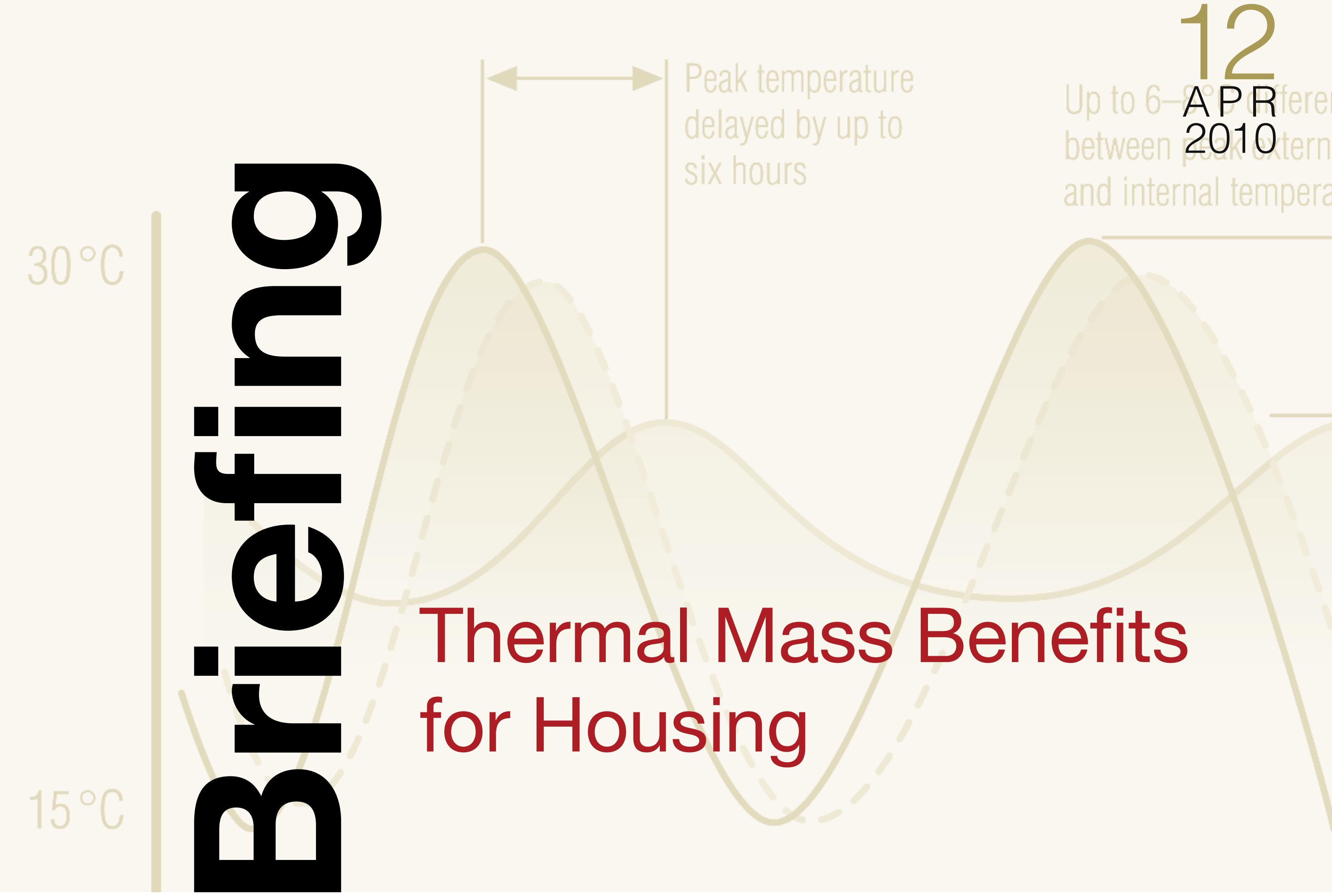
Briefing
12
APR
2010



Thermal Mass Benefits for Housing

Thermal mass is the ability of a material to absorb and store heat. Concrete's high thermal mass, as part of an integrated passive solar design approach, can significantly reduce heating and cooling energy requirements and the associated green house gas emissions. It makes economic sense for householders to invest in a thermally comfortable home that will provide cost savings for the rest of its life. This Briefing demonstrates that concrete is the responsible choice for energy efficient and sustainable homes.

INTRODUCTION

Global warming is widely recognised as a significant threat to our on-going wellbeing; and there is a world-wide effort to reduce greenhouse gas emissions, the principal cause of global warming. Building sustainable energy-efficient housing is one of the ways to effectively address global warming, with the added benefit of reducing heating and cooling costs. Using concrete's high thermal mass (as part of an integrated passive solar design approach) can significantly reduce energy consumption and the associated CO_2 emissions by reducing or, in some climates, eliminating altogether the need for heating and cooling systems.

Environmental life cycle studies have demonstrated that the majority of energy used in a house is consumed during its operational phase[1]. Space heating and cooling to provide comfort conditions is one component of energy household consumption. Recent studies[2] show that almost eight in ten dwellings across Australia are artificially heated. There has also been a substantial increase in the number of households with air conditioners.

