading (www.YourHome.gov.au/technical/fs44.html)

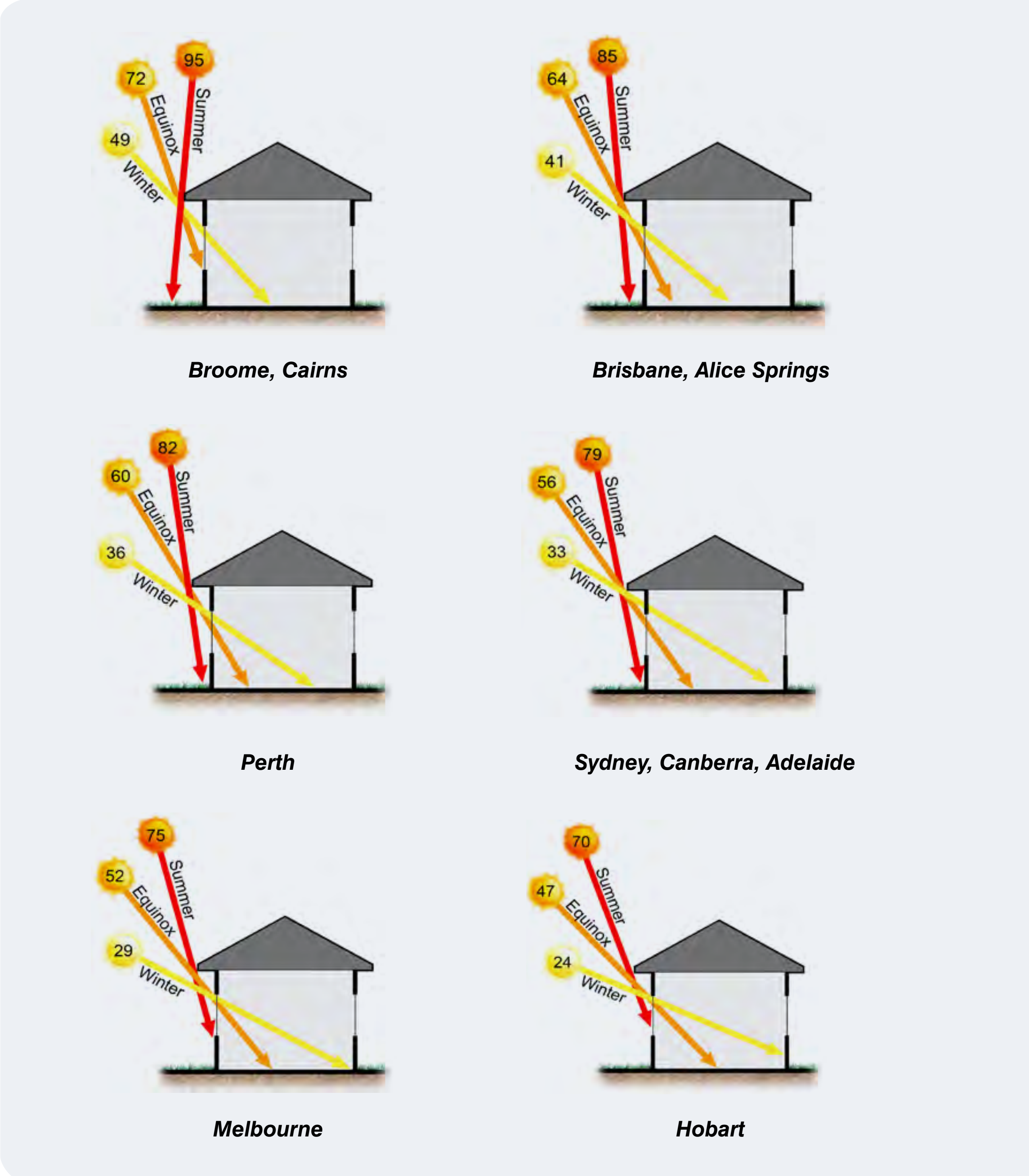


Figure 69: Sun altitude diagram.

5.8 Thermal Mass and Thermal Capacity

Thermal mass is a general term used to describe materials that are able to absorb and hold warmth (or 'coolth'). With good design, thermal mass can work in most climates to make interiors more comfortable by evening out the daily minimum and maximum temperatures. This can be used to make cool nights warmer or hot days cooler. In tropical summers, where both the day and the night time temperatures are uncomfortable, there is no value in using thermal mass to even out temperatures.

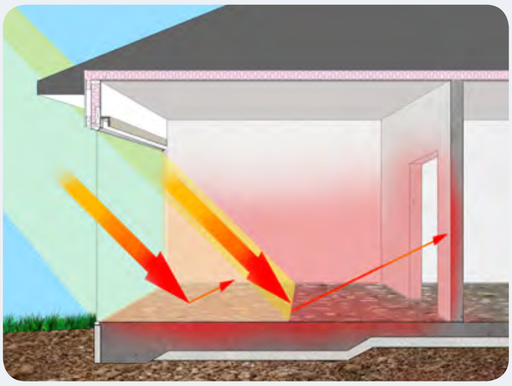
Materials with a high thermal mass, such as concrete and mass timber, are able to slowly absorb considerable amounts of heat energy. In cool climates, the thermal mass can warm up to absorb air and solar energy during the day and give this energy back to the cooler room at night. In hot climates, fully shaded thermal mass, if cool, can absorb unwanted air energy during the day and, with the use of natural ventilation, can lose it during the cooler evening and early morning (Figure 70).

In a well-designed timber house with a concrete floor, low-angle winter sun can shine directly onto a bare concrete floor, which will re-radiate out of the slab at night to warm the room. Useful thermal mass arrangements include an insulated slab on-ground, an insulated timber platform floor with a concrete topping, or an insulated high-mass timber floor or wall.

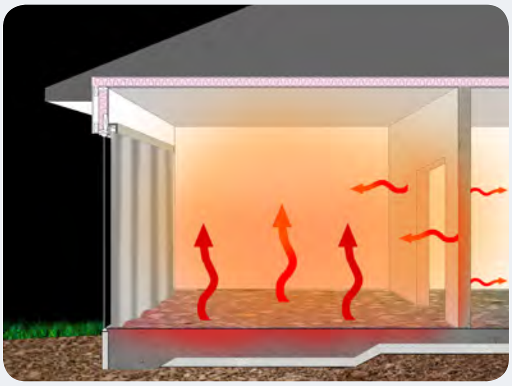
In a well-designed timber platform-floored house, partition walls can be constructed from mass-timber or clay bricks that can absorb heat in the day and, like the concrete floor mentioned above, give the energy back to the room at night. This principle operates in winter and summer. In summer, the cool walls absorb excess heat during the day and can release the heat during the cooler evening in a well-ventilated room.

