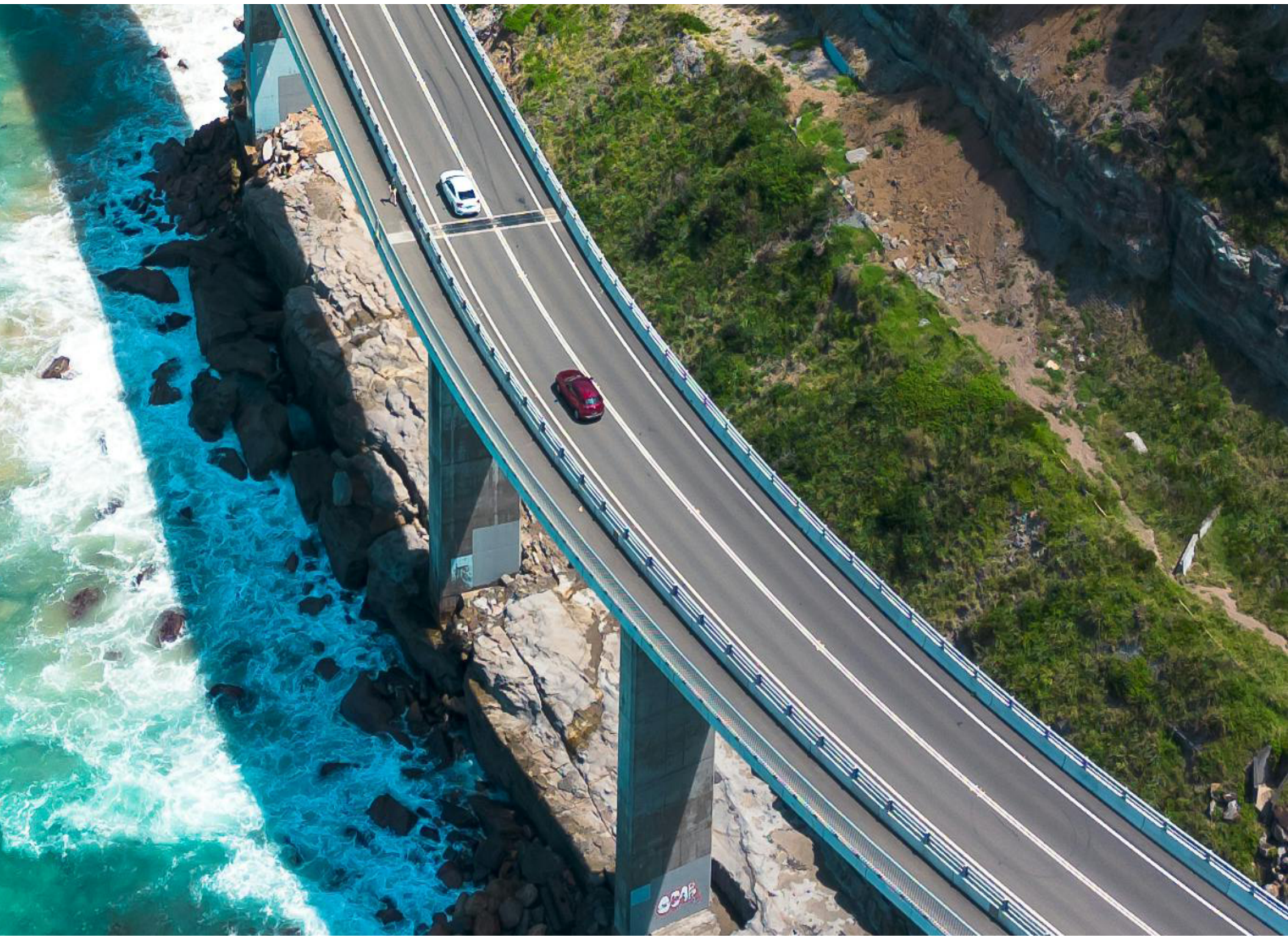
GUIDE

CEMENT CONCRETE & AGGREGATES AUSTRALIA

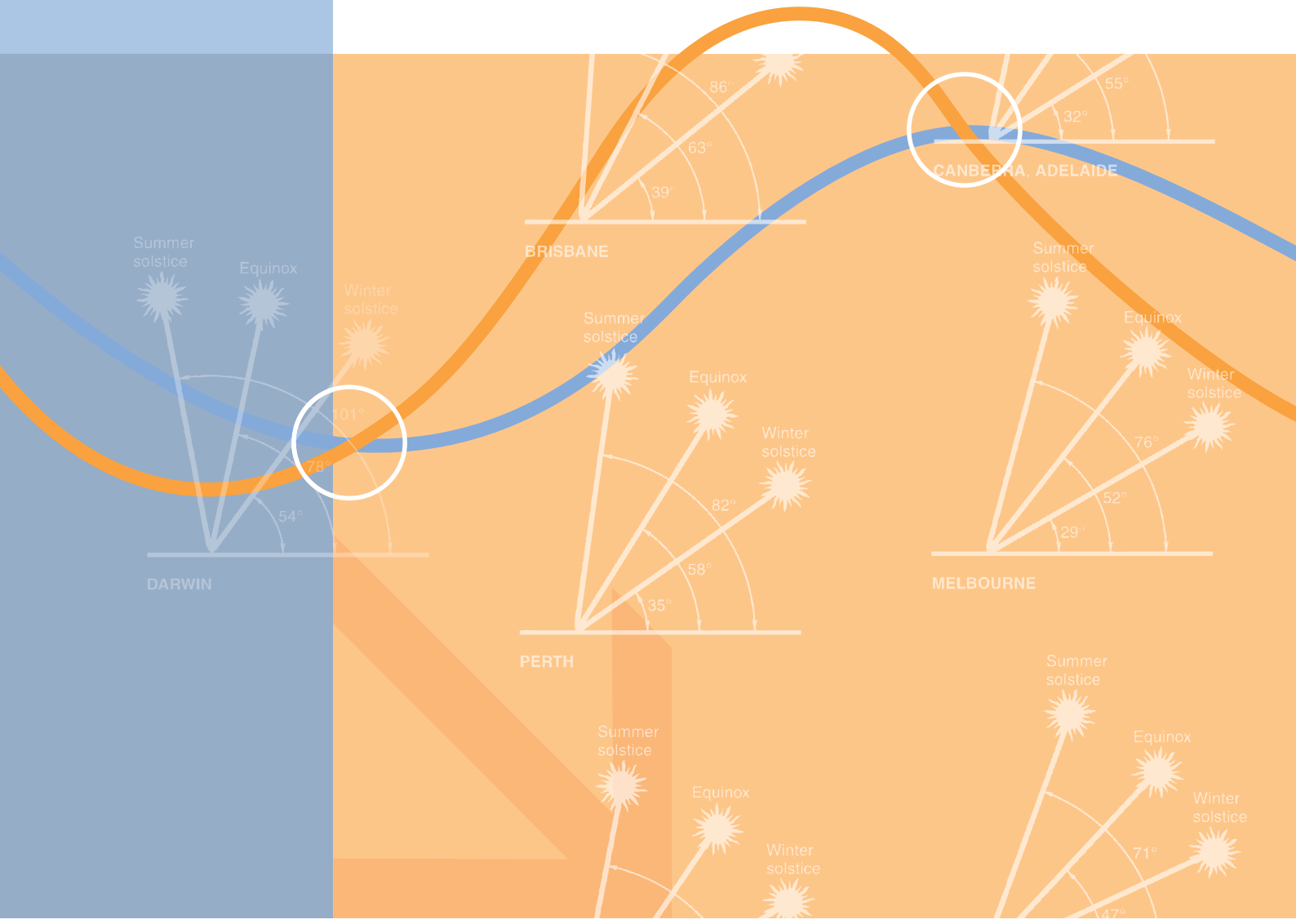
Climate-Responsive House Design with Concrete



This publication has been prepared by Cement Concrete & Aggregates Australia (CCAA) as general industry information only. It is not intended to provide engineering, technical, legal or other professional advice and must not be relied upon as a substitute for project-specific or professional advice. While reasonable care has been taken in preparing this publication, CCAA does not guarantee that the information is complete, accurate or current. Standards, regulations, technologies and industry practices may change over time. Users are responsible for independently assessing the relevance and accuracy of the information for their particular circumstances and obtaining appropriate professional advice where required. To the maximum extent permitted by law, CCAA disclaims all liability arising from use of or reliance on this publication.

CCAA T58

Climate-responsive house design with concrete



CEMENT CONCRETE
& AGGREGATES AUSTRALIA

Climate-responsive house design with concrete

Cement Concrete & Aggregates Australia

First published November 2007

CCAA T58

© Cement Concrete & Aggregates Australia 2007

Except where the Copyright Act allows otherwise, no part of this publication may be reproduced, stored in a retrieval system in any form or transmitted by any means without prior permission in writing from Cement Concrete & Aggregates Australia.

The information provided in this publication is intended for general guidance only and in no way replaces the services of professional consultants on particular projects. No liability can therefore be accepted by Cement Concrete & Aggregates Australia for its use.

DESIGN AND LAYOUT Helen Rix Design

TECHNICAL ILLUSTRATION TechMedia Publishing Pty Ltd

ISBN 978-1-877023-21-7

Cement Concrete & Aggregates Australia is a not-for-profit organisation established in 1928 and committed to serving the Australian construction community.

CCAA is acknowledged nationally and internationally as Australia's foremost cement and concrete information body – taking a leading role in education and training, research and development, technical information and advisory services, and being a significant contributor to the preparation of Codes and Standards affecting building and building materials.

CCAA's principal aims are to protect and extend the uses of cement, concrete and aggregates by advancing knowledge, skill and professionalism in Australian concrete construction and by promoting continual awareness of products, their energy-efficient properties and their uses, and of the contribution the industry makes towards a better environment.

Cement Concrete & Aggregates Australia
ABN 34 000 020 486

CCAA OFFICES

SYDNEY OFFICE:
Level 6, 504 Pacific Highway
St Leonards NSW Australia 2065
POSTAL ADDRESS:
Locked Bag 2010
St Leonards NSW 1590
TELEPHONE: (61 2) 9437 9711
FACSIMILE: (61 2) 9437 9470

BRISBANE OFFICE:
Level 14, IBM Building
348 Edward Street
Brisbane QLD 4000
TELEPHONE: (61 7) 3831 3288
FACSIMILE: (61 7) 3839 6005

MELBOURNE OFFICE:
2nd Floor, 1 Hobson Street
South Yarra VIC 3141
TELEPHONE: (61 3) 9825 0200
FACSIMILE: (61 3) 9825 0222

PERTH OFFICE:
45 Ventnor Avenue
West Perth WA 6005
TELEPHONE: (61 8) 9389 4452
FACSIMILE: (61 8) 9389 4451

ADELAIDE OFFICE:
Greenhill Executive Suites
213 Greenhill Road
Eastwood SA 5063
POSTAL ADDRESS:
PO Box 229
Fullarton SA 5063
TELEPHONE: (61 8) 8274 3758
FACSIMILE: (61 8) 8373 7210

EXTRACTIVE INDUSTRIES OFFICE
PO Box 243
Henley Beach SA 5022
TELEPHONE: (61 8) 8353 8151
FACSIMILE: (61 8) 8353 8151

TASMANIAN OFFICE:
EXTRACTIVE INDUSTRIES OFFICE
PO Box 246
Sheffield TAS 7306
TELEPHONE: (61 3) 6491 2529
FACSIMILE: (61 3) 6491 2529

WEBSITE: www.concrete.net.au

EMAIL: info@ccaa.com.au

Contents

Introduction 1

Ecologically sustainable development 1

Orientating the design process

- General 2
- The building life cycle 2
- Energy 3
- Water 3
- Waste 3
- Biodiversity and specifying materials 3
- Thermal comfort 4

Climate-responsive design

- General 5
- Australian climate zones 5
- Analysing climate data 6
- Orientation and sun control 7
- Ventilation and air velocity 9
- Mass 9
- Zoning 10
- Landscape and microclimate 11

Case studies and design guide for major climate zones

- General 12
- ZONE 1 Tropical: Darwin 12
- ZONE 2 Sub-tropical: Brisbane 15
- ZONE 3 Hot arid summer, warm winter: Alice Springs 19
- ZONE 5 Warm temperate: Sydney, Adelaide, Perth 21
- ZONE 6 Mild temperate: Melbourne + ZONE 7 Cool temperate: Canberra, Hobart 25

Bibliography 27

Figures

Figure 1 Stages of the building life cycle **3**

Figure 2 ASHRAE 55 2004 Acceptable operative temperature ranges for naturally conditioned spaces **4**

Figure 3 Climate zones based on temperature and relative humidity **5**

Figure 4 Monthly diurnal averages plotted with adaptive comfort zone for naturally ventilated buildings in Brisbane **6**

Figure 5 Eaves overhang chart **8**

Figure 6 Control of ventilation in a hot climate **9**

Figure 7 Zoning for hot humid climates **10**

Figure 8 Case study design for tropical climate **13**

Figure 9 Bar chart showing the environmental impact of using high mass material vs lightweight cladding in Darwin house **15**

Figure 10 Air temperature frequency distribution in Darwin house **15**

Figure 11 Case study design for sub-tropical climate **16**

Figure 12 Bar chart showing the environmental impact of using high mass materials in Brisbane house **18**

Figure 13 Air temperature frequency distribution in Brisbane house **18**

Figure 14 General design for hot arid climates **19**

Figure 15 Case study design for warm temperate climate **20**

Figure 16 Modified section of project house to improve solar access and ventilation **21**

Figure 17 Illustrations of construction type **23**

Figure 18 Environmental comparison of various construction – environmental impacts over a life cycle of 50 years (cradle to grave) **24**

Figure 19 Bar chart indicating thermal comfort **24**

Figure 20 General design for mild and cool temperate climates **25**

Figure 21 Direct gain heating cycle **26**

Figure 22 Insulation of cavity wall in severe cold climate areas **26**

Figure 23 Slab-edge insulation in cold-climate areas **26**

Introduction

This publication covers the role of concrete in climate-responsive house design for each of Australia's climate zones. It provides a resource to designers for the development of a design solution for a particular climate type, including the choice of materials, effective passive design for solar control and ventilation. Most importantly, through detailed analysis it provides a strategic approach to sustainable design by identifying the biggest impacts and outlining design responses. This reduces the complexity of sustainable design objectives and highlights the issues that must be addressed to move towards sustainable residential building. The sustainability of the building is considered over its life. The publication draws on detailed case studies to illustrate climate-responsive design. The case studies were conducted by Cement Concrete & Aggregates Australia (CCAA) over the past five years.