Electricity produced by coal-fired power stations is the main source of energy for household heating and cooling in Australia. In the two-year period ending in 2010, the cost of electricity has risen 20% on average across Australia[3]. An additional rise, as much as 60% in some states, is expected over the next three years[4].

The health and comfort of occupants are primary objectives of any house design. The thermal mass of solid concrete elements in a house can be used to reduce energy consumption for space heating or cooling, while maintaining a comfortable environment. Concrete can be used for internal and external walls, slab-on-ground and, in multi-storey dwellings, suspended floors. A house using well established passive solar design principles, will use less energy, and result in less greenhouse gas emissions during its life cycle, when compared with houses built of low-thermal-mass lightweight materials.

This Briefing outlines how concrete's thermal mass can be utilised in house designs to create a comfortable thermal environment all year round, in summer and winter.

PRINCIPLE OF THERMAL MASS

Thermal mass (also called thermal capacitance or heat capacity) is the ability of a body to store heat. It is designated by *C* and typically measured in units of MJ/m^3K or MJ/tK or the equivalent $MJ/m^3{}^\circ C$ or MJ/t°C.

Dwellings with high thermal mass are characterised by their inherent ability to store thermal energy, and then release it several hours later. In summer, heat is absorbed on hot days, preventing the internal temperature from rising excessively. Provided that the climate is such that the nights are cooler than the comfort level, the cool night air can ventilate the building and purge the accumulated heat that is emitted from the concrete building fabric.

During winter, when heating is required, the thermal mass is used to help keep the dwelling warm and to reduce heat energy consumption. The principle is effectively the same as for summer, except that solar gains are encouraged through appropriately specified windows on a north facing facade. Heat is absorbed by the thermal mass during the day, and then slowly released at night. This is the same as for summer nights, the only difference being that, during winter, this is useful heat, with windows kept shut to minimise heat loss.

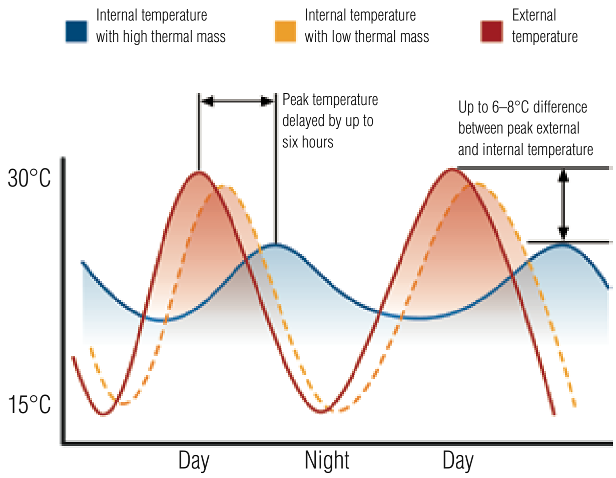


Figure 1 Stabilising effect of thermal mass on internal temperature (Source: *Thermal Mass Explained* The Concrete Centre[5])

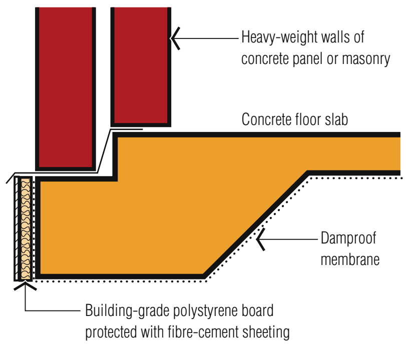


Figure 2 Slab-edge insulation in severe cold climate areas

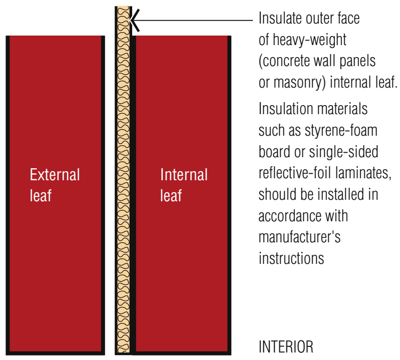


Figure 3 Insulation of cavity wall in severe cold climate areas

THERMAL MASS IN HEATING

Concrete can be used in dwellings as floor slabs, wall panels, structural elements—such as beams and columns—ceiling soffits or as interior features—such as cabinet, bench tops and staircases.

The benefit of concrete floor slabs is particularly apparent in winter, as most of the sunlight, entering through the windows, falls on the floors. If the slab is to be covered for aesthetic reasons, materials such as quarry tiles, slate or vinyl with good conductance should be used on those parts of the floor receiving direct sunlight. Increasingly, concrete floor slabs are being left exposed (and typically polished.) If the concrete is coloured, dark colours permit the solar energy to be absorbed directly into the concrete. While mid-range coloured materials will reflect some of the solar energy—this may be an effective way of distributing it to other thermally massive surfaces, such as walls elsewhere in the direct-gain space. Carpets or rugs should not be used on slabs receiving winter sunlight.