If a house is poorly designed, thermal mass can hold unwanted summer heat within a house, or take too much winter warmth and make conditions uncomfortable. The type and location of thermal mass should be modelled in a House Energy Rating program to test thermal performance.

Harnessing warmth of day for warmer nights

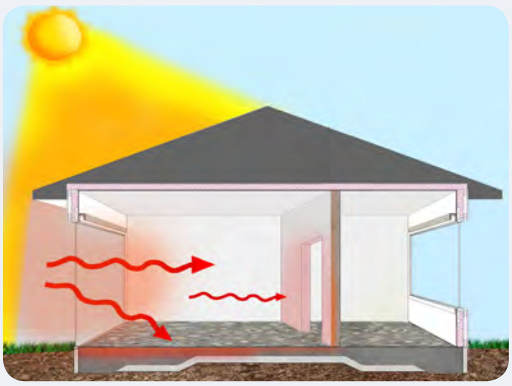


Daytime heat absorption

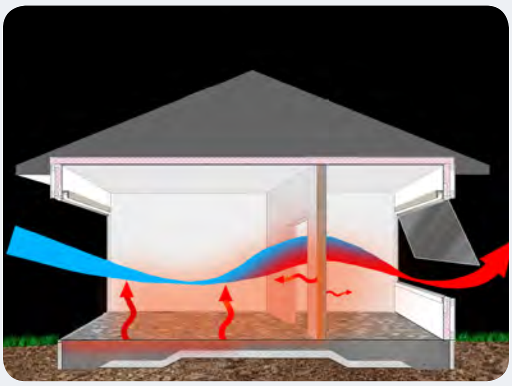


Night-time heat release

Harnessing cool of night for cooler days



Daytime heat absorption



Night-time heat release

Figure 70: Thermal mass – night-time heat release in a hot climate.

5.8.1 Tips for Thermal Mass per Climate Zone

General considerations:

- ***Expose internally*** - expose thermal mass to room interiors so that it can moderate interior temperatures.
- ***Insulate externally*** - in all climates, fully insulate or isolate the thermal mass from the exterior such as locating it in internal walls, platform floors or an insulated concrete floor.
- ***Formats*** - useful thermal mass arrangements include an insulated slab on-ground, an insulated timber platform floor with a concrete topping, or an insulated mass-timber floor or wall.

Climate specific considerations:

<table>
<tr><th>Zones 1 and 2
Hot and humid</th><th>Zones 3 and 4
Hot and dry</th><th>Zones 5 and 6
Temperate</th><th>Zones 7 and 8
Cool temperate and cold climates</th></tr>
<tr><td colspan="2">• Shade - the thermal mass should be shaded at all times as it needs to be cooler than the outside daytime air temperature to be effective.</td><td rowspan="2">• Thermal mass - can be applied to northern and southern rooms in most temperate climates.</td><td rowspan="2">• Summer use – external shading should exclude direct solar gain in summer.
• Winter use – only include thermal mass in rooms with direct winter sun or the mass might make then too cool.</td></tr>
<tr><td>• Thermal mass – is generally not helpful due to the high night-time air temperatures.</td><td>• Close-up – on hot days, strictly limit ventilation to keep interiors cool.
• Night-purge – ventilate the interior well in the cool of the night to release heat stored from hot days.</td></tr>
</table>

Further resources:
Your Home Technical Manual – for details about Thermal Mass (www.yourhome.gov.au/technical/fs49.html)
Wood Solutions Guide: Using thermal mass in timber framed buildings in Australia

5.9 Equipment and Services

A house with a House Energy Rating of 10 stars should require no heating or cooling; however, most new 6-star houses will require some form of supplementary heating and cooling.

Heating equipment suppliers may still use 'rules of thumb' principles developed when houses and other building types were uninsulated, leading to oversized – and often less efficient – equipment. House thermal performance software should be used to estimate the house's heating and cooling requirements.

Equipment efficiency

As energy efficiency regulation increases, these systems may need to be selected before a planning and building permit is issued. The efficiency of heating and cooling equipment is often referred to as its Coefficient of Performance (COP). A COP of 2.7 indicates that one unit of electricity will be used to give off 2.7 units of heat or 'coolth'. Energy star ratings simplify this process further. For more information see the Federal Government's website: energyrating.gov.au.

5.9.1 Forms of Home Heating and Cooling

Common forms of heating and cooling use either one or a mixture of radiant, conductive and convective methods:

- ***Radiant*** - radiant heaters do not require air-movement or contact as the heat 'shines' through the air, as does the heat of the sun.
- ***Conductive***-– this method heats via contact, which is often contact with air, and the heated air is then circulated around the room through convection.
- ***Convective*** - this is movement of heat carried by air, such as a common fan heater.

Heaters are commonly fuelled by electricity, gas, solar energy or wood, and cooling equipment is usually fuelled by electricity.

In most climate types, reverse cycle air-conditioners provide the most efficient form of mechanised heating and cooling. They are also the most common form of heating and cooling in Australian residential building. Air-conditioners range from units for a single room through to whole-of-house ducted systems. Common COP values range from 2.0 to 4.3. Because of how an air conditioner operates with refrigerant gases, they are often more efficient at heating air than cooling air. This results in units having different star ratings for heating and cooling operation on energy use labels. A correctly sized air-conditioner can be of great benefit in most climate types.

In hot and humid climates, a reverse cycle air-conditioner will remove moisture from the air, making the conditioned room more comfortable. However, if the system is 'wrong sized', and not enough moisture is removed from the air, condensation can form on cold surfaces inside the house and within the building fabric. In these climate types, a supplementary dehumidification system can be incorporated with the air-conditioner to reduce thermal discomfort and save operational energy. This can be very advantageous in an energy-efficient house design as there should be less need for house cooling, and removing humidity from the air may provide a house's cooling requirements.

The reverse cycle air-conditioner's action of removing moisture from the air in both the cooling and heating processes makes this method suitable for cool and temperate climates. However, in hot and dry climates, the additional removal of moisture from the air can make the room feel unpleasant.

In hot and dry climates, an evaporative cooler is the most efficient form of cooling. Moisture is added to the air, lowering its temperature, and the increased humidity significantly improves thermal comfort. Evaporative coolers have a higher COP value than reverse cycle air-conditioners.

Hydronic heating and cooling systems circulate heated or cooling liquids through floors, ceilings, ceiling mounted radiators known as 'chilled beams' and floor or wall-mounted radiators in a reticulation system. The source of energy to heat or cool the liquid may be solar, ground-sourced, a heat-pump, a fire box or a gas boiler. Each of these energy sources has differing COP values and costs of operation. The advantage of a hydronic system is that it allows for the choice of energy source and the capacity to change the energy source when prices, efficiency or technology change.