The houses illustrated in this document were designed by Peter Poulet of the NSW Government Architect's Office.

Ecologically sustainable development

'Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs'
Brundtland Report 1987

This definition provides a broad overall objective. The challenge of meeting sustainable development can be influenced by the current environmental impacts of the building industry.

This publication takes a strategic approach to guide architects to actions that give the greatest shift towards sustainable development.

The environmental impact of the construction industry

The construction industry has a large impact on the environment and is responsible for roughly 40% cent of all resource consumption and 40% of all waste production (including greenhouse gas emissions).

du Plessis et al 2001, also see Malin et al 1995

Resource consumption and waste production over the building's life cycle triggers a number of environmental problems such as loss of arable land, release of toxins into the biosphere, deforestation, and noise and dust pollution.

du Plessis et al 2001

Orientating the design process

GENERAL

This section provides a broad view of sustainable development to orientate the design process and targets.

The environmental considerations in Australian building codes focus heavily on the thermal performance of the building envelope. This emphasis is appropriate because the building form and fabric have a long-term impact and are important responsibilities of the architect. However, improved thermal performance of the envelope falls well short of sustainable energy use let alone sustainable development. Although often receiving minor attention, the hot water system can have much greater impacts on climate change. For example, a gas-boosted solar hot water system can be one of the most effective ways of improving the energy performance of the household.

THE BUILDING LIFE CYCLE

The architect is in the position of creating a structure that may last many generations. To assess sustainability, the structure's impacts need to be considered over this time frame. The life-cycle energy use of a building includes that needed for material extraction, production, construction, operation, maintenance, waste management, and resource recovery at the end of the building's life. The design of the building can affect all stages in the building's life cycle **Figure 1**.

A broad range of indicators is needed to measure the potential environmental impact of a building. Energy, water and waste are three common indicators that capture important resource flows for buildings. Other indicators also reflect the potential effect of emissions on human and ecosystem health. Based on a life-cycle approach, the following areas are a starting point in considering sustainable design.

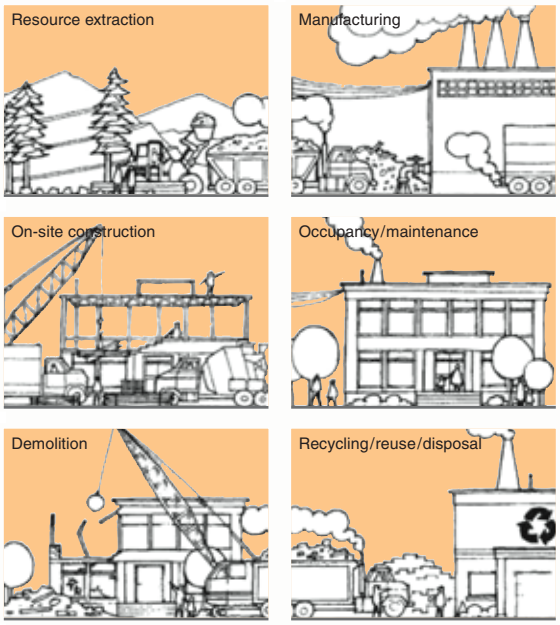
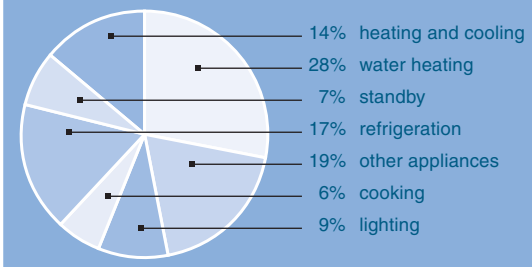


FIGURE 1
Stages of the building life cycle

Life cycle energy

Heating and cooling represent only a portion of the greenhouse gas emissions within a household, typically about 14%.



Greenhouse gases from home energy use
[Australian Greenhouse Office]

In 1993–94 less than 5% of Australian households used solar energy to heat water. The majority (62%) used electricity while most of the remainder used mains gas (31%) (Australian Bureau of Statistics www.abs.gov.au).

Solar hot water systems, efficient refrigerators and other appliances should be essential for new households and a focus for retrofitting existing housing stock.

>>

ENERGY

In respect of environmental impact, energy is often considered in terms of global warming potential as well as the use of non-renewable resources. This impact can be addressed through greater efficiency as well as changing to renewable energy sources. Renewable or 'green' energy is increasingly available through the grid and can reduce global warming potential and non-renewable energy use.

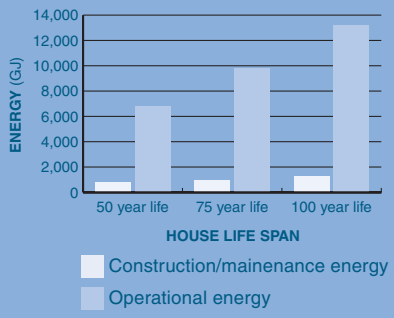
Gas-boosted solar hot water systems can also play an important part in reducing the amount of energy used, as are efficient appliances. The location of the house and modes of transport should also be considered. See the box **Life Cycle Energy** for information on energy efficiency and the importance of operational energy.

A climate responsive design, including passive solar winter heating is also important and is perhaps the one area where the architect has greatest control.

>> Based on CCAA LCA studies of houses using a range of construction types, energy used to produce materials to make the house itself (embodied energy) is generally less than 20% of the operational energy used for a house over a fifty-year life. Materials with high embodied energy used in much greater quantities than usual for housing can have a bigger effect. In general, specification of materials should focus primarily on other impacts where materials are the biggest contributor, such as biodiversity.

From a planning perspective, households also use a lot of energy for transport – this can vary greatly from household to household depending on the location of the house.

Construction vs operational energy
[www.concrete.net.au]



WATER

The water use for a household needs as much attention as energy-efficient design, especially where water resources are limited. Many government agencies promote water efficiency through water-efficient fixtures and rainwater tanks. In addition, native vegetation that requires less water should also be considered for sustainable design. Water-efficient fixtures also have the benefit of reducing energy consumption for water heating.

WASTE

Reducing waste needs to consider both waste generated by the household as well as waste created at the end of the building's life. A well designed system for managing household waste can make it easier to sort and store materials for composting, reuse and recycling. A house that can be dismantled and the elements reused also reduces demolition waste at the end of its life. The quantity of waste generated during the use of a house is often about the same as all the waste created through demolition at the end of a 50-year building life.

Waste from the construction process is generally small in comparison. However, waste for the production of materials can be much greater than all other waste streams combined. The production of each kilogram of building material can result in several kilograms of waste. This includes waste from materials extraction (such as mineral waste and mining over-burden) and can vary greatly for the production of the same material. In some cases it can be relatively benign or can be toxic and present a major waste problem. It is therefore difficult to specify materials according to waste impacts without information on production processes and waste criteria being more readily available.

BIODIVERSITY AND SPECIFYING MATERIALS

Some environmental impacts for buildings are difficult to quantify but are very important for sustainable development. To avoid 'compromising the ability of future generations to meet their needs', the architect must take a proactive approach to manage the potential impact. For example, the source of raw materials is rarely known on a building site and is usually dictated by cost. The architect should specify materials from known sustainable sources and check that these materials arrive on site. Materials that appear 'natural' can have large impacts on the ecosystem from which they are sourced. Mining operations can also affect adjacent ecosystems, especially in areas where environmental regulation is poor. Protecting biodiversity should be the primary focus in specifying materials rather than energy – see the box **Life Cycle Energy**.

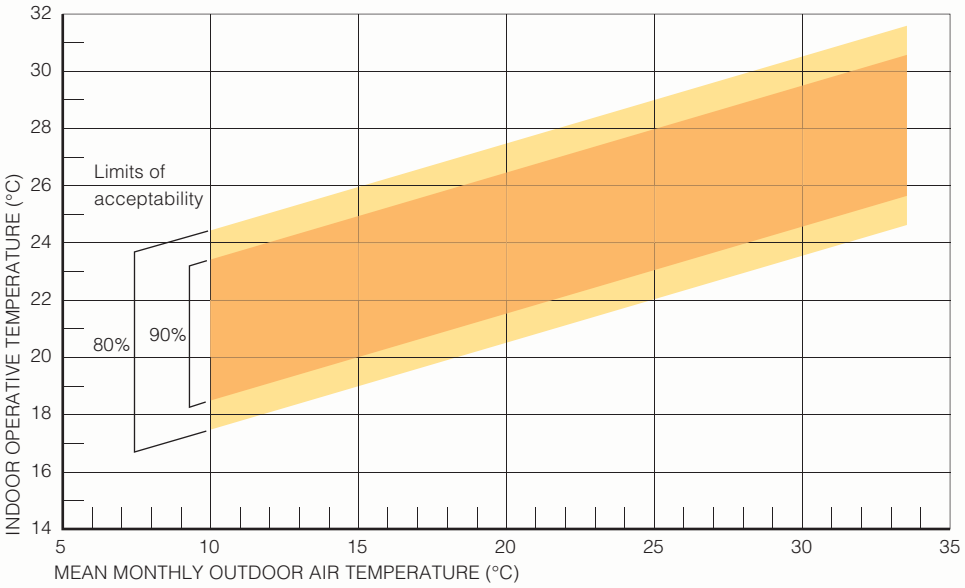


FIGURE 2

ASHRAE 55 2004 Acceptable operative temperature ranges for naturally conditioned spaces

THERMAL COMFORT

Heating and cooling energy is not necessarily the dominant use of energy by a household. However, the comfort of occupants is a primary function of a building and a major determinant of the material used for the building envelope and of its form – see the box **Life Cycle Energy**.

ASHRAE Standard 55 2004 *Thermal Environmental Conditions for Human Occupancy* presents thermal comfort limits for naturally ventilated spaces. Field studies show that people adapt to conditions as shown in the chart reproduced in **Figure 2**.

For example, in February in Sydney the mean monthly outdoor temperature is 22.6°C. Entering the above chart from the 'mean monthly outdoor air temperature' axis and using the 80% acceptability gives indoor *operative* temperatures of about 21°C to 28°C. Using the winter month of July mean monthly outdoor temperature of 11.9°C gives *operative* temperatures of about 18°C to 25°C. This includes the effect of humidity and assumes that the occupant can freely adjust clothing and is engaged in near sedentary activities.

Data on air temperature is freely available from the Bureau of Meteorology website (www.bom.gov.au/climate/averages/). The mean monthly outdoor air temperature can be calculated from the average of the mean maximum and mean minimum air temperature. A summer and winter calculation give the range of values expected for the location. The ASHRAE 55 2004 Standard specifies that this method can be applied to mean outside air temperatures between 10°C and 32.5°C.

The *operative temperature* is a combination of air and radiant temperature and can be estimated as the average of the two when a person is sedentary, not in direct sunlight and exposed to wind velocities less than 0.2 m/s.

Radiant temperature is calculated from the surface temperatures of the materials in the building. In many cases, radiant temperature will be very similar to the air temperature because the surfaces in the building are affected by the air temperature. Differences occur for surfaces of windows and massive elements. For example, in cold months, a large glass area of one fifth the floor area can give a mean radiant temperature 3°C less than the indoor air temperature (page 8, A52 *Radiant Heating and Cooling* ASHRAE Handbook, 1991). This lowers the operative temperature by about 1.5°C. The converse is true in warmer months – large glass areas can increase the mean radiant temperature above the indoor air temperature. In hot climates the temperature of the ground can be lower than the air temperature. A ground-connected slab can be used to lower the operative temperature, because it allows the occupant to radiate heat to the large cool surface of the slab.

The use of comfort limits should be guided by a notion of discomfort. Close to the comfort limit most people will consider it comfortable and some will consider it mildly uncomfortable. At a large distance from the comfort limit most people will consider the conditions very uncomfortable. This is particularly important for hot climates where it is difficult to lose heat from the body. The comfort limits are a starting point for building design. The architect must then consider factors such as radiation and air movement combined with building form and material properties to improve thermal comfort.