The edge of a slab-on-ground floor, especially the northern edge that acts as the prime heat store, should be insulated to reduce the heat loss to the ground. (When using edge insulation, designers should consider the appropriate means of providing for termite inspection). Thickening the concrete slab to a depth of 250 mm in a two-metre-wide strip along the northern edge, and insulating the outer face of the internal masonry leaf of external walls may also be considered **Figures 2 and 3**.

THERMAL MASS IN COOLING

In summer, a concrete slab-on-ground acts as a large heat sink, benefiting from the ground's near-constant low temperature. When concrete internal walls and insulated concrete external walls are also used, the total heat storage capacity is enhanced. The house reacts slowly to outside temperature fluctuations, and there is thus a reduced dependency on mechanical cooling to produce a comfortable internal temperature.

To maximise the benefits of the cooling cycle in summer, good cross-ventilation should be provided. If the night-time external air temperature is lower than the comfort level, air flowing though the building will remove the heat stored in the building fabric during the day. This is commonly referred to as 'night purging'. When this cooled air is circulated by fans, particularly ceiling fans, it can rapidly assist in achieving comfort conditions.

Solar shading should be configured over northern windows so as to minimise the amount of summer sun reaching the interior. Further protection by means of a pergola covered with deciduous vines or adjustable fabric or metal blinds on the north-facing windows is also desirable. This protects the windows from heat gain in unseasonably hot weather occurring in early autumn or late spring.

As the outside air temperature increases during a summer day, the walls and floor absorb heat from the outside air and delay the rise in the internal-air-temperature. Additional measures include:

- Foster vegetation near southern and side openings. If these plants are watered in summer, the air passing through them will be partly cooled before entering the internal space.
- Plant deciduous trees or vines on the northern and western sides of a building to provide shade in summer and admit sunlight in winter.
- In sub-tropical and tropical humid zones, and in humid areas of other zones, provide a ventilated space between the roof and ceiling.
- Add suitable insulation under the roofing material.

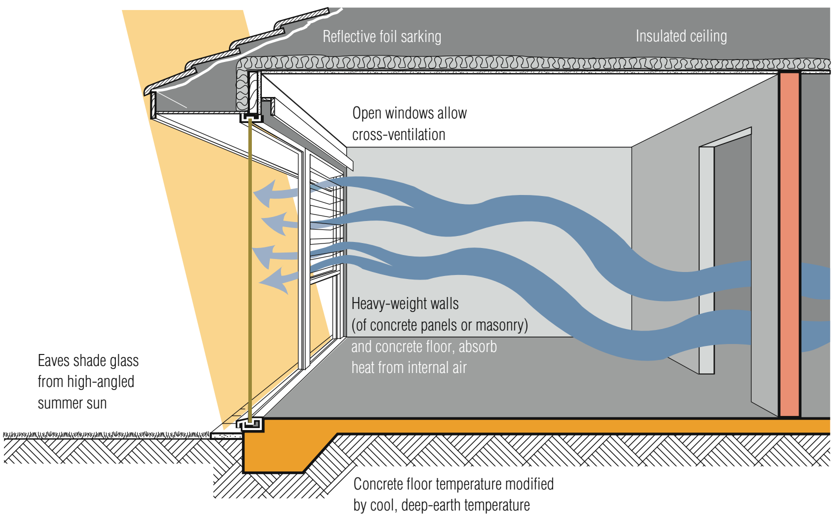


Figure 4 Concrete floor temperature modified by cool, deep-earth temperature

LIFE CYCLE ASSESSMENT STUDIES

A true indication of the sustainability of building materials and buildings can be achieved only by consideration of both the construction phase and the operational phase of the building, over its whole service life, ie a Life Cycle Assessment.

A Life Cycle Assessment (LCA) examines the environmental impact of a system throughout the whole of its life, ie from the time the resources are removed from the ground to the time when they are retrieved at the end of the system's life. It must also include consideration of the effect that the particular building system has on the operational (heating and cooling) energy. Cement Concrete & Aggregates Australia commissioned a series of case studies to be conducted by the then Department of Public Works and Services (DPWS) of NSW to demonstrate the use of LCA as a tool for assessing and comparing whole buildings over their entire life cycle. Details can be found on www.ccaa.com.au[1].

Five case studies were conducted with a range of materials for floors, walls and roofing as shown in **Table 1**.

The following assumptions were made in conducting the study:

- Four occupants (two adults and two children).
- User waste is recycled in accordance with local council practices.
- On-site construction waste where possible was sorted and recycled in accordance with local council practices.
- Lighting and other electricity use 7500 kWh. (This is an average calculated from data on the Ministry of Energy's website – www.doe.nsw.gov.au/doenew/neww/Statistics/spdstats/index.html for energy use statistics).
- All electricity is grid connected.
- Location: Sydney 'Climate Zone 6'.

The best performing was Case 4, **Figure 5**, with concrete slab-on-ground, tilt-up walls with plasterboard lining, timber battens and concrete-tile roof. In this case, the total heating and cooling energy was about 30% lower than Case 1.