More detailed information and specifications on heaters and coolers are available from product manufacturers or installers.

Ducts in heating and cooling systems

Reverse cycle air-conditioners, hydronic systems and evaporative coolers can use ducts to circulate the conditioned air. Good duct installation requires that ducts be:

- installed straight, without unnecessary bend of joins as each bend reduces system efficiency (Figure 71)
- fully insulated to maximise the use of conditioned air, and ideally ducts should travel through insulated roof and sub-floor spaces (Figure 72)
- well sealed at each connection and join to reduce system leakage.

Systems with poorly insulated and leaky ducts can generate condensation and increase the moisture load in the roof or sub-floor spaces.

Figure 71: Duct runs. *Straight duct runs improve efficiency.*

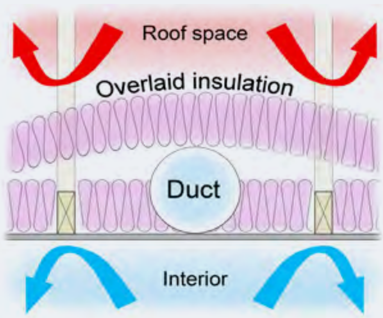


Figure 72: Duct Insulation.
Insulate ducts from the temperature extremes in the roof space.

5.9.2 Tips for Heating and Cooling per Climate Zone

Limiting artificial heating and cooling

General considerations:

- ***Good passive design*** – correct orientation, good planning for windows, shading, etc, will limit the need for artificial heating and cooling.
- ***Insulation*** – contain heat/cool and also limit the need for heating and cooling.
- ***Zoning*** – doors to separate living areas from bedrooms or other areas that do not need conditioning, such as hallways, can allow zoned conditioning and much improved energy efficiency.
- ***Sealed combustion heating*** – if wood or gas heating is installed, units should be free-standing to limit heat loss through walls, and sealed and externally flued to maximise efficiency.
- ***Efficient and correctly sized equipment*** – the design and sizing of the cooling and heating system should include a careful thermal simulation of the house to avoid under or oversized systems that cost more to operate.
- ***Straight and short services pipes and ducts*** – 30 to 50% of operational energy can be saved if ducts are carefully designed and installed. All duct runs should be short, straight, well-sealed and well-insulated without bends and 'S' shapes.

Climate specific considerations:

Zones 1 and 2 ***Hot and humid***	**Zones 3 and 4** ***Hot and dry***	**Zones 5 and 6** ***Temperate***	**Zones 7 and 8** ***Cool temperate and cold climates***
Heating Patterns			
• Intermittent in winter	• Often in winter	• Mostly in winter	• Most of the year
Heating Methods			
• Heat pump • Radiant heating • Solar thermal	• Heat pump • Radiant heating • Solar thermal	• Reverse cycle air-conditioning • Solar thermal	• Reverse-cycle air-conditioning (heat pump) • Radiant heating • Solar thermal
Cooling Patterns			
• Most of the time	• Mostly in spring, summer and autumn	• Mostly in spring, summer and autumn	• Intermittent in summer
Cooling Methods			
• Natural ventilation • Ceiling fans • Air-conditioning • Solar-thermal with absorption chiller	• Natural ventilation • Ceiling fans • Evaporative cooling • Solar-thermal with absorption chiller	• Natural ventilation • Ceiling fans • Reverse cycle air-conditioning • Solar thermal with absorption chiller	• Natural ventilation • Ceiling fans • Reverse cycle air-conditioning (heat pump)

Further resources:
Your Home Technical Manual – for details about Heating and Cooling (www.yourhome.gov.au/technical/fs62.html)
Living Greener – for details about Heating and Cooling (www.livinggreener.gov.au/energy/heating-cooling)
Equipment Energy Efficiency – www.energyrating.gov.au

6 Learning from Case Studies

6.1 Introduction

To explore the principles discussed in this Guide, the thermal performance of two generic house designs were modelled for a range of Australian climates using the NatHERS accredited AccuRate software.

Modifications tested against the base model included: building orientation, eave size, increased levels of insulation, glazing types and the addition or removal of walls.

General simulation notes

- The base design followed passive solar design practices, but shading and the addition of thermal mass were not considered.
- Some modifications had only a small impact compared to the base model. This did not indicate they were not worthwhile pursuing; however, it did illustrate that the house is a living building subject to the climate of its location.
- The importance of balancing approaches was demonstrated. For example, the simulations clearly showed that increasing floor, wall, or ceiling insulation yielded little benefit unless there was a corresponding improvement to glazing.
- The simulations showed that a lightweight house requires careful design tuning to suit the climate and location. Aspects that work well in a cool climate may be detrimental to thermal performance in a hot climate; concepts that work well in a hot and dry climate may not work well in hot and humid climates.

Key simulation results

The simulations demonstrated some distinctive and climate-specific results. These included:

- ***Downlights*** - there was a significant benefit, in all climate types, if the recessed downlights were removed.
- ***Eaves*** - for the hotter climates, the increase from no eaves to 450 mm, 600 mm and 1800 mm eaves all showed an increased thermal performance as the walls and windows were shaded.
- ***Insulation area*** - Increasing floor, wall, or ceiling insulation yielded little benefit unless there was a corresponding improvement to glazing. The increase in wall insulation was affected by the glazing area and had a more significant impact in the cooler climates.
- ***Tiled floors*** - the use of tiles in the northern dining and living area showed a positive result, as this small element added effective thermal mass to the rooms.
- ***Thermal mass*** - replacing internal stud-framed walls with mass timber walling improved thermal performance; however, once this house design approached 6 stars, the additional mass in hotter climates could hinder the effect of further improvements.
- ***Double glazing*** - the shift from single to double glazing had a significant impact.