Climate-responsive design

GENERAL

Thermally massive materials such as concrete are generally advocated as part of passive design approach in temperate and arid zones. This is reflected in building codes and the abundant literature available for passive solar heating. This section also considers the use of thermally massive materials to improve thermal comfort in tropical areas. It follows a zoned or 'hybrid' approach with high mass connected to the ground in the lower floor to act as a heat sink to minimise daytime extremes. Building occupants would use different parts of the building at different times to optimise their comfort.

AUSTRALIAN CLIMATE ZONES

The following climate zones as identified in the Building Code of Australia are based upon temperature and relative humidity **Figure 3**.

ZONE 1 Tropical, high humidity summer, warm winter eg Darwin

ZONE 2 Sub-tropical, warm humid summer, mild winter eg Brisbane

ZONE 3 Hot arid summer, warm winter eg Alice Springs

ZONE 4 Hot arid summer, cool winter eg Oodnadatta

ZONE 5 Warm temperate eg Sydney, Adelaide and Perth

ZONE 6 Mild temperate eg Melbourne

ZONE 7 Cool temperate eg Canberra, Hobart

ZONE 8 Alpine eg Snowy Mountains

The climate zones that incorporate the major population centres are considered in detail. In addition, tropical and sub-tropical climates are covered to illustrate how concrete can contribute to sustainable and climate-responsive design in these zones. Only general information is provided for hot arid climates where the benefits of the use of massive materials are well established.

FIGURE 3

Climate zones based on temperature and relative humidity [Building Code of Australia]

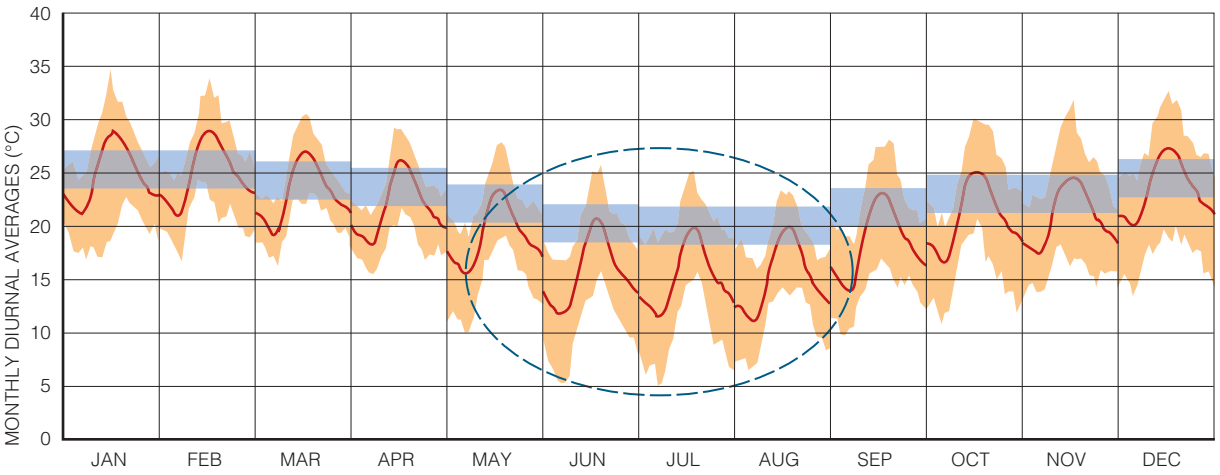


FIGURE 4

Monthly diurnal averages plotted with adaptive comfort zone for naturally ventilated buildings in Brisbane [Weather Tool software]

ANALYSING CLIMATE DATA

This section indicates how climate data analysis can be used as the basis for appropriate climate responsive design strategies generally and to design appropriate shading specifically. Analysis of the different times of the year and the relationship between the comfort zone and the outdoor conditions provides a strategy for design. In some climates, heating and cooling are required at different periods of the year while others require only heating or only cooling.

A good source of summary climate data is freely available from the Bureau of Meteorology website (www.bom.gov.au/climate/averages/). **Figure 4** shows an example of such climate data graphed in the Weather Tool software (www.squ1.com).

Figure 4 shows the times of year when the effective temperature (orange) is above or below the comfort zone (blue) for naturally ventilated buildings in Brisbane. In May, June, July and August the effective temperature falls below the comfort zone, some heating will thus be needed (circled with dashed line). The other months are warm, with November, December, January and February being the hotter months. Brisbane climate averages from the Bureau of Meteorology show that the mean maximum is less than 30°C for all months of the year. On average there are approximately 50 days per year when the temperature is above 30°C, 3.5 days per year above 35°C and very rarely exceeds 40°C.

In the case study for Brisbane described later, emphasis was given to keeping cool. It was reasoned that greater discomfort would occur in peak summer than in the mild winter. This was reflected in the design by the choice of dates for shading and allowing sun into the house. Up to 1 May all sun was excluded from the building. This means that sun was also be blocked from 11 August due to the symmetry of the sun's movement about the solstice. As can be seen circled with a dashed line in **Figure 4**, this means that in part of August the effective temperature may fall below the comfort zone and there will be no sun to improve conditions. However, sun will enter the building from 1 May to 11 August to improve comfort.

ORIENTATION AND SUN CONTROL

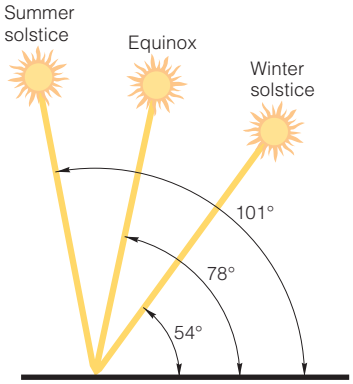
Orientation and sun control is a basic design consideration for climate-responsive design. The change in sun angles over the year allows the shading to be designed to allow sun to enter the building in winter and be excluded in summer. In locations such as Darwin, shading will be required for all times of the year; in June, the sun will even hit a south-facing wall if shading is not provided.

The chart in **Figure 5** provides a quick reference to the appropriate eaves overhang. Sun control on the east and west elevations of the building should also be considered. Low-angle sun that hits the north and east facade also needs consideration but is more effectively controlled with vertical shades or external shutters. The Eaves Overhang Chart in **Figure 5** gives a co-efficient of 0.95 for 1 May for Brisbane. This means that a north-facing wall 2.7 m high will need an eaves overhang of at least 2.57 m to be shaded up until 1 May. Additional shading will be required for low-angle morning and afternoon sun.

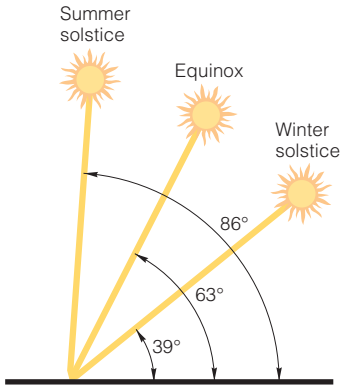
Typical sun altitude angles at 12 midday for northern facing walls for major Australian cities

	Summer solstice 22 December	**Equinox** 21 March and 23 September	**Winter solstice** 21 June
Sydney, Canberra, Adelaide	79	56	33
Melbourne	76	52	29
Brisbane	86	63	39
Perth	82	58	35
Darwin*	101	78	54
Hobart	71	47	24
Alice Springs	90	67	43

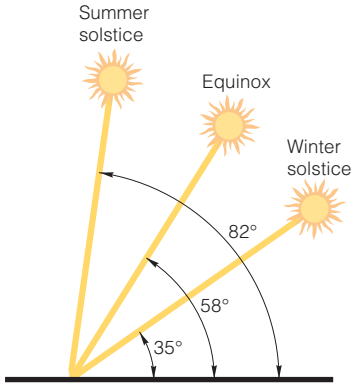
** in summer the sun is in the southern sky*



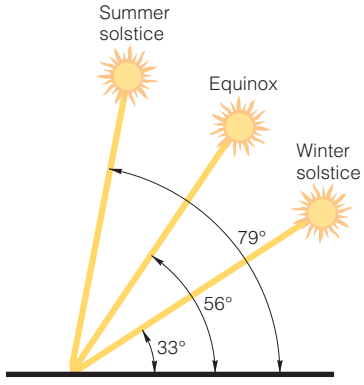
DARWIN



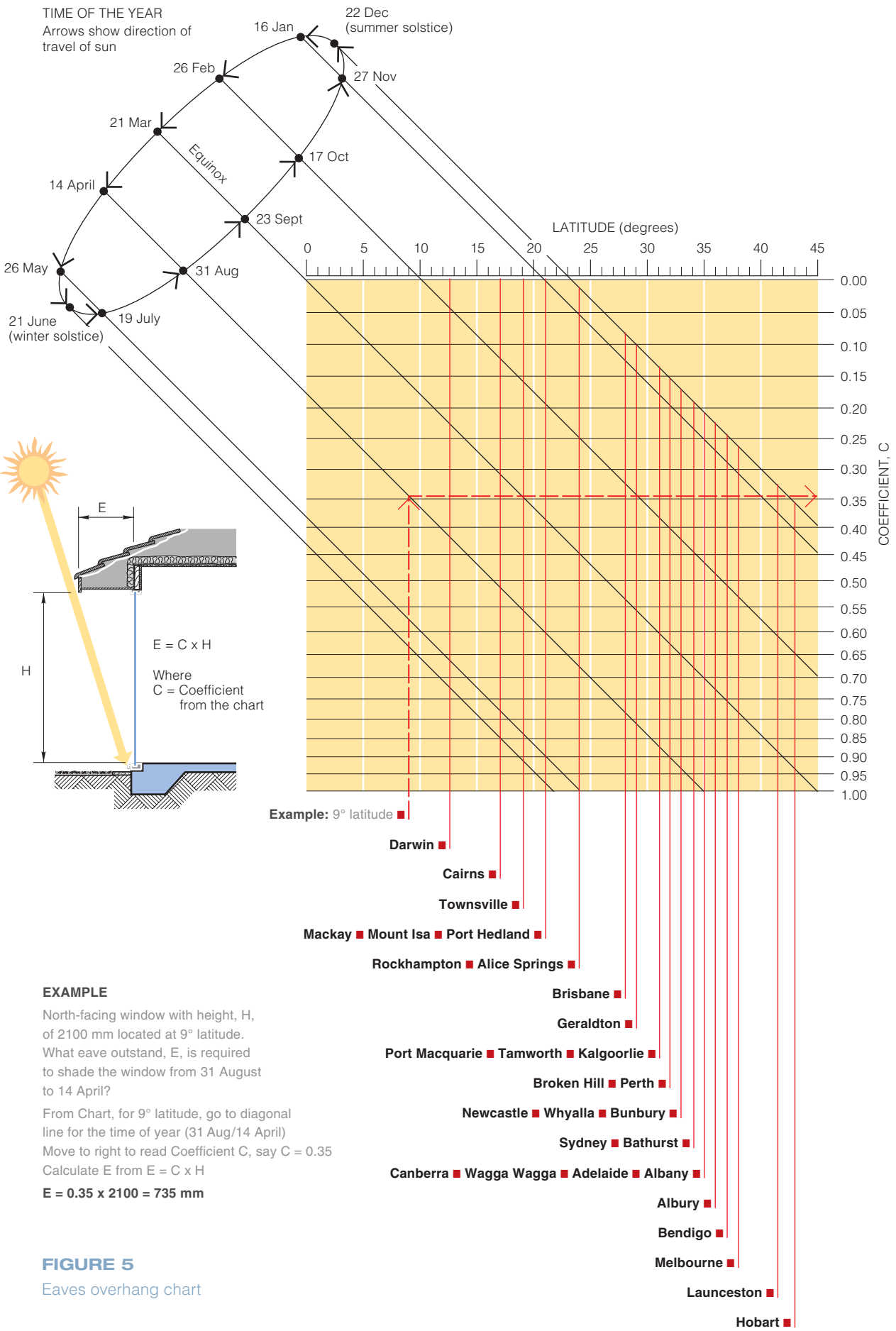
BRISBANE



PERTH



SYDNEY



EXAMPLE

North-facing window with height, H, of 2100 mm located at 9° latitude. What eave outstand, E, is required to shade the window from 31 August to 14 April?

From Chart, for 9° latitude, go to diagonal line for the time of year (31 Aug/14 April) Move to right to read Coefficient C, say C = 0.35 Calculate E from E = C x H

E = 0.35 x 2100 = 735 mm

FIGURE 5

Eaves overhang chart

VENTILATION AND AIR VELOCITY

Air velocity can have the effect of reducing the perceived temperature by 2°C or more. Air change is also important for shedding heat from the building. However, to avoid heating the building when outdoor temperatures are greater than indoor temperatures, natural ventilation should be restricted until the inside temperature reaches the outside temperature Figure 6. This is especially in places where it is noticeably cooler at night, such as in Brisbane and other temperate climates where the dwelling can be kept cool longer into the day by restricting ventilation. In cases where night temperatures drop below comfort limits care should be taken to prevent the building from becoming too cold. Fans should be used to provide air movement when windows are closed or conditions are still.

Orientation for control of solar radiation should generally take precedence over access to prevailing breezes. However, building form can be used to maximise cross ventilation using narrow floor plans (only one room in width), and wing-walls or landscaping to channel breezes. High ceilings, raked ceilings and vertical space allow heat to stratify and escape. High and low ventilation openings and ceiling fans assist large convection cycles and increased air movement. These strategies can be seen in the Brisbane and Darwin case studies.