Table 1 **Construction details of five case studies**

Case	Floor	External walls	Internal walls	Roofing
1	Timber	Timber/stud/ plasterboard	Plasterboard	Pre-painted steel roof
2	Concrete slab on ground	Brick veneer	Plasterboard	Terracotta tiles
3	Concrete slab on ground	Double brick	Rendered cement brick	Concrete tiles
4	Concrete slab on ground	Tilt-up panel with plasterboard and battens	Tilt-up panel	Concrete tiles
5	Concrete slab on ground	Tilt-up panel	Tilt-up panel	Concrete tiles

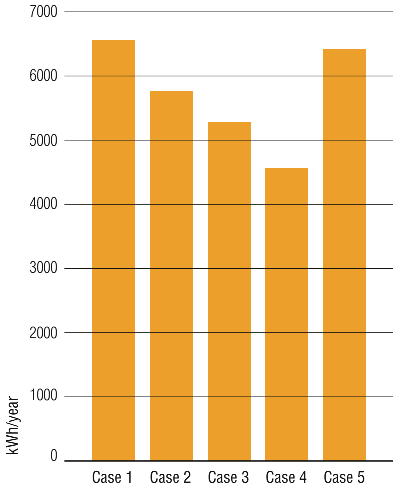


Figure 5 Annual heating and cooling

When other eco-indicators are considered, there are even more significant differences.

These studies indicate that the energy used to produce the construction materials (embodied energy) is generally less than 20% of the operational energy used over a fifty-year life. The operational energy demand thus has a much more significant impact on the overall energy usage—and therefore on the environmental impact—than does the embodied energy.

OPTIMISING THE BENEFITS OF THERMAL MASS

Designing to take advantage of thermal mass requires an integrated approach, where the interaction between the main components of the dwelling are evaluated to find the best overall balance of orientation, glazing and use of concrete elements.

Orientation

Residential buildings, designed to capitalise on the benefits of solar energy, should be planned with living areas placed to admit the sun in the cooler months. The key to a house that is naturally warmer in winter and cooler in summer is consideration of the earth's diurnal rotation about its axis and the tilt of the earth's axis in relation to its orbit around the sun. The diurnal rotation causes the change from night to day, and the tilted axis produces summer and winter. These phenomena cause the sun's position in the sky to appear higher at noon in summer than in winter, and daylight to extend for a longer period in summer.

Building orientation should account for the location of a site, the sun's altitude (which varies with latitude), and the position of true north. This causes a variation in the angles of sun penetration into a room. There are many publications that elaborate on this point, including CSIRO Technical report No. 92/2[6].

When glass is oriented to the north, it is essential to provide an eaves overhang that allows sun penetration in winter, but excludes it in summer. The extent of this overhang can be easily calculated according to location, using the eaves overhang design chart in *Passive Solar Design*[7]. It is also essential to ensure that plenty of sun can reach the glass in winter, and that it is not obstructed by vegetation or neighbouring property.

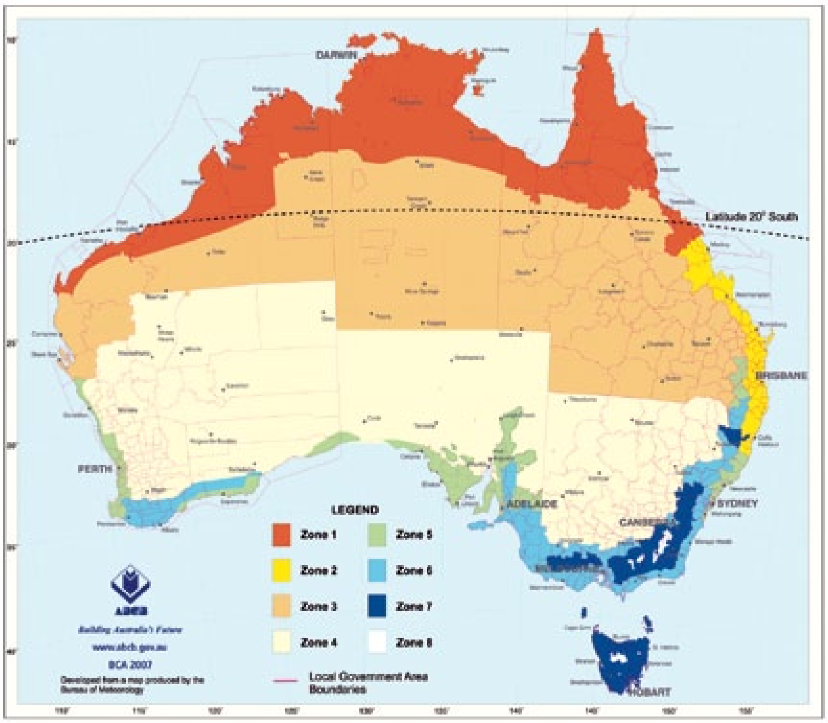


Figure 6 Climate zones based on temperature and relative humidity *(Building Code of Australia)*