Description	House 1 3 bedroom	House 2 4 bedroom
Summary	single-storey detached house higher glazing ration	single-storey detached house higher thermal mass (concrete slab)
Size	smaller (182 m^2)	larger (203 m^2)
Floor	suspended particleboard floor R1 insulation batts under finished with carpet on underlay and tiles	concrete slab-on-ground finished with carpet on underlay, and tiles
External walls	brick veneer (timber frame) reflective building wrap R1.0 glass wool batt R1.5 insulation	brick veneer (timber frame) reflective building wrap R1.0 glass wool batt R1 insulation
Ceiling	plasterboard R4.0 glass wool batt	
Roof	sheet metal roofing with no eaves reflective sarking	
Windows	aluminium frames single-glazed, clear glass	
Glazing	11.37% (20.7 m^2) high glazing ration	10.11% (20.5 m^2) single-glazed, clear glass

6.2 Case Study House 1

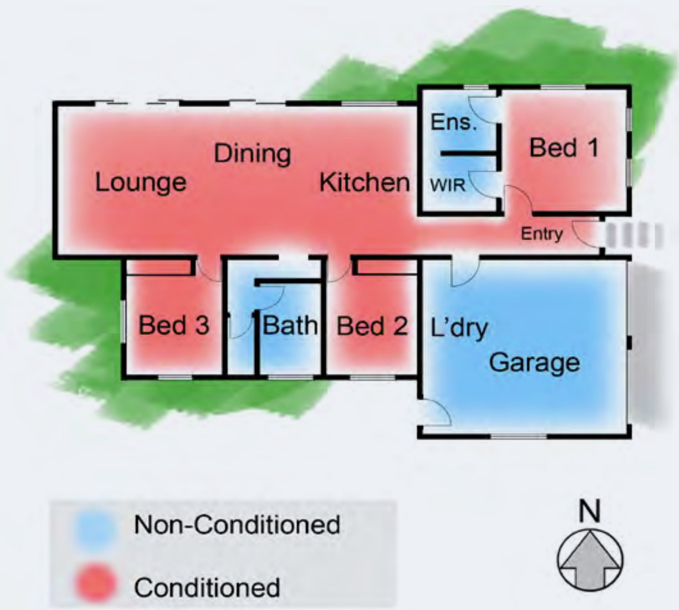


Figure 73: Plan of House 1.
Sixteen design variations were tested for House 1. The comparative impact on thermal performance has been modelled and the results recorded in Table 12.

Table 12: House 1 simulation results.

Platform Floored Case Study House	Hobart 7000 MJ/m^2.annum				Melbourne 3053 MJ/m^2.annum				Adelaide 5000 MJ/m^2.annum				Alice Springs 870 MJ/m^2.annum				Brisbane 4000 MJ/m^2.annum				Broome 6725 MJ/m^2.annum			
	Star Rating	Heating	Cooling	Total	Star Rating	Heating	Cooling	Total	Star Rating	Heating	Cooling	Total	Star Rating	Heating	Cooling	Total	Star Rating	Heating	Cooling	Total	Star Rating	Heating	Cooling	Total
Base Design, carpet, R1.0 subfloor insulation, no eaves	5.4	167.5	13.8	181.3	5.1	106.0	40.7	146.7	4.7	62.9	74.7	137.6	4.1	33.0	158.8	191.8	3.2	14.8	76.2	91.0	3.9	0.1	390.4	390.5
Base Design + 90deg change of orientation to West	5.0	185.5	15.0	200.5	4.8	117.7	42.2	159.9	4.4	69.5	77.8	147.3	3.6	40.7	182.3	223.0	2.9	18.3	84.2	102.5	3.6	0.4	410.5	410.9
Base Design + 270deg change of orientation to East	5.2	180.7	9.0	189.7	4.8	113.0	45.0	158.0	4.4	66.0	82.2	148.2	3.6	32.7	186.6	219.3	2.7	15.4	91.2	106.6	3.5	0.1	413.5	413.6
Base Design + 450 Eaves	5.3	181.8	6.5	188.3	5.1	116.2	30.1	146.3	4.9	69.4	59.0	128.4	4.6	36.3	130.3	166.6	3.9	16.8	57.0	73.8	4.8	0.1	345.4	345.5
Base Design + 600 Eaves	5.2	186.8	4.8	191.6	5.1	119.5	27.1	146.6	4.9	71.7	54.5	126.2	4.7	37.5	123.0	160.5	4.1	17.5	51.1	68.6	5.0	0.1	334.2	334.3
Base Design + 1800 Shade	4.6	219.0	1.9	220.9	4.7	141.6	19.7	161.3	4.9	87.3	41.3	128.6	4.9	48.1	100.3	148.4	4.5	22.9	38.6	61.5	5.9	0.2	288.6	288.8
Base Design no recessed down lights	5.7	152.6	14.1	166.7	5.4	96.1	40.1	136.2	4.9	56.1	73.7	129.8	4.2	28.9	157.8	186.7	3.4	12.8	74.0	86.8	4.5	0.1	358.6	358.7
Base Design + R2.5 Insulation to entire floor	5.7	154.2	15.0	169.2	5.2	98.8	43.8	142.6	4.7	59.6	77.5	137.1	4.0	32.7	163.3	196.0	3.1	14.4	80.5	94.9	3.9	0.1	391.2	391.3
Base Design + R 2.5 wall insulation	5.6	160.6	13.3	173.9	5.2	101.5	40.1	141.6	4.8	59.9	73.2	133.1	4.2	31.4	155.4	186.8	3.3	14.1	75.6	89.7	4.0	0.1	386.4	386.5
Base Design + R8 ceiling insulation	5.7	156.6	13.3	169.9	5.3	98.4	39.0	137.4	4.9	57.4	70.2	127.6	4.3	29.0	149.2	178.2	3.3	12.8	75.8	88.6	4.1	0.0	382.4	382.4
Base Design + door to air lock	5.4	167.4	13.8	181.2	5.1	106.0	40.4	146.4	4.7	62.8	74.5	137.3	4.1	32.9	158.9	191.8	3.2	14.8	76.7	91.5	3.9	0.1	391.5	391.6
Base Design + Tiles to dining, lounge and hall floors	5.3	176.3	10.8	187.1	5.0	112.2	36.0	148.2	4.8	66.3	67.1	133.4	4.4	34.4	142.4	176.8	3.5	15.6	67.1	82.7	4.2	0.1	375.3	375.4
Base Design + additional windows for cross ventilation (up to 16% floor area)	4.7	187.3	30.0	217.3	4.3	119.1	61.1	180.2	3.7	72.9	108.2	181.1	3.1	39.1	225.3	264.4	1.9	17.7	122.3	140.0	2.6	0.2	480.1	480.3
Base Design + additional windows for cross ventilation (up to 16% floor area) + 1800 Shade	4.3	237.3	3.5	240.8	4.3	154.2	26.1	180.3	4.3	96.3	54.2	150.5	4.2	53.6	130.8	184.4	3.9	25.4	46.5	71.9	5.1	0.3	329.3	329.6
Base Design + double glazing to living, dining and kitchen	5.8	155.6	10.2	165.8	5.4	97.6	34.7	132.3	5.1	57.5	64.3	121.8	4.5	30.5	138.5	169.0	3.7	13.4	65.2	78.6	4.4	0.1	361.8	361.9
Base Design + double glazing to all rooms	5.9	147.1	10.1	157.2	5.6	92.3	33.8	126.1	5.3	53.9	62.2	116.1	4.7	27.8	132.1	159.9	3.7	12.3	65.5	77.8	4.6	0.1	356.4	356.5
Base Design + added thermal mass to internal walls of northern rooms	5.6	160.9	9.9	170.8	5.4	101.1	32.8	133.9	5.2	55.4	63.8	119.2	4.9	23.6	125.4	149.0	3.7	9.9	67.4	77.3	4.2	0.0	376.9	376.9
Base Design + added thermal mass to internal walls of all rooms	5.4	169.3	9.9	179.2	5.3	106.4	31.5	137.9	5.2	58.2	61.4	119.6	5.1	23.7	119.4	143.1	3.4	10.2	74.0	84.2	4.1	0.0	383.3	383.3
Base Design + added thermal mass to Floor (mass timber)	5.8	151.4	12.0	163.4	5.5	93.9	35.9	129.8	5.2	52.7	67.2	119.9	4.5	24.3	143.9	168.2	3.6	10.1	70.1	80.2	4.2	0.0	376.0	376.0