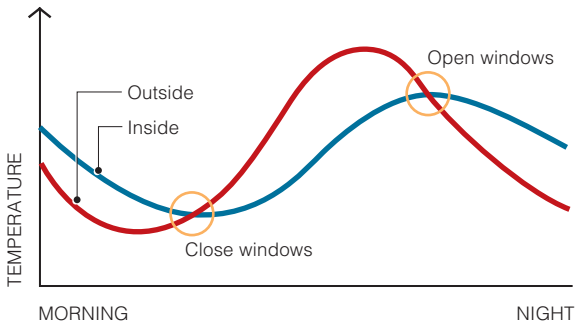


FIGURE 6
Control of ventilation in a hot climate

Air movement and comfort in Darwin

Air velocity makes conditions more comfortable in a hot humid climate at the higher of air velocities that can be achieved with, for instance, ceiling fans, the perceived temperature may be up to 6°C cooler than the actual air temperature. With even the more modest air velocities due to natural cross ventilation, for example, outside conditions of 31°C can be perceived as up to 1–2°C cooler, bringing them within the comfort zone.

MASS

Thermally massive materials have the ability to 'even out' temperature extremes. In colder climates this can be combined with additional heat from the sun to improve thermal comfort. In hotter climates, heat from the sun should be excluded and mass connected to the ground to act as a heat sink and to improve comfort during the hottest part of the day. In both cases, extreme conditions can be modified and the comfort improved.

Another important factor of mass is its surface temperature and the flow of heat from the body. In hot climates, a ground slab can draw radiant heat from the human body and improve thermal comfort. This effect is captured in the concept of the operative temperature used to define the comfort zone for naturally ventilated buildings.

Thermally massive materials used in building elements that are not ground-coupled such as walls will be more responsive to the diurnal variation when cooled by night purge ventilation. In Brisbane, this effect helps to keep the building cool in summer, see Figure 6. In Darwin, the difference between night and day temperatures is only about 5–7°C and the effect will be marginal.

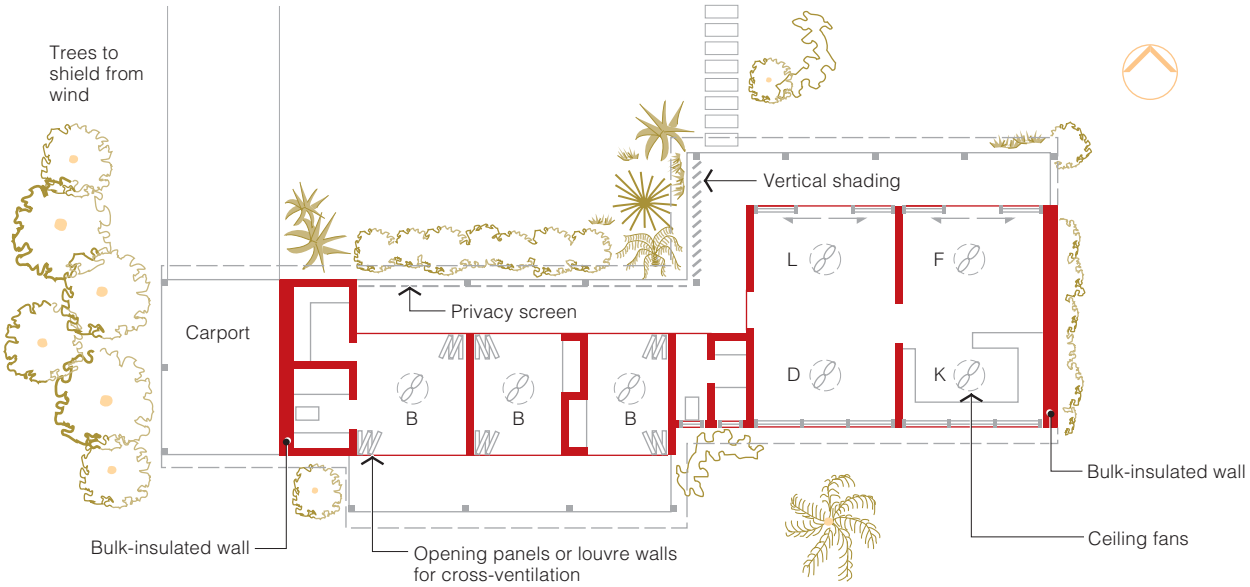


FIGURE 7
Zoning for hot humid climates

Use of thermally massive materials to improve comfort in tropical climates

In a hot humid climate with little seasonal variation, thermally massive materials can reduce daytime maximum temperatures. The slab-on-ground can be used to moderate temperatures on hot days.

In addition, walking barefoot on a concrete or tiled slab will result in a cool feeling as the body conducts heat to the slab.

ZONING

In hot humid climates, living areas should be located at ground level to take advantage of ground-coupled mass and moderation of daytime peak temperatures; bedrooms can be on the ground floor also but in a separate zone as shown in **Figure 7**. Alternatively, bedrooms should be upstairs to take advantage of lower night-time temperatures and to capture prevailing breezes. Such bedrooms should be generally of lightweight construction because mass will not be ground-coupled or act as a heat sink.

In climates where passive heating is required for winter, rooms can be located according to heating needs. Living areas are usually located to the north to improve daytime comfort. On sites where a longer east-west axis is not possible, a second storey can be used to increase the number of rooms with a northern aspect.

LANDSCAPE AND MICROCLIMATE

Landscaping is very important for good thermal comfort within the house, especially in hot climates. Planting reduces the amount of solar radiation reaching the ground and creates a microclimate around the building. Attention is also required for re-radiation off hard surfaces which can bypass shading intended for direct radiation. A good microclimate can reduce radiation and provide cooler air surrounding the building, promoting heat loss from the building and providing cooler air for ventilation. For example, air temperature under the shade of a tree can be 4°C lower than the general ambient air temperature above a grassed surface. However, perhaps more important is the need to avoid surfaces that dramatically increase the ambient air temperature. The air temperature above an asphalt surface in the sun is approximately 52°C; above a concrete surface, 42°C (La Roche et al 2001). If the preheated air then passes into the building, it would obviously make thermal conditions unbearable.

The use of vegetation for shading is particularly useful on the east and west facades where eaves overhangs are less effective. Landscaping can also be used to channel predominant breezes through the building.

In colder climates vegetation can serve as a wind break and reduce the rate of heat loss from the building fabric.

Native vegetation that has a low water demand should be used.

Sustainable developm
development that mee
needs of the present v
compromising the abil
future generations to
their own needs' 'Sust
development is develo
that meets the needs
present without compr
the ability of future ge
to meet their own nee

Case studies and design guide for major climate zones

GENERAL

This section focuses on tropical, sub-tropical and warm temperate climates with reference to case studies. General guidance is given for other climate zones focusing on direct and indirect heat gain systems.

Life cycle assessment

Life cycle assessment was carried out using LCAid software and the NSW Department of Commerce (previously DPWS) Life Cycle Inventory (LCI) database. The LCI database was compiled between 1995 and 2000 by the Environment Design Unit, a specialist LCA group within DPWS. The database contains all Australian data collected and compiled in accordance with the International Standard ISO 14040 *Environmental Management – Life Cycle Assessment – Principles and Framework* and stored in the Boustead model.

ZONE 1 TROPICAL: DARWIN

The design rationale adopted in this project for house design in the tropics was to minimise the periods of greatest discomfort during the day. The body can acclimatise to a certain point but high temperature and humidity make it difficult to lose heat in order to maintain thermal comfort. In Darwin, although the maximum temperature rarely exceeds 35°C it is very common for it to exceed 30°C and to be coupled with high relative humidity. This means that it will be common for thermal comfort, as defined by ASHRAE 55, to be at its limits for part of the day even with good passive design. Thermal comfort for sleeping is also important but is more achievable as temperatures generally fall to their lowest at night time. The use of fans is important to improve thermal comfort by air movement.

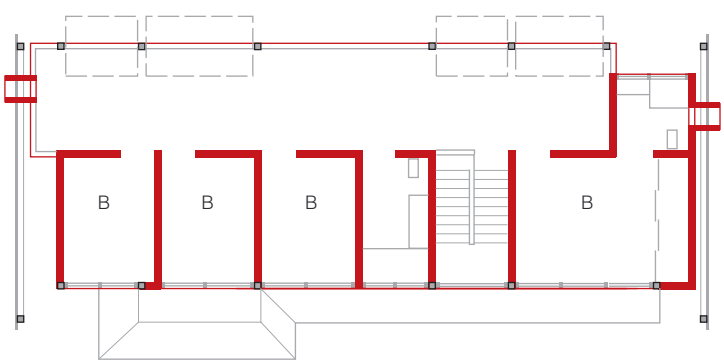
Sustainable design to improve thermal comfort

Orientation and zoning

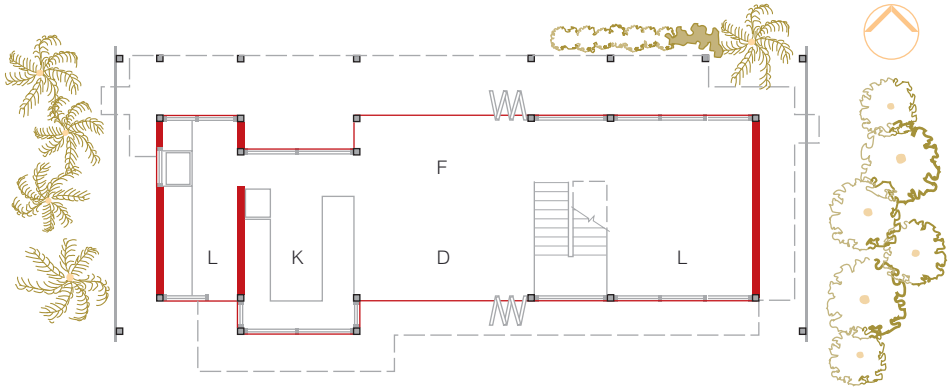
- Orientated with the long axis running east-west to provide effective shading and access to predominant breezes from the north-west.
- Bedrooms located upstairs to provide maximum access to cooling breezes and to provide a sleeping area separate from other zones that may have gained heat during the day.
- Only foil insulation in bedroom ceiling to avoid radiant heat gain.

Ventilation – *design features to ensure maximum ventilation when the internal temperature is higher than that outside*

- Shallow floor plan of one-room width to allow maximum cross ventilation.
- Louvres from floor to ceiling – openings of approximately 65% of the floor area.
- A minimum floor-to-ceiling height of 2.7 m – higher in bedrooms with raked ceilings.
- Vertical space for upward movement of heat from ground floor (internal stairs), which vents to outside living spaces.
- Raked ceiling in bedrooms assists by increasing stratification and allowing hotter air to be out of the occupied zone and more easily ventilated, eg by ridge vents.
- Ceiling fans for physiological cooling when there is no breeze.



FIRST FLOOR PLAN



GROUND FLOOR PLAN

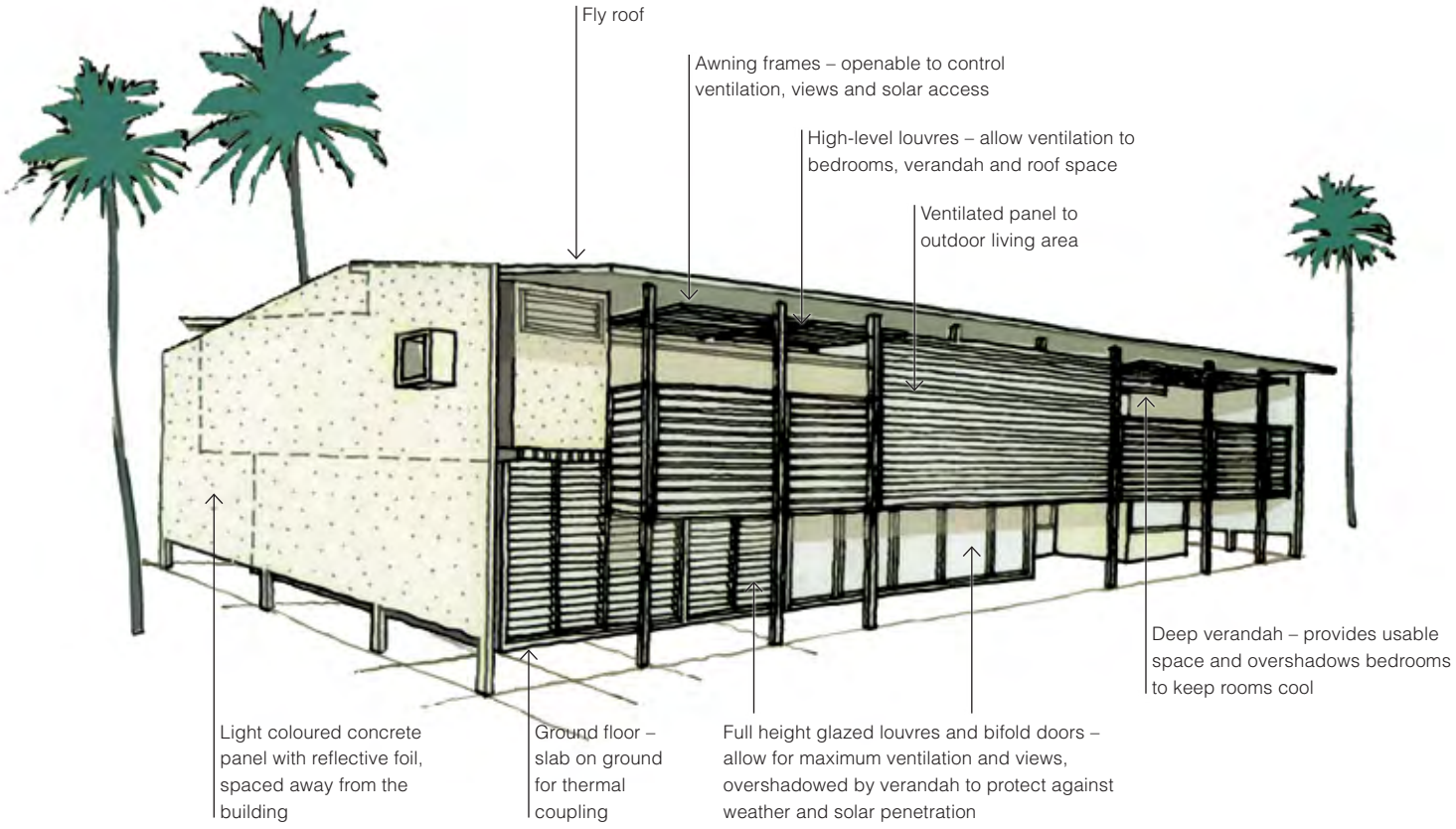


FIGURE 8

Case study design for tropical climate

- Single loaded planning to facilitate cross ventilation
- Concrete mass to ameliorate temperature fluctuations
- Panel system allows for prefabrication/systems construction

- Louvres are part of a convective ventilation loop utilising high and low level openings to exchange internal air.
- Kitchen with bay window to increase ventilation of cooking, refrigeration and other heat sources.
- Air cavity between ceiling and roof is permanently ventilated (fly roof).