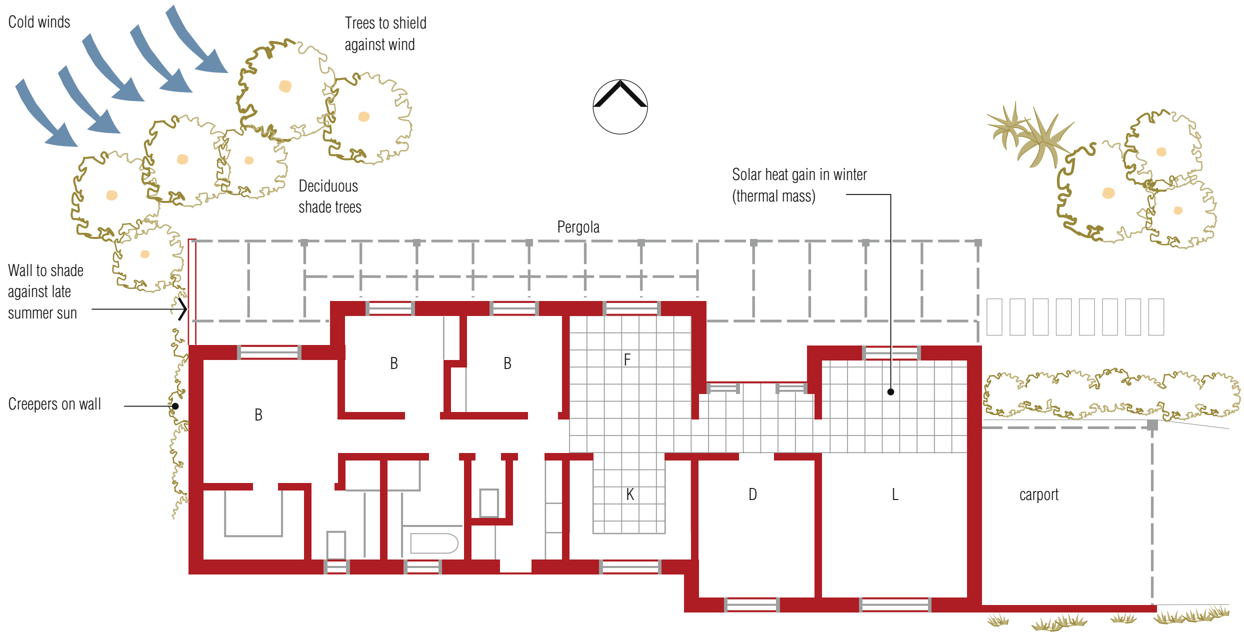


Figure 7 Planning for temperate climates

Design for climate

For the comfort of occupants and for energy efficiency, houses should be designed to suit the particular climate at its location. Australia has a diverse range of climate zones, **Figure 6**. These vary from tropical regions in the north, through the arid expanses of the interior to temperate regions in the south. Most Australians live near the wetter more moderate south eastern coasts, primarily in major cities.

For tropical areas such as Darwin, focus is on the control of radiation and the dissipation of heat. For sub-tropical areas in summer, a similar concept to that for tropical areas is appropriate with some passive heating for the winter season. Passive solar design concepts are particularly suited to the temperate and arid zones. Adelaide, Hobart, Melbourne, Perth, Canberra and Sydney lie within warm, mild and cool temperate zones. Comprehensive guidance on house design for each climate zone can be found in *Climate-Responsive House Design with Concrete*[8].

The climate can vary dramatically within one climate zone, depending on the latitude and whether the location is coastal, alpine (mountainous) or arid (desert). The climate can also vary markedly from one valley to the next, by the orientation of a slope or by the effect of prevailing winds.

A thorough knowledge of the micro-climate of a particular site, the direction of cooling summer breezes, cold winter winds, wind-borne dust, etc is required.

Planning

In temperate climates, buildings that are longer in the east-west direction, rather than in the north-south direction, are more efficient for both winter heating and summer cooling. This planning allows for maximum glazing to the north and minimum east-west exposure to morning and afternoon sun, **Figure 7**.

This does not mean that all buildings must be so planned. Different building solutions can cope with the particular conditions of each site. These include the building shape, number of levels, and effective glazing, including the use of clerestory windows and roof lights, combined with adequate shading.

Hot arid climates demand high thermal mass construction, with the ability to night purge with cool breezes and cross ventilation to re-charge the thermal mass for the following day. Sub-tropical humid climates demand a focus on cross-ventilation, particularly in the bedrooms, **Figures 8, 9 and 10**.

Interior spaces

When the location, general orientation and shape of the building have been decided, the organisation of interior spaces is then considered. In temperate climates, living spaces should be placed along the north face of the building. Least occupied spaces—such as storage areas, circulation areas and garages—should be placed along the south, where they act as a buffer between living space and the cooler south facing wall. Rooms that may benefit from morning sunlight, like bedrooms, bathrooms or kitchen areas, should be on the east wall. However, children's bedrooms can benefit from northern sunlight if they are to be used extensively for play or study. Attention should always be given to particular local climatic conditions.