The most significant improvements, House 1

Cool Temperate Climates (Hobart)	Temperate Climates (Melbourne)	Hot and Dry Climates (Alice Springs)	Hot and Humid Climates (Broome)
1. The change from single glazing to double glazing provided the most significant benefit by reducing outward heat flow in this cooler climate. 2. The removal of recessed downlights provided the second-greatest thermal benefit. 3. The third most significant improvement was equally shared by increasing sub-floor insulation to R2.5, increasing ceiling insulation to R8.0 and the inclusion of carefully placed thermal mass within the home.	1. The change from single glazing to double glazing provided the most significant benefit by reducing heat flow in on hot days and heat flow out on cold nights. 2. The introduction of carefully placed thermal mass provided the second most significant benefit. 3. The removal of recessed downlights and the increase of ceiling insulation up to R8.0 provided very similar thermal performance improvements	1. The most significant improvement resulted from the inclusion of thermal mass in internal partition walls. 2. The addition of 600 mm eaves and a veranda around the entire perimeter of the house to shade the house from direct solar radiation provided the second most significant benefit. 3. The change from single glazing to double glazing provided the third-greatest benefit by reducing heat flow in on hot days and heat flow out on cold nights.	1. The addition of significantly sized eaves (+600 mm) or a 1800 mm veranda around the entire perimeter of the house to shade the walls from direct solar radiation provided the greatest benefit. 2. The design and placement of operable windows to promote cross ventilation provided the second most significant benefit. 3. The removal of vented downlights and the use of double glazing provided a very similar thermal improvement.
Having a veranda around the house or increasing window area to 16% of floor area provided the most thermally uncomfortable improvements.	Increasing window area up to 16% of floor area provided most thermally uncomfortable improvement.	Increasing window area up to 16% of floor area provided most thermally uncomfortable improvement.	Rotating the building made the house more thermally uncomfortable.

6.2.1 Case Study House 1 in Hot and Humid Climate

Table 12 shows the inter-relationship between climate and effective design for thermal performance. While the House 1 base design and the individual variants could provide reasonable performance in Hobart, Melbourne and some other climates, they were generally not effective in providing adequate performance in hotter climates like Brisbane. This was due to the greater percentage of external walls relative to house floor area.

Suitable performance could be achieved in these climates but this required careful tuning of the built fabric to suit local conditions and Table 12 shows the effect on the base model's performance in Brisbane through applying variations *in combination.* These results also highlight the benefits of investigating multiple improvement options during the design process.

6.3 Case Study House 2

The design followed passive solar design practices but shading and the addition of thermal mass were not considered in the base design. In comparison to House 1, House 2 was larger, contained more thermal mass and a lower glazing ration. Eighteen design variations were tested for House 2. The comparative impact on thermal performance has been modelled and the results recorded in Table 13.

The thermal mass of the concrete slab-on-ground floor could bring thermal benefits in some situations and be thermal detriment in others. The other significant factor that improved the thermal performance of this house was the glazing ratio, which was 10.1% of the floor area. This resulted in more insulated external wall to reduce heat flow into or out of the house. The house did have some living spaces on the north that would allow the sun to warm the bare concrete floor, which could add thermal benefit in cold and some hot climates.

Key simulation results

The simulations demonstrated some distinctive and climate specific results. These included:

- ***Downlights*** – there was a significant benefit, in all climate types, if the recessed downlights were removed.
- ***Wall shading*** – for the hotter climates, the increase from no eaves to 450 mm, 600 mm and 1800 mm all showed an increased thermal performance as the walls and windows were shaded.
- ***Wall Insulation*** – increasing insulation had a more noticeable impact due to the low glazing ratio.
- ***Mass timber walls*** – a significant thermal improvement occurred when the existing internal stud partition walls were replaced with mass-timber walling.
- ***Double glazing*** – shifting from single to double glazing had a significant impact.
- ***Balance modifications*** – increasing floor, wall, or ceiling insulation needed to be balanced with a corresponding improvement to glazing and other insulation systems.

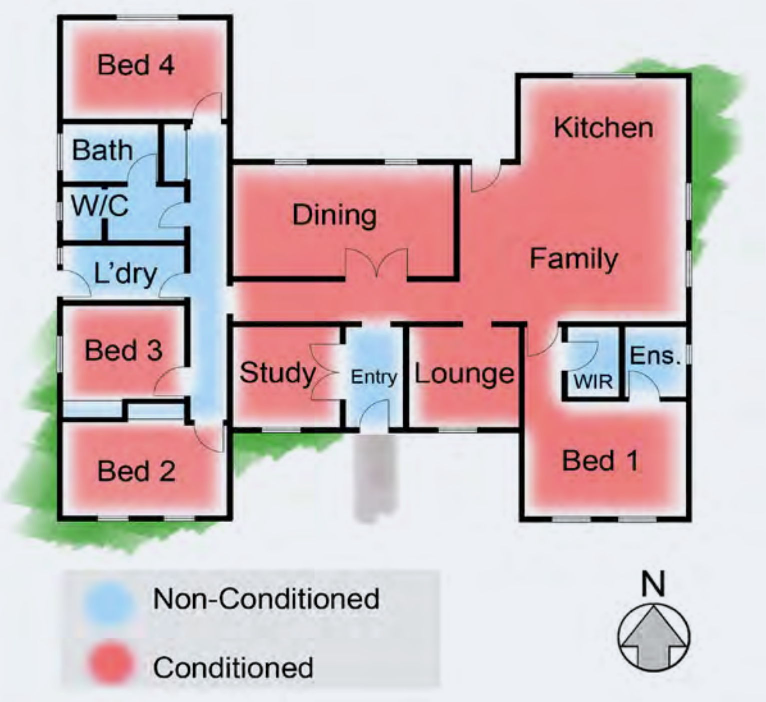


Figure 74: Plan of case study House 2.
A four bedroom house with some living areas oriented to the north.