Radiation and ventilation – *design features to block radiant heat gain and vent any heat gain from the building*

- Fly roof with reflective foil to block radiant heat and to allow breeze and roof pitch to vent roof heat gains.
- Wing walls with reflective foil 1 m from the building to completely shade east and west facades and to channel predominant breeze through the building. (On the windward side of the building, the north-facing wall extends to the screen to ensure the breeze is channeled through the building.)
- Balcony roof split to vent heat gain and avoid passing heat into adjacent rooms.
- Opaque white louvres from floor level to 900 mm and from 2100 mm to ceiling to reduce diffuse radiation gain while still allowing ventilation (the amount of glazing is less than 25% of the floor area).
- 'Garage door' adjustable shading to block diffuse radiation and provide semi-enclosed balcony space, louvred for ventilation.

Radiation – *design features that control radiant heat gain*

- Ground-coupled mass to absorb radiant heat from occupants.
- Complete shading of the building fabric for 'summer' and 'winter' sun.
- Vertical fins for low angle 'winter' and 'summer' sun – this shades all north- and south-facing windows AND walls from morning and afternoon sun due to window placement.
- All fixed shading is insulated to avoid radiant heat gain at openings.

Materials and water

- Work to standard dimensions for cladding and stud framing to reduce waste and increase reusability of construction elements. Simple window and door schedule to fit into standard dimensions.
- Water collection from roof (stored between the wing wall and the building fabric or combined with a solar hot water system on the western facade).

Life cycle assessment

Life cycle assessment results of a house designed using the principles outlined above utilising thermal mass in the ground floor and external walls (concrete slab on ground and concrete walls) are presented below. The results are presented in comparison with a typical design using lightweight fibre cement cladding. The results are also presented in environmental impact categories.

The design for each house includes a rainwater tank which reduces the demand for water from the public supply.

As can be seen in **Figure 9** there was not a great difference between the environmental impact indicators for the two construction assemblies. This is partly because the construction materials have a relatively small impact on the indicators presented. Over a 50-year life cycle, energy use during operation dominated many of the indicators presented.

The climate in Darwin is challenging and the thermal modelling indicated periods outside the comfort zone. This can be improved by using fans to improve comfort by the air movement. Thermal mass provides some buffer from peak conditions and acts as a heat sink. Thermal comfort is presented as air temperature frequency distribution in the family/living area.

The graph in **Figure 10** shows that the concrete panel option has more 28–34°C hours (warm to hot range) and less over 34°C hours (very hot range) than for the lightweight cladding (base) option.

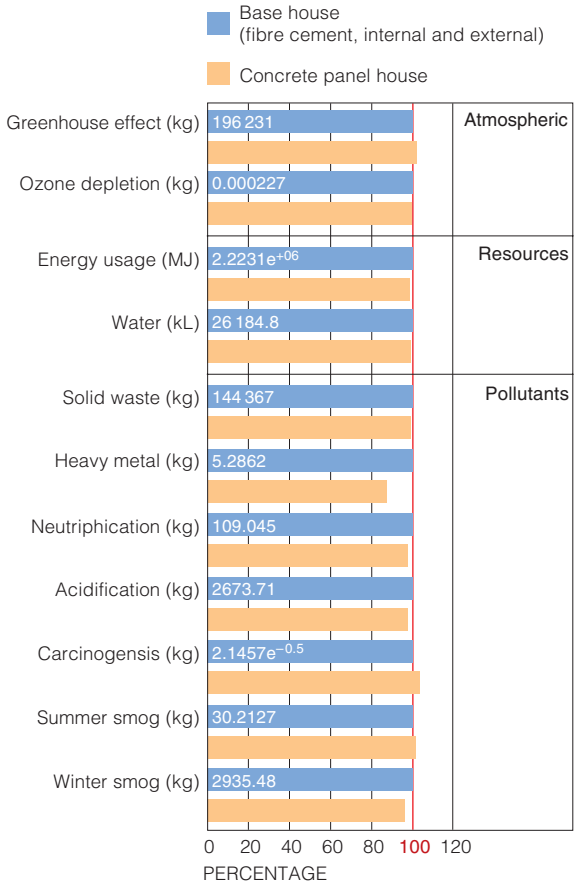


FIGURE 9

Bar chart showing the environmental impact of using high mass material vs lightweight cladding in Darwin house

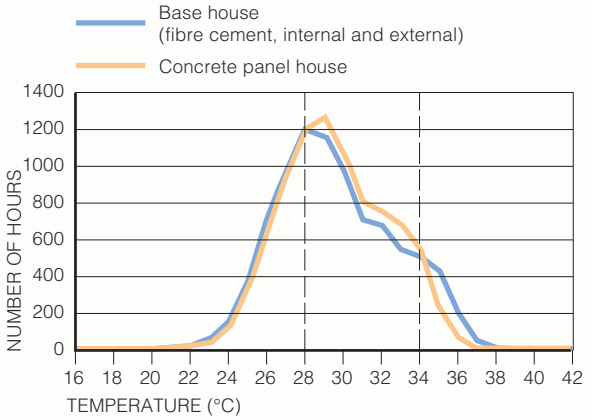


FIGURE 10

Air temperature frequency distribution in Darwin house

ZONE 2 SUB-TROPICAL: BRISBANE

For summer, the design for Brisbane is similar to that for Darwin with a focus on the control of radiation and the dissipation of heat, mainly through controlled daytime and night-time ventilation. However, Brisbane also has a greater diurnal range and a winter that requires some passive heating. This presents a greater opportunity for massive construction if combined with careful design of shading and fenestration. It also presents two modes of operation – a warm and cool season with the mass. However, as noted in the analysis of Brisbane's climate, page 6, the focus is on minimising discomfort which is more pronounced in summer than in the mild winter. As a result, the design follows the approach used for Darwin with a modification of shading, the amount and control of ventilation, the use of bulk insulation, the use of mass and the penetration of sun for the periods of the year when heating is needed.

Sustainable design to improve thermal comfort

Orientation and zoning

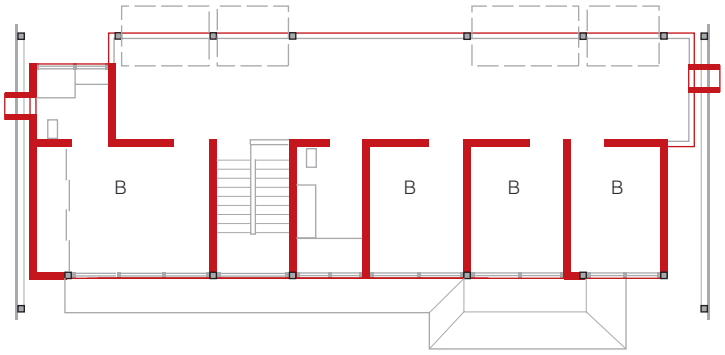
- Orientated with the long axis running east-west to provide effective shading and access to summer afternoon breezes from the north-east, although easterly breezes are not captured – priority given to orientation for the sun.
- Bedrooms located upstairs to provide maximum access to cooling breezes and to provide a sleeping area separate from other zones that may have gained heat during the day.

Note: The above should be considered in the context of the limitation of site size and orientation.

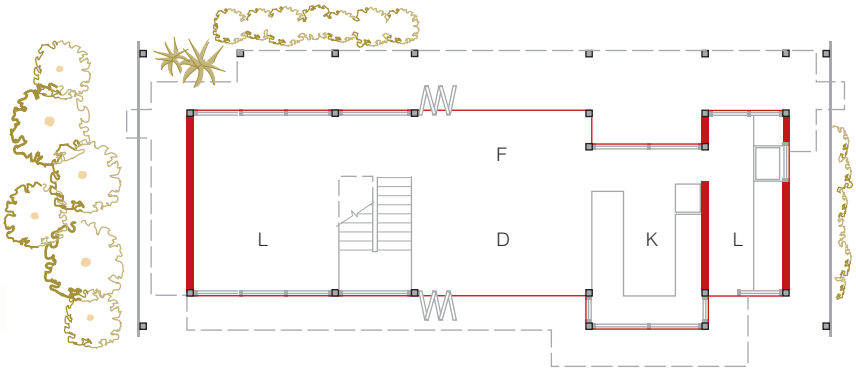
- Bedroom ceilings insulated for warmth in winter.

Ventilation – *design features to ensure maximum ventilation when the internal temperature is higher than that outside*

- Shallow floor plan of one-room width to allow maximum cross ventilation.
- Louvres from 900 mm to 2100 mm above floor level – providing more thermal mass.
- A minimum floor-to-ceiling height of 2.7 m – higher in bedrooms with raked ceilings.
- Vertical space for upward movement of heat from ground floor (internal stairs), which vents to outside living spaces.
- Raked ceiling in bedrooms assists by increasing stratification and allowing hotter air to be out of the occupied zone and more easily ventilated.



FIRST FLOOR PLAN



GROUND FLOOR PLAN

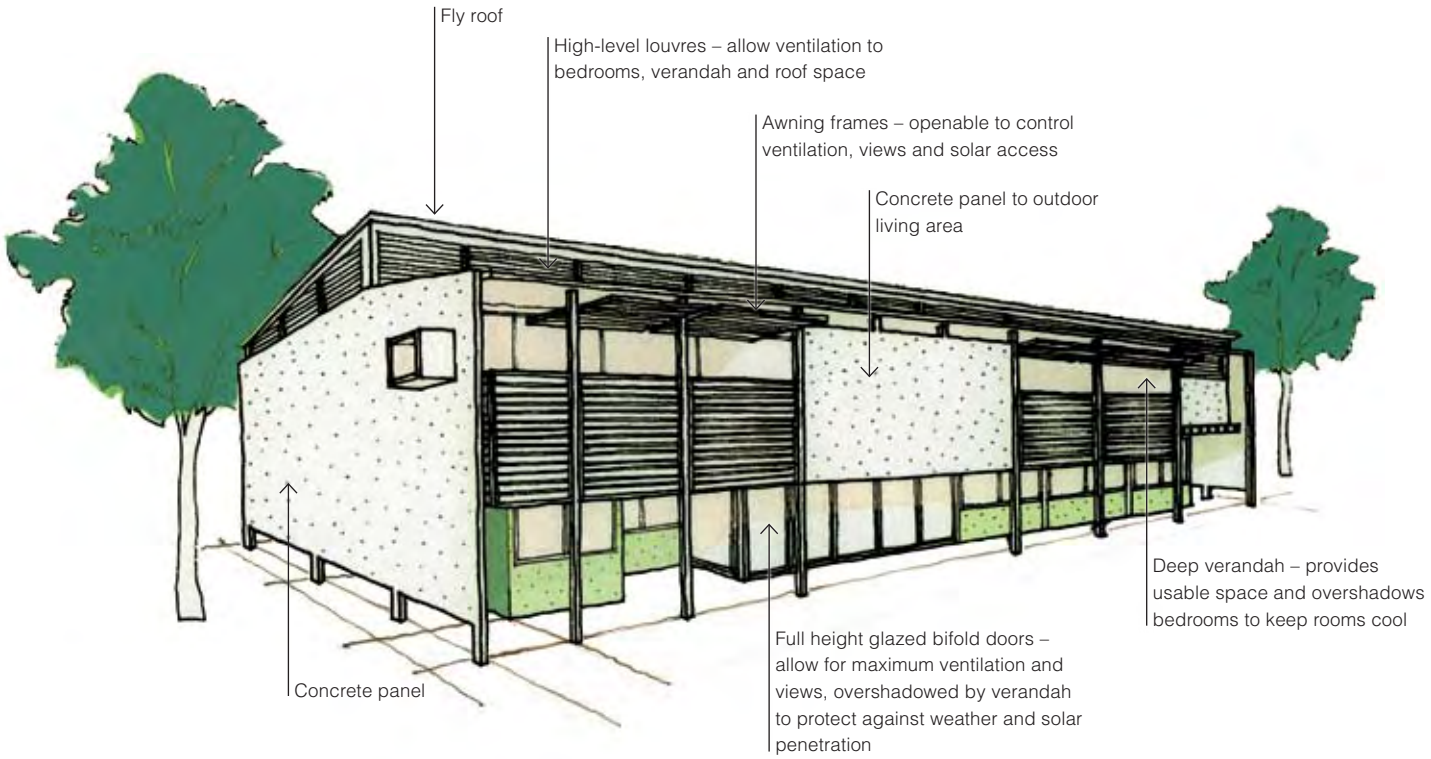


FIGURE 11

Case study design for sub-tropical climate

- Single loaded planning to facilitate cross ventilation
- Concrete mass to ameliorate temperature fluctuations
- Panel system allows for prefabrication/systems construction

- Ceiling fans for physiological cooling when there is no breeze.
- Louvres are part of a convective ventilation loop utilising high and low level openings to exchange internal air.
- Kitchen with bay window to increase ventilation of cooking, refrigeration and other heat sources.
- Air cavity between ceiling and roof can be closed to further insulate bedrooms in winter.