Walls and windows

Internal walls can add substantially to the thermal mass of a building. External walls should provide insulation, surrounding thermally massive internal elements.

Windows required for light and ventilation also play an important role in the collection and retention of solar radiant energy. However, they should be treated differently depending on their orientation.

- Windows in north-facing walls have the greatest potential exposure to sunlight and can, when combined with heat-absorbing interior elements, benefit most from winter sun. However, they must be provided with appropriate sun-shading devices, such as eaves overhangs, to allow winter sun penetration while excluding summer sun.

- Full-height glazing in the northern wall of a house may be provided by sliding glass doors opening onto a patio or veranda.
- East-facing walls may have a few windows intended to catch morning sunlight that can be pleasant in any season in a temperate climate. However, north-east orientation should be used judiciously, as it is a potential source of excessive solar gain in summer months.
- South-facing walls never get useful direct sunlight in temperate Australia. Therefore, south walls should have only the minimum window area required for lighting, ventilation, and to admit cooling summer breezes. Alternatively, if there are significant views to the south and large windows are wanted, double glazing should be considered.
- West-facing walls should also have minimal window area, and should be protected (eg with external awnings or deciduous vegetation) from the low summer afternoon sun.
- In temperate and cold climates, all openings in walls (windows, doors or any other penetration) should be sealed around their perimeter to prevent seepage of air (infiltration). Because of their frequent use, the front and rear entry doors deserve special consideration. Infiltration around the frames may be controlled with self-adhesive sponge or mohair strips and a draught-excluder bar at the threshold. By recessing entry doors, protection against prevailing winds improves the performance of the door sealing. The planning of a small enclosed space or entry vestibule may be considered to act as an air lock, preventing further losses, especially in cool temperate climates. For rear doors, a laundry may provide this vestibule space.