Table 13: House 2 simulation results.

Platform Floored Case Study House	Hobart 7000				Melbourne 3053				Adelaide 5000				Alice Springs 870				Brisbane 4000				Broome 6725			
	MJ/m² annum				MJ/m² annum				MJ/m² annum				MJ/m² annum				MJ/m² annum				MJ/m² annum			
	Star Rating	Heating	Cooling	Total	Star Rating	Heating	Cooling	Total	Star Rating	Heating	Cooling	Total	Star Rating	Heating	Cooling	Total	Star Rating	Heating	Cooling	Total	Star Rating	Heating	Cooling	Total
Base Design	5.4	195.4	1.8	197.2	5.8	114.2	19.1	133.3	6.3	57.7	41.3	99.0	5.8	23.4	107.6	131.0	5.7	9.7	40.8	50.5	5.4	0.0	330.3	330.3
Base Design +90 East	5.3	203.2	3.2	206.4	5.6	119.4	22.1	141.5	5.9	60.1	47.8	107.9	5.4	22.4	123.3	145.7	5.3	9.0	47.7	56.7	4.8	0.0	365.5	365.5
Base Design +90 West	5.4	200.4	2.9	203.3	5.6	118.0	23.3	141.3	5.0	60.2	50.2	110.4	5.1	24.0	130.9	154.9	4.4	9.6	60.9	70.5	4.8	0.0	360.6	360.6
Base Design +450 Eaves	5.1	217.1	1.1	218.2	5.6	128.5	14.5	143.0	6.2	66.7	33.3	100.0	6.2	27.7	89.5	117.2	6.5	11.4	30.5	41.9	5.9	0.0	304.8	304.8
Base Design +600 Eaves	4.9	223.9	0.9	224.8	5.5	132.9	13.4	146.3	6.2	69.7	31.4	101.1	6.2	29.3	86.2	115.5	6.5	12.1	29.7	41.8	6.0	0.0	298.7	298.7
Base Design +1800 Eaves	4.4	263.6	0.9	264.5	4.9	159.9	10.1	170.0	5.7	91.3	25.0	116.3	6.3	42.9	71.7	114.6	6.3	19.3	24.5	43.8	6.4	0.0	274.4	274.4
Base Design +50 Polystyrene under Slab	5.4	195.1	1.8	196.9	5.9	113.8	18.7	132.5	6.3	57.7	40.6	98.3	5.8	23.5	104.6	128.1	5.9	9.7	40.0	49.7	5.4	0.0	326.7	326.7
Base Design no recessed down lights	5.9	177.1	1.8	178.9	6.2	102.2	18.3	120.5	6.6	50.0	40.1	90.1	5.9	19.6	104.2	123.8	6.4	7.8	35.7	43.5	5.9	0.0	302.1	302.1
Base Design +change bedroom window for cross ventilation	5.4	196.4	2.2	198.6	5.8	115.0	21.3	136.3	6.1	58.1	45.5	103.6	5.5	23.6	116.6	140.2	5.4	9.7	43.3	53.0	5.2	0.0	341.2	341.2
Base Design + door to air lock	5.4	195.4	1.8	197.2	5.8	114.2	19.0	133.2	6.3	57.7	41.3	99.0	5.8	23.4	107.6	131.0	5.7	9.7	40.8	50.5	5.4	0.0	330.3	330.3
Base Design + door to hall way	5.4	195.4	1.8	197.2	5.8	114.2	19.0	133.2	6.3	57.7	41.3	99.0	5.8	23.4	107.6	131.0	5.7	9.7	40.8	50.5	5.4	0.0	330.3	330.3
Base Design + Remove wall between dining and family	5.4	195.1	1.7	196.8	5.9	114.0	19.1	133.1	6.2	57.7	41.6	99.3	5.7	23.4	109.3	132.7	5.7	9.8	40.8	50.6	5.4	0.0	331.3	331.3
Base Design + Study and Bedroom 4 interchanged	5.5	191.6	3.3	194.9	5.8	112.5	21.9	134.4	6.1	56.6	46.6	103.2	5.6	22.5	115.6	138.1	5.4	9.4	44.2	53.6	5.2	0.0	342.9	342.9
Base Design + R 2.5 wall insulation	5.9	174.4	1.6	176.0	6.3	100.3	17.1	117.4	6.7	49.9	36.4	86.3	6.2	19.3	96.9	116.2	6.1	7.8	38.2	46.0	5.7	0.0	316.6	316.6
Base Design + thermal mass internal walls to north facing windows (140 block grout filled)	5.4	201.5	1.1	202.6	5.9	118.1	13.9	132.0	6.6	55.7	32.7	88.4	6.8	17.6	80.6	98.2	6.7	5.7	34.8	40.5	5.7	0.0	317.8	317.8
Base Design + thermal internal wall to all rooms (140 block grout filled)	5.3	208.3	0.6	208.9	5.8	122.7	10.7	133.4	6.7	57.3	27.8	85.1	7.2	16.3	68.5	84.8	6.9	5.1	33.4	38.5	5.5	0.0	324.1	324.1
Base Design + R8 ceiling insulation	5.7	185.6	1.5	187.1	6.1	107.7	15.3	123.0	6.7	52.7	33.5	86.2	6.4	19.8	87.7	107.5	6.3	7.7	35.9	43.6	5.7	0.0	316.1	316.1
Base Design + double glazing to living rooms and dining	5.6	188.9	1.5	190.4	6.0	109.6	17.2	126.8	6.4	54.0	39.3	93.3	6.0	22.2	100.3	122.5	6.1	9.0	37.8	46.8	5.6	0.0	321.1	321.1
Base Design + double glazing to all rooms	5.9	177.7	1.4	179.1	6.2	102.6	16.1	118.7	6.7	50.9	35.7	86.6	6.3	19.8	94.0	113.8	6.3	8.0	36.1	44.1	5.8	0.0	312.9	312.9