Radiation and ventilation – *design features to block radiant heat gain and vent any heat gain from the building*

- Mass used to capture night-time temperature lows during summer with night ventilation. Brisbane has a diurnal range of approximately 8–9°C, measured by the difference between the mean maximum and mean minimum temperatures.
- Ideally, ventilation minimised until internal temperature equals external temperature. Ceiling fans to overcome 'stuffiness' and give physiological cooling when there is no breeze or vents are closed to reduce heat gain.
- Reduced window areas on the east and west facades to minimise early morning and late afternoon heat gain – this could be varied provided shading systems minimise heat gain and the amount of glazing is minimal.
- Control of roof ventilation – maximum ventilation in summer similar to a fly roof and minimum ventilation for winter. Roof pitch to vent roof heat gains in summer.
- Outer skin of the east and west walls extending as wing walls to channel NE summer afternoon breezes through building.
- Balcony roof split to vent heat gain and avoid directing heat into adjacent rooms.
- Balcony roof with a solar pergola that allows sun into bedrooms for cooler months.
- Glass louvres from 900 mm to 2100 mm above floor level (the amount of glazing is less than 25% of the floor area).
- 'Garage door' adjustable shading to block/diffuse radiation and provide semi-enclosed balcony space, louvred for ventilation.

Radiation – *design features that focus on radiant heat gain*

- East and west walls with reflective and a minimum bulk insulation of R1.0 (modified from Darwin as bulk insulation will provide similar heat block in summer but also reduce heat loss in winter).
- The roof has reflective foil and a minimum bulk insulation of R1.5 – R2.5.
- Ground-coupled mass to absorb radiant heat from occupants.
- Complete shading of the building fabric for hot months. In reference to monthly diurnal averages for Brisbane, under-heating occurs from May through to August. Suggested dates for acceptable sun penetration would be from 1 May to 11 August for passive solar heating (balcony solar pergola and other shading devices). Full shading is provided at all other times of the year.
- Vertical fins or other shading devices for low-angle summer sun – this shades all north- and south-facing windows AND walls from morning and afternoon sun due to window placement.
- All fixed shading can be separated from the structure to avoid 'heat bridges' and can be a light colour to avoid radiant heat gain at openings.

Materials and water

- Work to standard dimensions for cladding and stud framing to reduce waste and increase reusability of construction elements. Simple window and door schedule to fit into standard dimensions.
- Water collection from roof, preferably stored in tank on the east or west wall.
- Solar hot water system could also make use of the harvested/collected water.

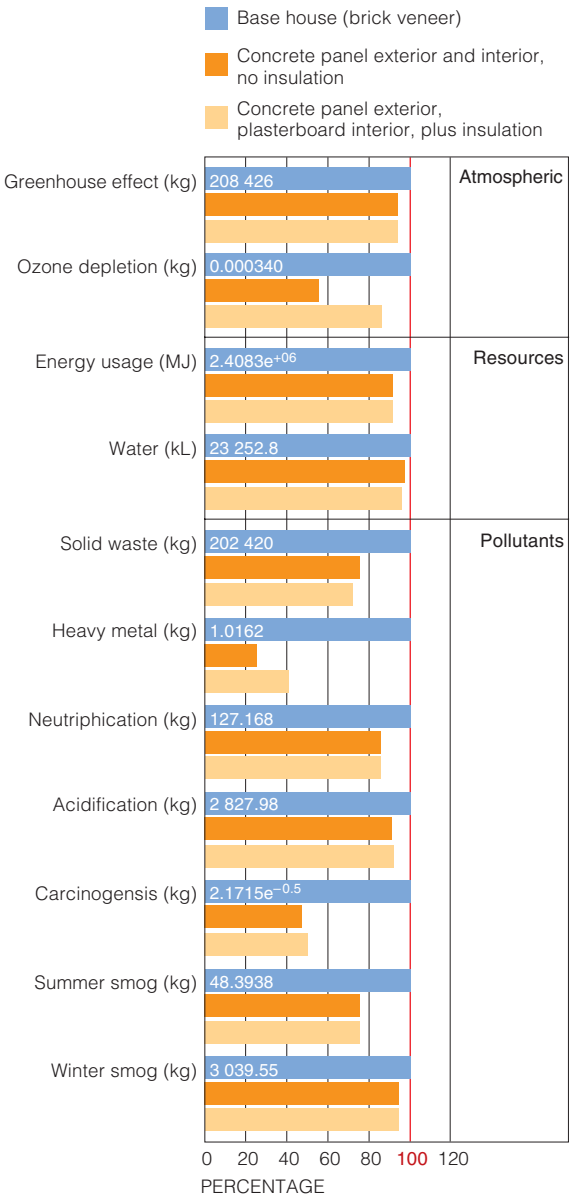


FIGURE 12

Bar chart showing the environmental impact of using high mass materials in Brisbane house

Life cycle assessment

Life cycle assessment results of a house designed using the principles outlined above utilising thermal mass in the ground floor and external walls (concrete slab on ground and concrete walls) are presented in Figure 12. The results are presented in comparison with a typical design using brick veneer assembly and in environmental impact categories. *Note: The design for each house includes a rainwater tank which reduces the demand for water from the public supply.*

As mentioned earlier energy use and global warming potential is largely due to the operation of the building. In the other environmental impact categories presented in Figure 12, concrete panel wall construction has the lowest ozone depletion potential, solid waste, heavy metals and carcinogens.

The design of the house in Brisbane explored the use of thermal mass for passive solar design to use the diurnal variation to improve comfort. Thermal comfort is presented as air temperature frequency distribution in the family/living area in Figure 13.

The thermal modelling indicated little difference between the various assemblies examined. The sudden spike at 18°C comes about because the simulation software assumes windows are closed at this set point. As designed, whether insulated or not, concrete panel walling provided a greater portion of the year within the temperature range 19 to 25°C (adaptive comfort temperature for Brisbane).

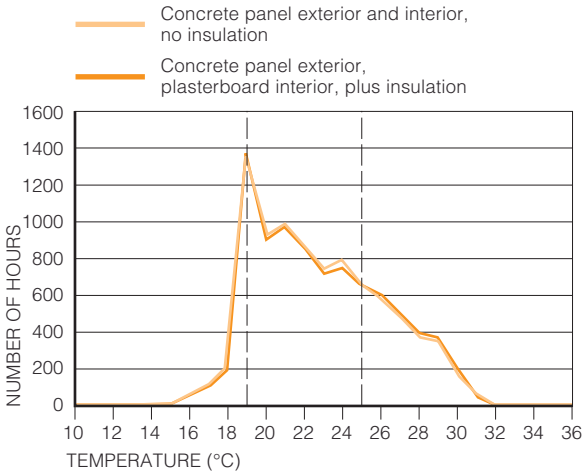


FIGURE 13

Air temperature frequency distribution in Brisbane house

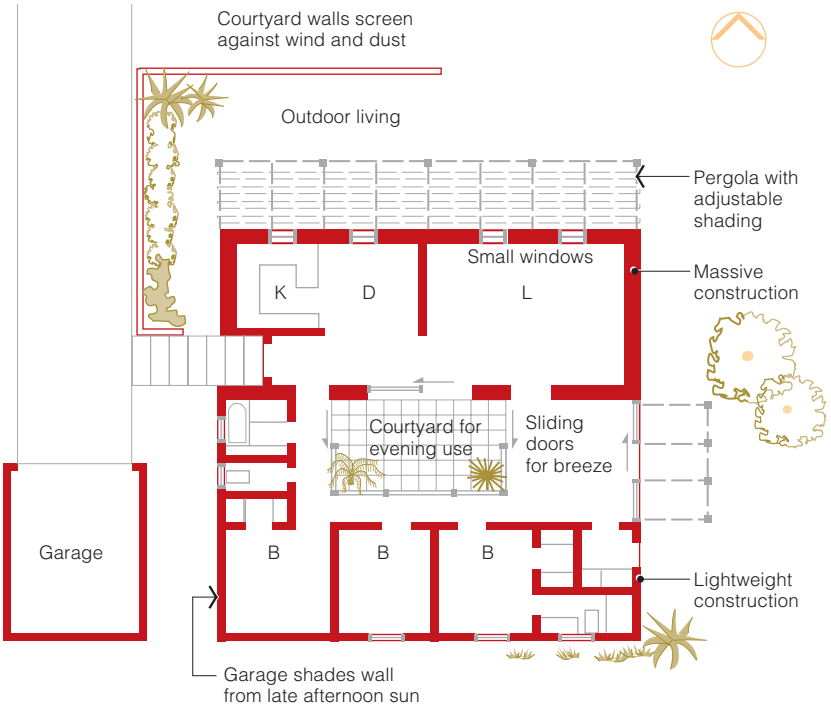


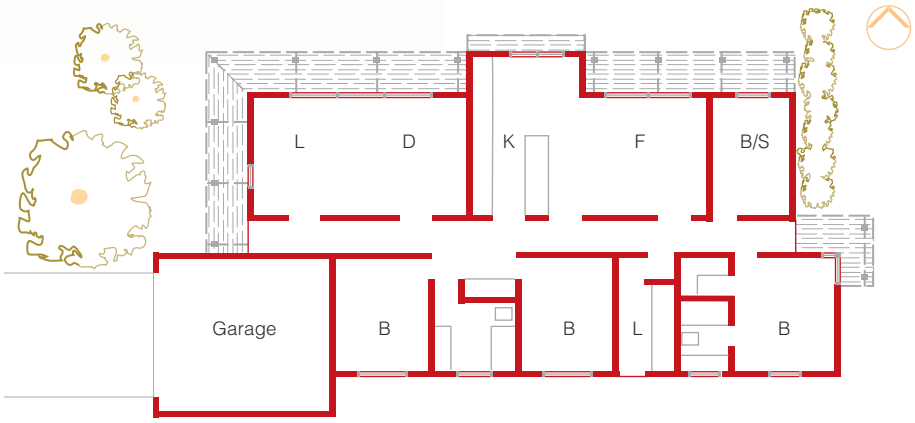
FIGURE 14
General design for hot arid climates

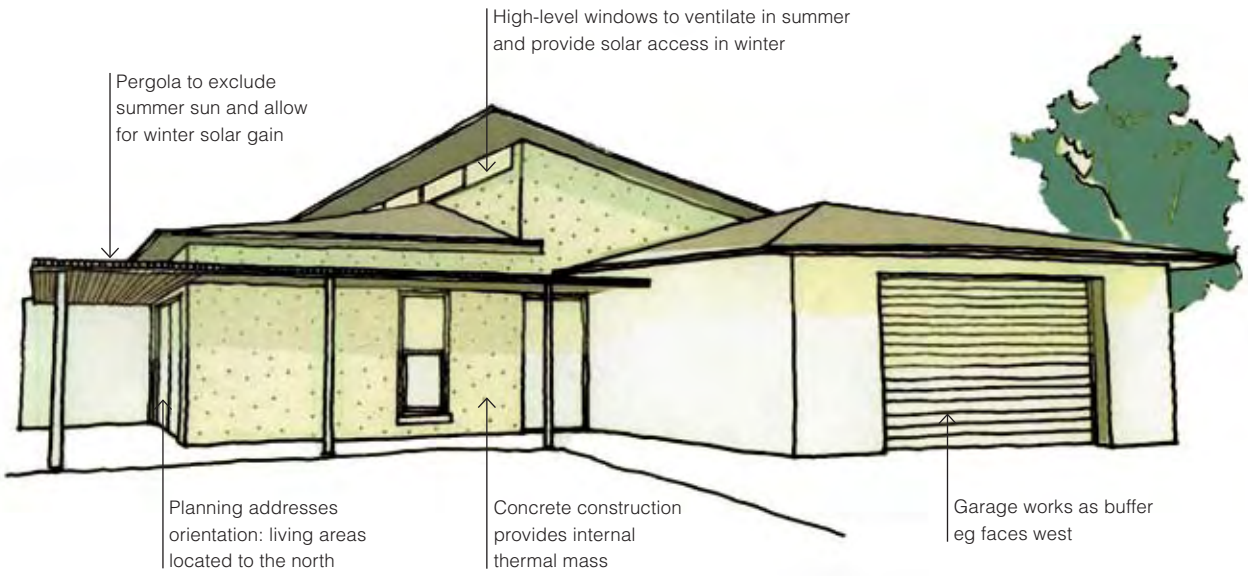
ZONE 3 HOT ARID SUMMER, WARM WINTER: ALICE SPRINGS

Sustainable design to improve thermal comfort

The following list covers some general environmental design features:

- High thermal mass stabilises temperatures and reduces daytime and night-time extremes.
- Heat gain is reduced as much as possible with no windows on the east or west and small, well-shaded windows elsewhere.
- Radiation heat gain is reduced with light coloured surfaces and reflective foil insulation.
- Courtyards are often used to protect against hot, dry winds and are combined with plants and water features, which reduces radiation and creates a micro climate enhanced by evaporative cooling.
- Ventilation is controlled to ensure the building is not heated when the inside temperature is less than that outside on a hot day.
- Evaporative cooling can be used to improve comfort when the relative humidity is low. For example, Alice Springs has an average relative humidity of 27% in January allowing for the use of evaporative cooling to improve comfort. In low-rainfall areas, consideration should also be given to the sustainability of available water resources.