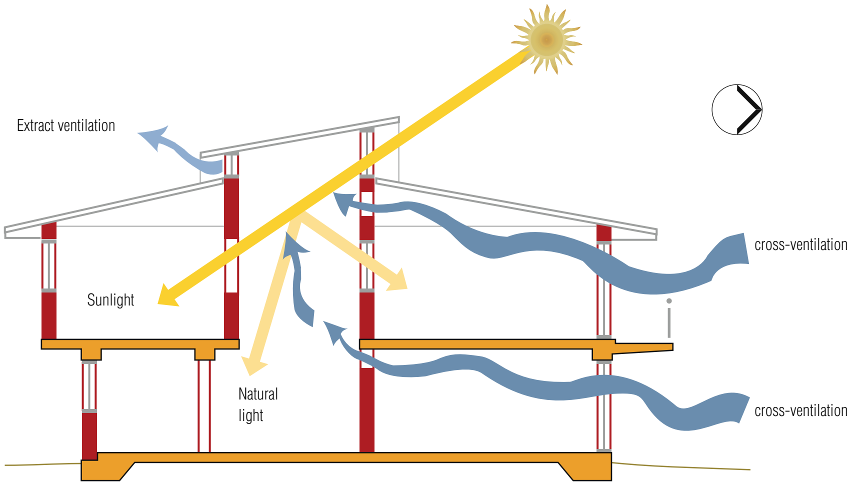


Figure 8 Ventilation strategies

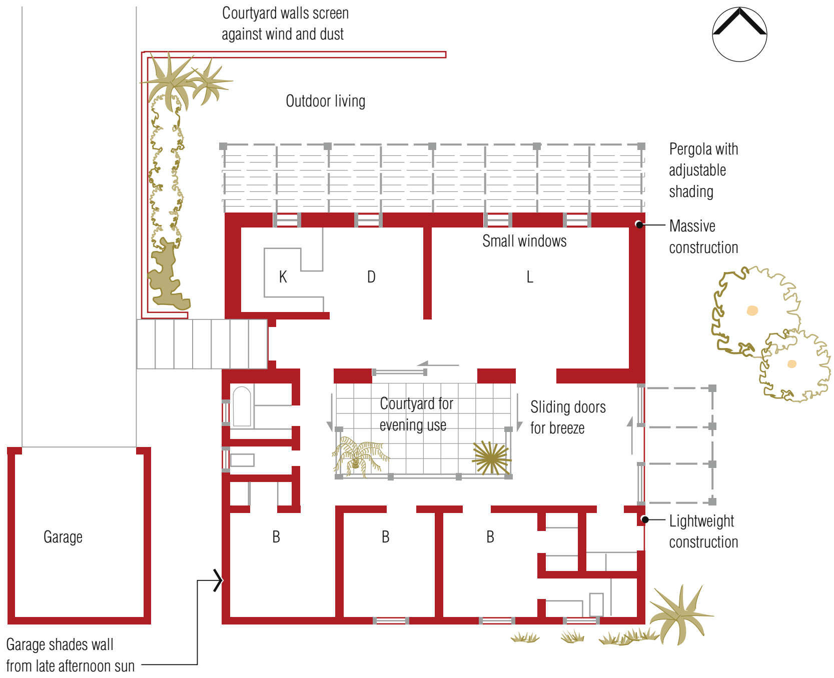


Figure 9 Planning for hot arid zones

CONCRETE OPTIONS

General

It is important that the distinction between the thermal mass and the structural weight of an element is understood. It does not necessarily follow that a heavyweight construction will automatically provide a high level of thermal comfort – this depends on the extent to which the elements can thermally interact with the occupied space, ie exchange heat with the internal environment. This relationship is known as thermal linking. It is therefore important that the insulation in external walls be behind the concrete inner leaf (eg in the cavity). If ground floors are insulated, the insulation should be located below the slab. The simple rule is that, as far as practicable, the surface of the concrete should be left thermally exposed, eg by using finishes such as paint, tiles, or plaster. The presence of internal finishes such as plasterboard and carpet (particularly with underlay) will, to some extent, act as an insulating layer and reduce available thermal mass.

Ground floors

Provided there is no insulation below a concrete slab-on-ground, it will act together with the ground, at near-constant temperature, to provide enhanced thermal mass.

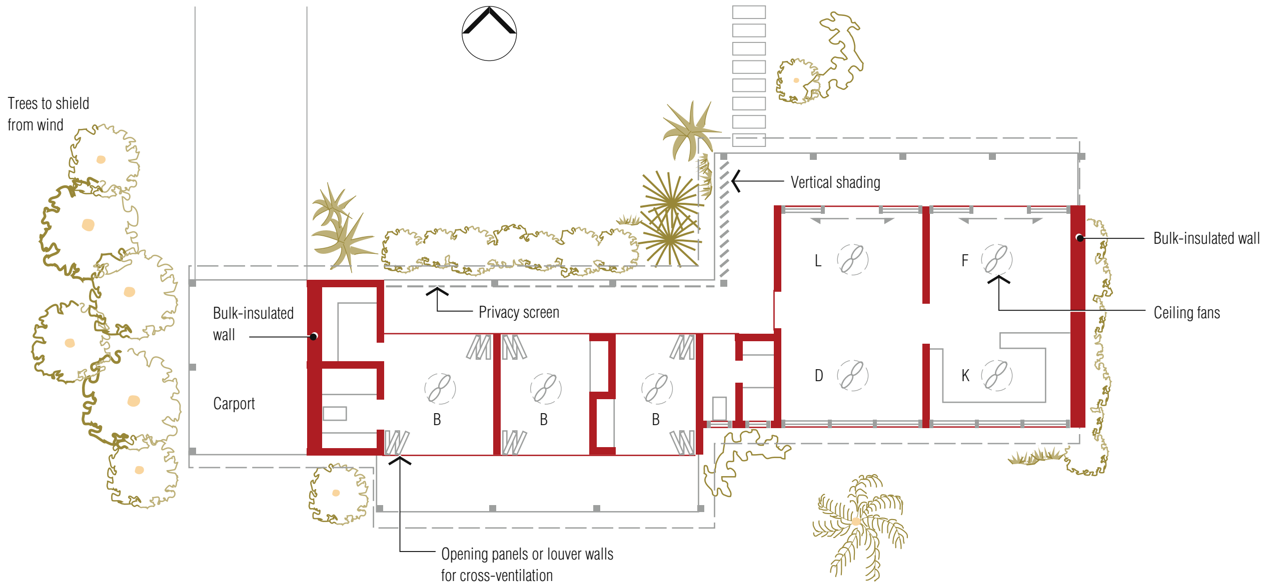


Figure 10 Planning for sub-tropical humid zones

The edge of the concrete slab-on-ground should be insulated in severe cold climates to prevent heat loss. To maximise heat exchange to and from the slab, the surface receiving sunlight should not be carpeted. A thermally-effective finish can be achieved by using materials such as high density concrete or terracotta tiles, fixed directly to the slab using a full-bed mortar-based adhesive. Alternatively, a vinyl floor covering will provide an intermediate level of effectiveness.

Slab-on-ground floors with under-floor insulation work well with under-floor heating, which is ideally suited to high thermal mass dwellings. Generally, the pipework for an under-floor system is located within the surface screed. Guidance on designing and sizing under-floor heating systems can be found in *Concrete Floor Heating*[9].

Upper floors

Concrete suspended floors may provide many of the same benefits as slab-on-ground by virtue of their substantial thermal storage capacity. Many precast concrete suspended flooring systems are structurally stronger, have better fire and acoustic ratings, and can offer speed of construction, when compared to lightweight alternatives.

The high quality fair-faced finish of precast *hollowcore* units makes them an ideal choice. The soffit only requires painting, leaving the concrete surface fully exposed for good thermal linking. A study[10] has shown that the use of *hollowcore* suspended floors provides additional passive cooling/heating effect, when compared to a masonry house with suspended timber floors.

Composite floors consisting of precast concrete permanent formwork (reinforced or prestressed) and an insitu concrete topping are also effective. The concrete formwork can immediately be used as a working platform. Minimum or zero propping is required. Services such as under-floor heating/cooling systems can be installed prior to placing the insitu concrete topping. The soffit of the panel usually has a high quality finish which can simply be painted.