The most significant improvements, House 2

Cool Temperate Climates (Hobart)	Temperate Climates (Melbourne)	Hot and Dry Climates (Alice Springs)	Hot and Humid Climates (Broome)
1. The most significant improvement resulted from the increase in external wall insulation. 2. Two items provided an equal second-best improvement, namely; the removal of recessed and ventilated downlights and the use of double glazing instead of single glazing. 3. The third most significant improvement was provided by increasing ceiling insulation to R8.0.	1. The most significant improvement resulted from increasing external wall insulation. 2. The adoption of double glazing instead of single glazing. 3. The removal of ventilated and recessed downlights.	1. The most significant improvement resulted from the inclusion of thermal mass in internal partition walls. 2. The increase in ceiling insulation to R8.0 provided the second-greatest thermal benefit. 3. Three actions equally provided the third most significant thermal benefit: the addition of 600 mm eaves around the entire perimeter of the house; increasing the R value of wall insulation to R2.5; and the use of double glazing rather than single glazing.	1. The addition of significantly sized eaves (+600 mm) or a 1800 mm veranda around the entire perimeter of the house shaded the walls from direct solar radiation and provided the greatest benefit. 2. The removal of vented and recessed downlights provided the second-greatest thermal benefit. 3. Four actions equally provided the third most significant thermal benefit: increasing wall insulation; increasing ceiling insulation; the adoption of double glazing instead of single glazing; and the careful placement of internalised thermal mass.
Having a veranda around the house provided the most thermally uncomfortable improvement.	Adding a veranda to this house design in Melbourne provided the most thermally uncomfortable improvement.	Rotating the building made the house more thermally uncomfortable.	Rotating the building made the house more thermally uncomfortable.

7

Thermal Comfort and Technical Principles

This section defines and describes concepts that are critical to achieving improved thermal performance with timber-framed construction in various climate zones.

7.1 Thermal Comfort

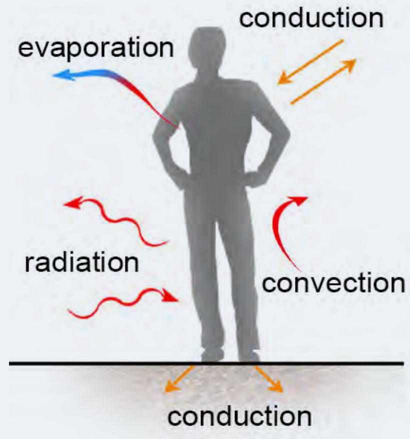


Figure 75: Personal energy balance.

Shows how heat is gained and lost from the body.

Thermal comfort is when a person feels thermally content psychologically within a particular space or environment. The way humans perceive thermal comfort is a mix of physical, physiological, psychological and other immediate influences. Subconsciously, our body attempts to regulate its temperature. Consciously, humans relate to three key variables: direct temperature, moisture and airflow, and their impact on the comfort or discomfort that our body feels. The body feels comfortable within a narrow range of these variables.

7.1.1 Mean Radiant Temperature

The mean radiant temperature is a key factor in thermal comfort as it may provide more than 60% of the thermal experience of the environment in a room. The mean radiant temperature is the average surface temperature of the floor, walls, windows, doors and ceiling, relative to position in a room (Figure 76). For example, when sitting in a room that has relatively still air, the surface temperatures of the floor, walls, windows and ceiling provide the major controlling influence on the sense of thermal comfort.

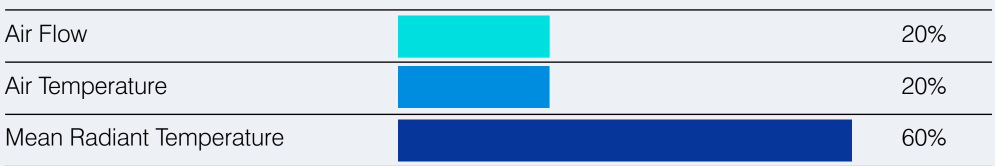


Figure 76: Relative impact of mean radiant temperature on personal comfort.

Humans might improve their thermal comfort by adding or removing clothing, becoming more or less active, or seeking shelter. Good residential design will aim for thermal conditions within a given room for specific likely activities at specific periods in a day.

It is essential to consider the room's function as function this influences the types of physical activity likely in the space, the times it is likely to be occupied and the expected internal energy loads. Thermally comfortable conditions required for sleeping are different to those required for periods of physical activity in the kitchen and they are required at different times.

7.2 Thermal Conductivity, Conductance and Resistance

Thermal conductivity (k) - is the quantity of heat that travels through a material resulting from a temperature difference between opposite faces.

- Thermal conductivity (k) is measured in Watts per metre per degree Kelvin (W/m.K)

Thermal conductance (C) - is the speed at which heat travels through a material caused by a temperature difference between the opposite surfaces.

- Thermal conductance (C) is measured in units of Watts per square metres per degree Kelvin (W/(m2.K))
- thermal conductance is thermal conductivity per thickness
- (The symbol K is for Kelvin. A temperature change of 1° Kelvin is equivalent to a temperature change of 1° Celsius).
- A high C value indicates a good conductor and a low C value indicates a good insulator

Thermal resistance (R) - A material's thermal resistance is its capacity to reduce or impede heat flow, which is the opposite of thermal conductance.

- R values are measured in units of (m2.k)/W
- high R value indicates a good insulator, and a low R value indicates a good conductor
- thermal resistance is the inverse of conductance (R-value = 1 / C).

Material	Thickness mm	Thermal Conductivity (K) W/(m K)	Thermal Conductance (C) W/(m^2·K)	Thermal Resistance (R-value) (m^2.k)/W
Glass Wool Insulation	90	0.038	0.42	2.381
Softwood	90	0.100	1.11	0.901
Hardwood	90	0.160	1.78	0.562
Paper Faced Plasterboard	10	0.160	16.00	0.063
Clay Brick Extruded	110	0.614	5.58	0.179
Glass	4	1.000	250.00	0.004
Steel	90	45.3	503.33	0.002
Aluminium	90	221.0	2455.55	0.000

Table 14: Thermal properties of common building materials.
There is considerable difference in the thermal conductivity and thermal conductance values of common building materials.

Beware when reviewing product R-values: some building materials include R-values that might not be for the given product, but for the whole of the building system once this item is installed. For building assemblies, the thermal resistance value of each material is added together to obtain a total R-value for the built system. When measuring the thermal resistance of a built assembly such as that for a timber-framed brick veneer wall shown in Table 15, the value of the more stable air film immediately adjacent to each face of the wall is also included for its insulative effect.

Thermal transmittance (U) – has the same formula as thermal conductance (W/(m^2.K) although whereas thermal conductance provides a value for each material, thermal transmittance is the overall co-efficient of heat transfer and must include the values for surface film conductance in the calculation.

Thermal Resistance of an External Wall Assembly		
System	**Thickness mm**	**Thermal Resistance (R-value) (m^2.k)/W**
Inner surface film coefficient	n/a	0.12
Internal plasterboard lining	10	0.06
R2.0 insulation in frame	n/a	2.00
Reflective foil with 40 air space	35	0.67
Clay brick veneer	110	0.18
Outer surface film coefficient	n/a	0.06
Total		3.09
Calculating the amount of heat coming through a wall		
Example of heat transfer of wall on a 33°C day if 25°C internally		
If the temperature inside the wall is 25°C (T_{inside}) and the exterior temperature is 33°C ($T_{outside}$), the heat flow inwards can be calculated as shown below:		
Heat Flow *inwards*	= U-Value x (T outside –T inside) = 1/3.09 x (33-25) = 0.32 x 8 = 2.56 Watts/m^2	

Table 15: Heat flow example.