View from north west

FIGURE 15
Case study design for warm temperate climate

ZONE 5 WARM TEMPERATE: SYDNEY, ADELAIDE, PERTH

Sustainable design to improve thermal comfort

Orientation and zoning

The principles provided below are based on optimal orientation and lot alignment. It is recognised that available sites in the major metropolitan areas may not have optimal conditions, however these principles should be applied to suit specific site conditions.

- Orientated with the long axis east/west to provide effective shading and access to prevailing breezes from the northeast.
- Living areas zoned to the north of the building plan to take advantage of solar access in winter. Sun access to internal bedroom walls in winter via clerestory windows. Solar ingress is controlled in summer by pergola and shading.
- Bedroom zoned to the south of the living area to provide a sleeping area separate from the active zones and to avoid heat gain during the day. Cellular nature of bedroom plan allows for efficient heating in winter.
- Garage works as a buffer against adverse environmental conditions eg garage orientated to west avoids afternoon heat gain in summer.

Ventilation

- Cross ventilation from both the living areas and the bedroom facilitated by high level openable clerestory windows.
- Floor to ceiling height a minimum of 2.7 m.
- Raked ceiling to facilitate air movement through all spaces.
- Ceiling fans for physiological cooling when there is no breeze.
- Kitchen segregated to avoid internal heat gain in summer.

Radiation and ventilation – *design features to control radiant heat gain and vent any heat gain from the building*

- Insulated roof with reflective foil to block radiant heat and to retain warmth in winter.
- Roof pitch to clerestory windows to vent heat gains when necessary.
- Ground coupled mass to absorb heat in summer.
- Complete shading of windows in summer.
- Winter sun penetration into the building to warm up mass elements. The warm surfaces increase comfort later in the evening.

Materials and water

- Work to standard dimensions for cladding and stud framing to reduce waste and increase reusability of construction elements.
- Simple window and door schedule to fit into standard dimensions.
- Water collection from roof to water garden and flush toilets.
- Gas boosted solar hot water system.

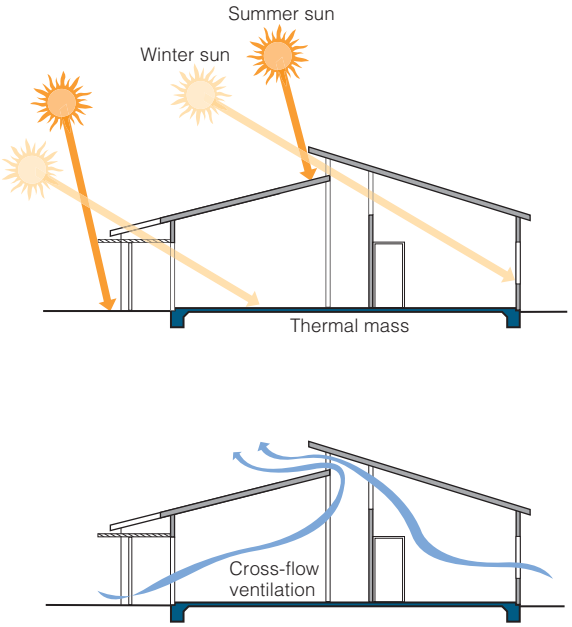


FIGURE 16
Modified section of project house to improve solar access and ventilation

Life cycle assessment

In 2001 a case study was completed for a 'standard' three-bedroom detached project home located in Sydney. The main outcome of the study was that, irrespective of changes to materials, the majority of environmental impacts were dominated by the operational phase of the life cycle. Energy use during operation was noted to be the biggest contributor to global warming as well as a number of other environmental indicators.

To address energy used during operation, a second study was completed in 2003. Using the same size and appearance of the project home, the design was modified for passive solar performance. **Figure 16** illustrates principal elements of passive solar design.

The two main construction materials used were brick veneer and concrete. The concrete construction types were optimised to find the best combination of thermal mass and insulation. The various construction options shown in **Figure 17** were examined over three different life spans for their environmental impacts.

In the options studied the best comfort was achieved by the reverse thermal mass wall construction (Type 2E) in **Figure 17**.

Life cycle assessment

The results of this case study, **Figure 18**, show that across the eleven indicators used in LCAid the life cycle assessment of the various concrete construction options was fairly similar. Overall, the concrete products performed well.

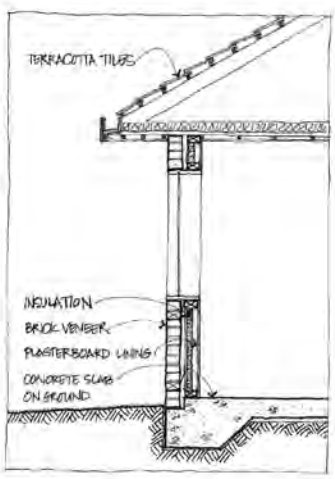
The study showed that concrete performs an important role in achieving energy efficiencies through the utilisation of thermal mass in a passive solar designed home. Such energy efficiencies are important as energy production using non-renewable sources was shown to have major impacts in six of the eleven indicators studied.

The results indicate that although heating and cooling energy have been reduced, energy use during operation still dominates the life cycle. This is due to the hot water system and appliances as described in the box **Life Cycle Energy** on page 2. The results for the indicators are very similar, showing that energy is the major influence for a number of the indicators presented. The large spikes that occur for a number of indicators for the first option are a little misleading for ozone depletion potential; it is a very small value but appears large when expressed as a relative difference. The other indicators are larger due to the metal roof and its replacement a number of times over the building life cycle.

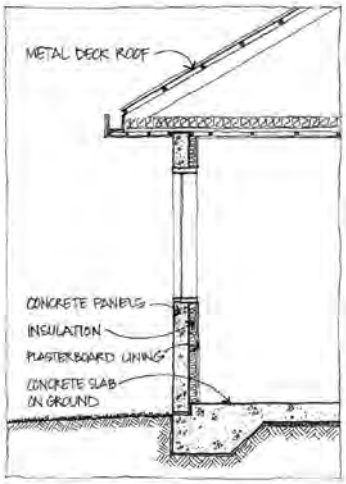
These results clearly show that the environmental impacts of material procurement can be offset against the gains achieved in reducing the environmental impacts of building energy use in the operational stage of the life cycle.

CONSTRUCTION MATERIAL TYPES

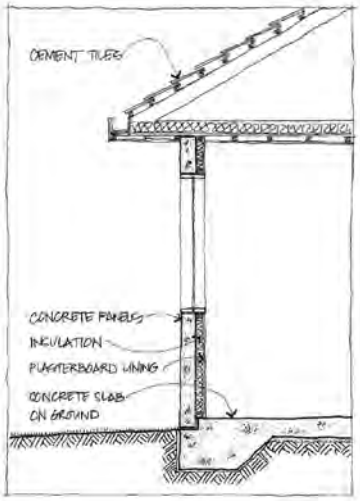
	Floor	External walls	Internal walls	Roof
TYPE 1	Concrete slab on ground	Brick veneer/insulation/ plasterboard	Plasterboard	Terracotta tiles
TYPE 2A	Concrete slab on ground	Concrete panel/insulation/ plasterboard	Concrete panel/ plasterboard lining	Pre-painted steel
TYPE 2B	Concrete slab on ground	Concrete panel/insulation/ plasterboard	Concrete panel/ plasterboard lining	Concrete tiles
TYPE 2C	Concrete slab on ground	Concrete panel	Concrete panel	Concrete tiles
TYPE 2D	Concrete slab on ground	Concrete panel/ plasterboard	Concrete panel/ plasterboard lining	Concrete tiles
TYPE 2E	Concrete slab on ground	Weatherboard/insulation/ concrete panel	Concrete panel	Concrete tiles



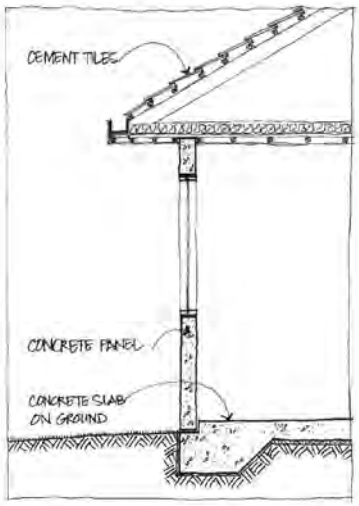
Type 1
External: brick veneer
Internal: stud wall + plasterboard
Roof: terracotta tiles



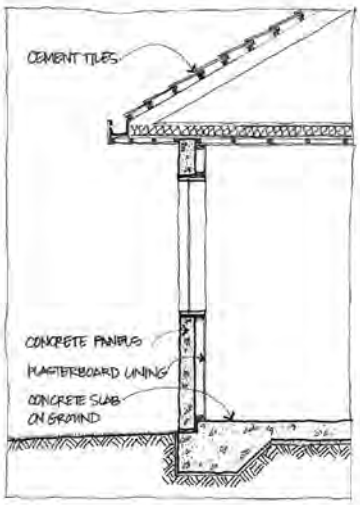
Type 2A
External: concrete, insulation + plasterboard
Internal: concrete + plasterboard
Roof: metal deck



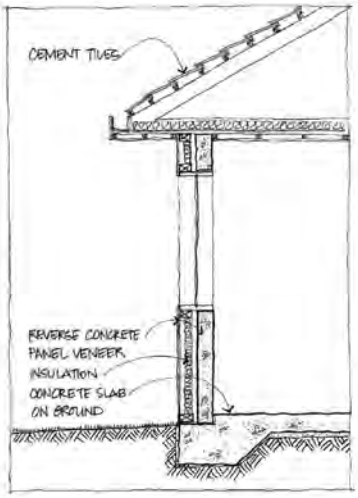
Type 2B
External: concrete, insulation + plasterboard
Internal: stud wall + plasterboard
Roof: cement tiles



Type 2C
External: concrete
Internal: concrete
Roof: concrete tiles



Type 2D
External: concrete + plasterboard
Internal: concrete + plasterboard
Roof: concrete tiles



Type 2E
External: weatherboard, insulation + concrete
Internal: concrete panel
Roof: concrete tiles

FIGURE 17
Illustrations of construction type

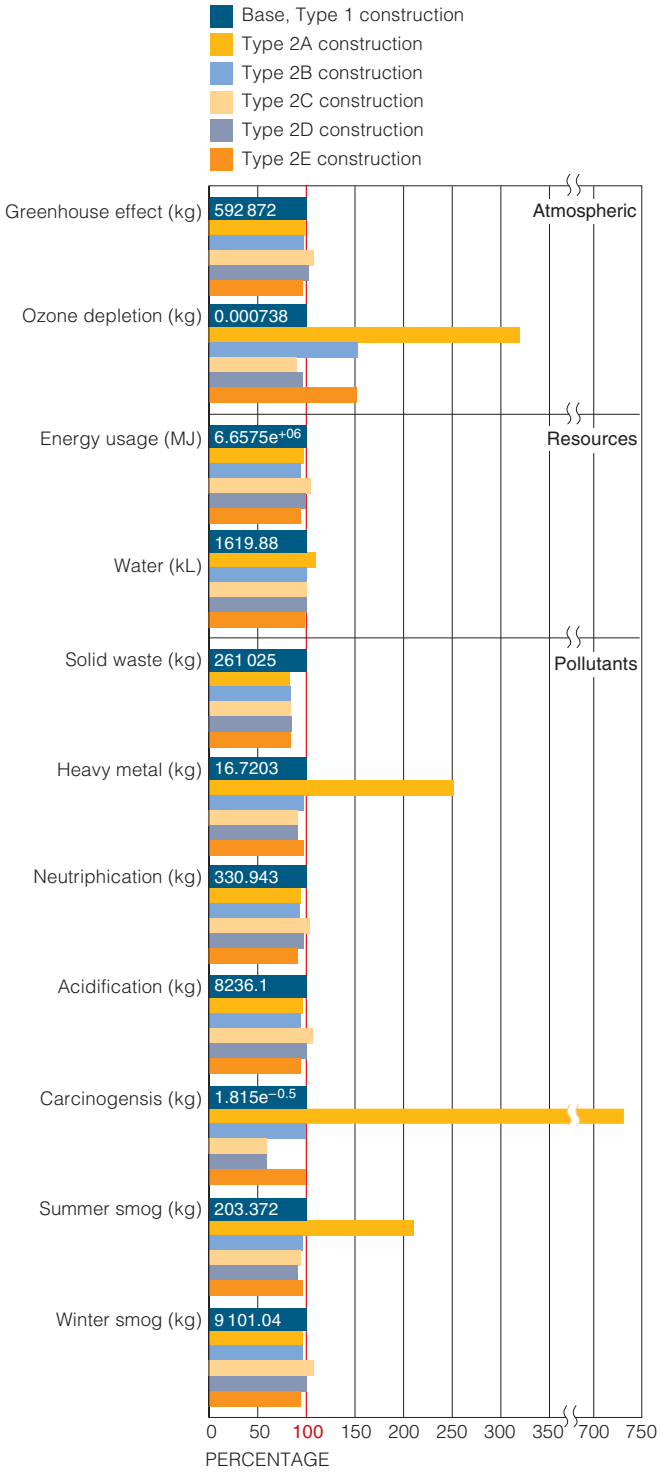


FIGURE 18
Environmental comparison of various construction – environmental impacts over a life cycle of 50 years (cradle to grave)