Walls

The Building Code of Australia (BCA)[11] provides the basis for building regulations in each Australian state and territory. Volume 2 is applicable to Class 1 detached housing and Class 10a minor structures, while Volume 1 applies to all other buildings. BCA 2010 Volume 2 makes provision for external walls with high thermal mass, ie having a surface density of 220 kg/m^2 or more. These are deemed to achieve acceptable levels of thermal performance in certain climate zones, due to their ability to store heat (thermal mass) and slow the heat transfer through the building fabric. Examples of typical wall constructions that achieve a surface density of at least 220 kg/m^2 are:

- Two leaves of 90-mm or greater concrete masonry.
- 140-mm or greater dense-weight hollow concrete blocks with
  - 10 mm plasterboard or render; and
  - at least one concrete-grouted horizontal bond beam; and
  - vertical cores filled with concrete grout at centres not exceeding 1000 mm.
- 140-mm or greater concrete wall panels and dense-weight hollow concrete blocks with all vertical cores filled with concrete grout.
- 190 mm thick or greater dense-weight hollow concrete blocks with at lease one concrete-grouted horizontal bond beam; and vertical cores filled with concrete grout at centres not exceeding 1800 mm.

The thermal resistance of concrete walls should be augmented by some form of insulation, particularly in colder climates, to ensure that the benefits of the thermal mass are realised. Ideally, the insulation should be placed on the outside of the building, and the thermal mass retained on the inside. Insulated concrete panels (or 'sandwich panels') offer a solution. They consist of a polystyrene core 'sandwiched' between two concrete panels, and bound together during casting with non-metallic ties.

12 APR 2010

Construction using these panels is no more difficult than with standard solid concrete panels, but it offers significantly better thermal and acoustic insulation.

Using concrete for internal walls can substantially increase the heat storage capacity of the whole building. Thickness of internal walls should meet BCA requirements for sound insulation and fire safety.

Concrete – the responsible choice

Sustainable development is the outcome of giving balanced consideration to the three pillars of sustainability; social, environment and economic.

- Social – Concrete's strength, thermal mass, fire resistance and sound insulation properties create housing with excellent living comfort, security, health and safety leading to an improved social infrastructure.
- Environment – Concrete's thermal mass reduces the whole-of-life energy use and associated greenhouse gas emissions from a typical house, and results in a lower environmental impact.
- Economic – Concrete's excellent durability, low maintenance requirements and high energy-efficiency reduces the overall cost of both construction and operation phases, and results in better economic outcomes.

In Australia, there has been growing awareness of the need to build energy efficient houses, with optimised thermal performance and occupancy comfort. When concrete's thermal mass is used in building design, household energy consumption and CO_2 emissions can be significantly reduced by reducing or eliminating the need for heating and cooling systems. It makes economic sense for householders to invest in a thermally comfortable home that will provide cost savings for the rest of its life. Concrete is the responsible choice for energy-efficient homes and sustainable development.

REFERENCES

1 CCAA website – www.ccaa.com.au/LCA.

2 *Environmental Issues: Energy Use and Conservation,* ABS Report 4602.0.55.001, March 2008.

3 *Electricity price rises across Australia*, www.dme.qld.gov.au.

4 http://news.theage.com.au/breaking-news-national/electricity-prices-to-rise-by-up-to-64-20100318-qgk9.html

5 *Thermal Mass Explained* The Concrete Centre, 2006.

6 Phillips, R O *Sunshine and Shade in Australia* Technical Report No. 92/2, CSIRO, 1992.

7 *Passive Solar Design* Briefing 09, Cement Concrete & Aggregates Australia, 2003.

8 *Climate-responsive House Design with Concrete* (T58) Cement Concrete & Aggregates Australia, 2007.

9 *Concrete Floor Heating* Briefing 07, Cement Concrete & Aggregates Australia, 2002.

10 *Thermal Mass for Housing* The Concrete Centre, 2008.

11 *Building Code of Australia* Australian Building Codes Board, 2010.

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:
Suite 2, Level 2, 485 Ipswich Road
Annerley QLD 4103
TELEPHONE: (61 7) 3227 5200
FACSIMILE: (61 7) 3892 5655

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:
PO Box 229
Fullarton SA 5063
TELEPHONE: (61 8) 8274 3758

PREMIXED CONCRETE AND EXTRACTIVE INDUSTRIES OFFICE
PO Box 243
Henley Beach SA 5022
TELEPHONE: (61 8) 8353 8151
FACSIMILE: (61 8) 8125 5822

TASMANIAN OFFICE:
PO Box 246
Sheffield TAS 7306
TELEPHONE: (61 3) 6491 1509
FACSIMILE: (61 3) 6491 2529

WEBSITE: www.ccaa.com.au

EMAIL: info@ccaa.com.au

ISSN 1447-199X

CEMENT CONCRETE & AGGREGATES AUSTRALIA

concrete
the responsible choice