7.3 Thermal Emittance and Reflectance

While dark materials tend to heat up in the sun, light coloured and reflective materials stay cooler. Thermal emittance is the heat emitted by a material's surface, which is measured relative to a black surface at the same temperature, to give an emittance value between 0 and 1. A dark surface may have an emittance of 0.9, while a reflective roof foil product may have an emittance of 0.05.

A material with a high emittance ratio will absorb excess energy and release stored energy to its surroundings as the surroundings cool, whereas a material with a very low emittance ratio will absorb and release very little energy. This is an important factor when considering the use of thermal capacitance, discussed below.

While reflective foils might be highly conductive of heat, their low emittance allows them to reflect heat. Several building materials are now marketed as reflective insulation. Most need to be installed with still airspace between the reflecting material and adjacent materials.

7.4 Thermal Capacitance

The temperature swings between warm days and cooler nights can be evened out with the addition of thermal mass to the building interior to store heat. The ability of materials to absorb and store heat from a warmer surrounding environment and release it when the surrounding environment cools is known as its thermal capacitance or thermal mass.

Thermal mass can also help in hot climates by storing night-time 'coolth' and easing daytime internal temperatures. In turn, this can reduce the reliance on energy-intensive heating and cooling systems. If properly applied, this process can be of benefit in some warm and cool climates. If applied poorly, it can make a cool house harder to heat, and store unwanted heat in a warm house.

Figure 78 and Figure 78 illustrate this concept. They show the temperatures measured inside an unconditioned room in buildings that are similar in arrangement but are of three different constructions:

- a very lightweight building – with the lowest thermal capacitance
- a lightweight building
- a medium-weight building – with the highest thermal capacitance.

During warm periods, the temperatures inside the building with the highest thermal capacitance were cooler than the very lightweight building, and warmer during cooler periods.

In cold climates, thermal mass can be used to store the days warmth and release it in the cooler evening. Conversely, in hot climates, well-shaded thermal mass can absorb unwanted heat in the day and this mass can cool again overnight through the use of night-time cross ventilation. For this to be effective, night-time temperatures must be significantly lower than the daytime temperatures – otherwise the use of thermal mass can retain heat keeping interiors excessively warm.

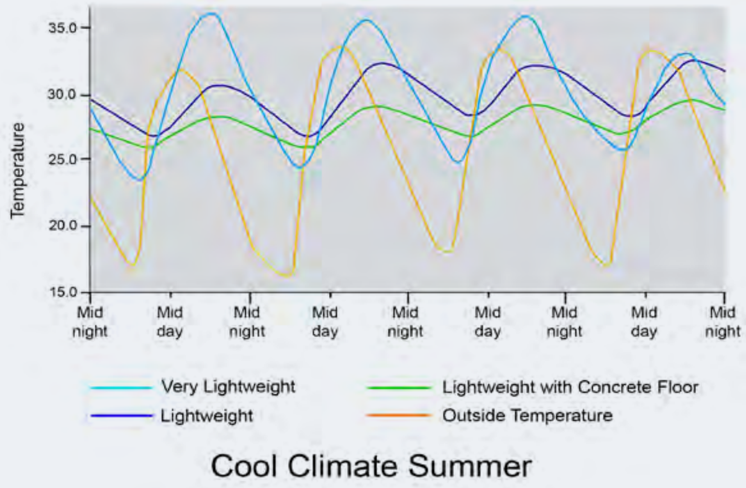


Figure 77: Thermal mass during a warm period (Launceston 2007).

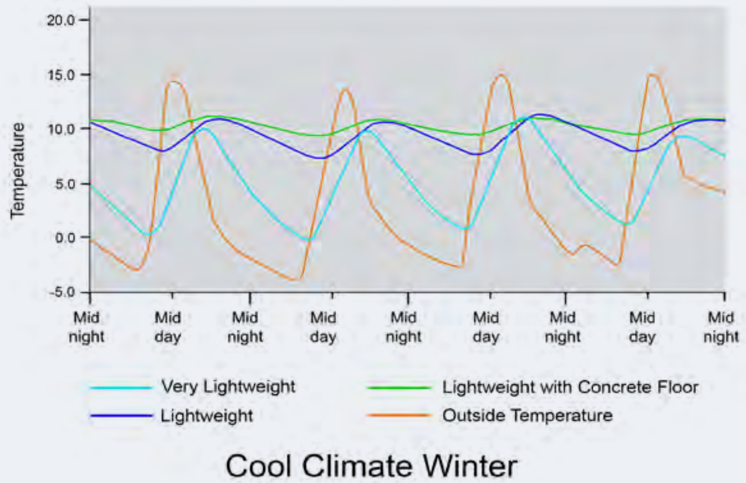


Figure 78: Thermal mass during a cool period (Launceston 2007).

Note: the most even temperatures come from the most thermal mass, keeping the internal temperatures closer to the comfort zone.

All materials within the home provide some form of thermal capacitance. Table 16 lists the values for some of these materials. Note that softwood has better properties than plasterboard and hardwood has very similar properties to clay brick. To date, timber-framed buildings have not been designed to effectively harness the ability of timber to store heat. Recent research shows the value of incorporating mass timber construction within a timber-framed house for effective thermal storage.

Material	**Density Kg/m³**	**Specific Heat J/(kg.K)**	**Thermal Capacitance kJ/m³.K (1m³)**
Air	0	1	0
Glass wool insulation	12	840	10
Paper faced plasterboard (6.8kg/m²)	680	1090	741
Softwood (pine)	500	1630	815
Hardwood (Euc. Obliqua)	780	1630	1271
Clay brick extruded	1700	800	1360
Concrete	2300	840	1932
Aluminium	2700	877	2367
Steel (AISE-SAE 1020)	7860	490	3851

Table 16: Thermal capacitance values for common building materials.

8

Acronyms

AS	Australian Standard
ACH	Air changes per hour
COP	Coefficient of Performance
DTS	Deemed to Satisfy the requirements of the NCC
HERS	House Energy Rating Software
NatHERS	Nationwide House Energy Rating Scheme
NCC	National Construction Code. This includes the Building Code of Australia or BCA
R-value	Thermal resistance value
SHGC	Solar Heat Gain Co-efficient
WERS	Window Energy Rating Scheme

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