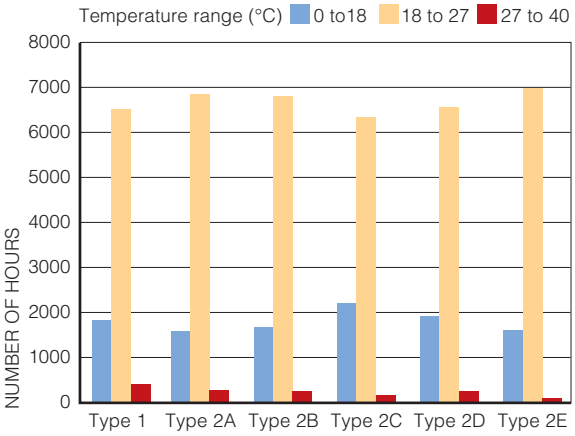


FIGURE 19
Bar chart indicating thermal comfort

Comfort The results of the thermal comfort analysis demonstrated that when emphasis is placed on utilising the thermal properties of concrete a home can maintain comfortable indoor temperatures for much of the year.

Thermal modelling of the house indicated that even without artificial heating and cooling the best performing option would maintain temperatures between 18 and 27°C for 80% of the year. Temperatures were above 27°C for only a couple of percent of the year, while temperatures were below 18°C for less than 20% of the year (most of those hours being during the night). This performance suggests that the average project home can easily obviate the need for extensive heating and cooling by appropriate attention to passive design.

ZONE 6 MILD TEMPERATE: MELBOURNE + **ZONE 7 COOL TEMPERATE**: CANBERRA, HOBART

General sustainable design to improve comfort

These climate zones have been combined because similar design strategies are appropriate to improve comfort in winter. Information is readily available for general design of the building envelope and for basic thermal characteristics generally required by building codes. The focus of this section is on the design of passive systems to improve thermal comfort during winter. However, comfort in summer also needs consideration. As a minimum, shading should exclude summer sun and reflective foil used to reduce heat gain through the roof. The massive construction used for passive heating in winter is also useful for stabilising temperatures in summer.

The focus of the design is heat gain for winter and controlling heat loss.

- **Heat gain** Moderate thermal mass with windows facing north to capture winter sun (see the following information on direct and indirect passive heating). Reflective foil in ceiling to reduce heat gain in summer.
- **Reducing heat loss** Double glazing and reduced amounts of glazing especially east, west, and southern sides; high levels of bulk insulation; compact shape and well sealed building with controlled ventilation.

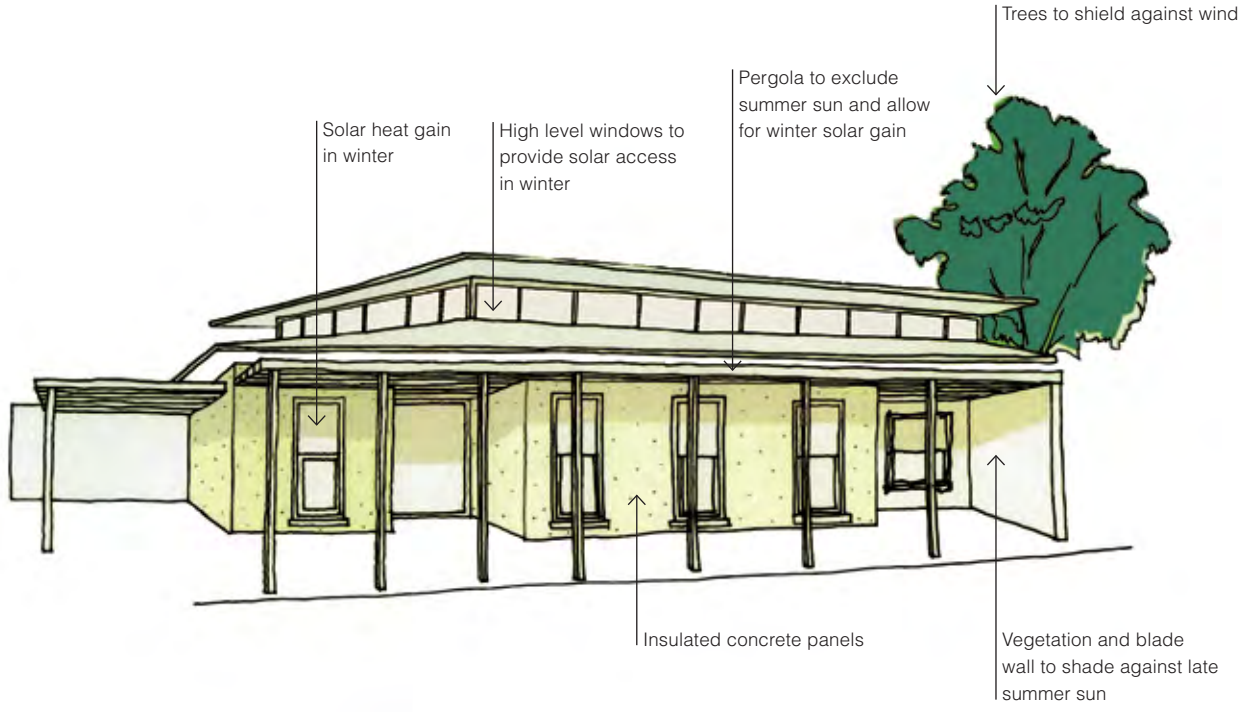


FIGURE 20
General design for mild and cool temperate climates
→ Concrete mass to ameliorate temperature fluctuations

Passive solar systems

Passive design is not complicated and is compatible with traditional building elements and Australian house design. Concrete slabs as currently used in 80% of Australian homes can be used to store heat from the sun. In cool climates, sun can be used to heat the room in winter using north-facing windows of approximately one fifth of the floor area. Figure 21 shows a room directly gaining heat from the sun.

The next focus for a passive design is ensuring heat (when required) is retained in the building. The same measures are also required for an efficient artificial heating system.

- Windows are a major source of heat loss. Double glazing can increase resistance to heat loss while still allowing heat from the sun to enter. Window shutters for night time are also effective and pelmet-hung, close-fitting curtains can also reduce heat loss.
- Ceilings should be insulated to prevent heat loss, as should walls and floors to at least the minimum specified in the Building Code of Australia Figures 21 and 22.
- The edges of the ground slab should be insulated, especially the northern edge that acts as the prime heat store Figure 23. Thickening the slab to a depth of 250 mm in a 2-metre-wide strip along this northern edge is also useful.

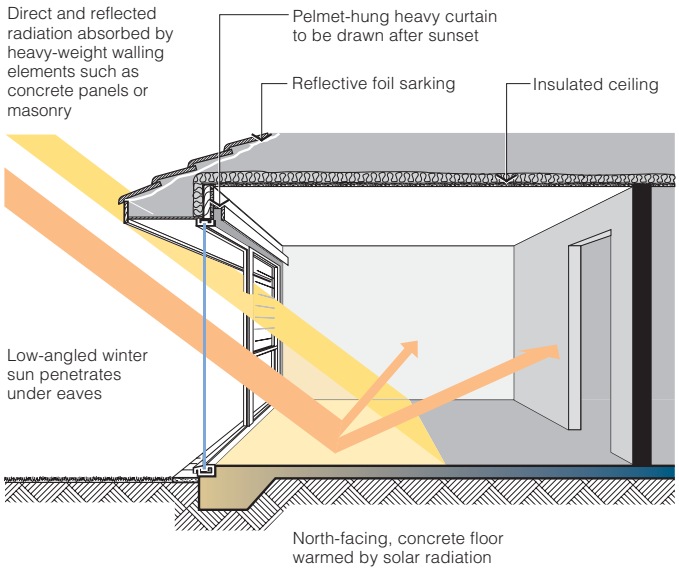


FIGURE 21
Direct gain heating cycle

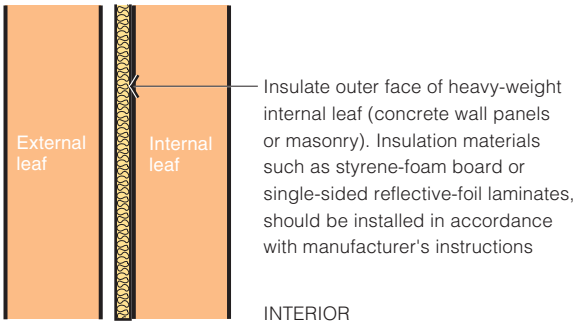


FIGURE 22
Insulation of cavity wall in severe cold-climate areas

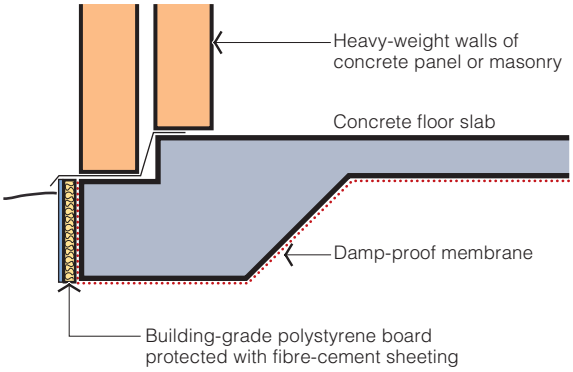


FIGURE 23
Slab-edge insulation in cold-climate areas

Bibliography

- ASHRAE Standard 55 2004 *Thermal Environmental Conditions for Human Occupancy.*
- Auliciems A and Szokolay S (1997) *Thermal Comfort PLEA Note 3* Passive Low Energy Architecture in association with the University of Queensland, Australia.
- Australian Bureau of Statistics www.abs.gov.au accessed 23 Dec 2005 *Australian Social Trends 1997 Housing – Housing & Lifestyle: Environment & the home*.
- Australian Greenhouse Office 'Energy Use Introduction' *Your Home Guide Technical Manual* Fact Sheet 40, 2001.
- Brown G Z and DeKay M (2001) *Sun, Wind and Light: Architectural Design Strategies, Second Edition* John Wiley and Sons Inc.
- du Plessis (Editor) (2001) "Agenda 21 for Sustainable Construction in Developing Countries, First Discussion Document" International Council for Research and Innovation in Building and Construction (CIB) Reference No. BOU/C336.
- Ecotect V.20 (b) Square One Research Pty Ltd.
- Greenland J (1998) *Foundations of Architectural Science* University of Technology, Sydney.
- Givoni B (1962) *A Basic Study of Ventilation Problems in Hot Countries* Building Research Station, Haifa.
- Hyde R (2000) *Climate Responsive Design: A study of buildings in moderate and hot humid climates* E and FN Spon.
- Koenigsberger O H; Ingersoll T G; Mayhew, A and Szokolay S V (1979) *Manual of Tropical Housing and Building, Part 1 Climatic Design*, Longman.
- La Roche P, Quiros C; Bravo G; Gonzalez E and Machado M (2001) *Keeping Cool: Principles to Avoid Overheating in Buildings PLEA Note 6 Design Tools and Techniques*, Passive and Low Energy Architecture International with Research, Consulting and Communications.
- Moreland Energy Foundation Ltd *Home Greenhouse Audit Manual* Cool Communities; www.mefl.com.au/documents/Transport_Pollution_in_Moreland.pdf.
- Szokolay S (2004) *Introduction to Architectural Science: The Basis of Sustainable Design Architectural Press*, Elsevier Science.
- The Athena Sustainable Materials Institute (1998) *The Athena Sustainable Materials Institute… improving environmental performance in the building industry* The Athena Sustainable Materials Institute, Canada.

Acknowledgement

Steve King
Senior Lecturer
Faculty of the Built Environment
University of New South Wales

Leena Thomas
Senior Lecturer – Architecture
Faculty of Design Architecture & Building
University of Technology, Sydney