

# BDP ENVIRONMENT DESIGN GUIDE

## Thermal Mass in Building Design

David Baggs & Neal Mortensen

*This paper was originally published in August 1995. It has now been fully reviewed by the authors and republished to reflect updates to the topic since original publication.*

### Summary of

## Actions towards Sustainable Outcomes

### Environmental Issues/Principal Impacts

- Materials with properly incorporated thermal mass enhance thermal comfort in residential and low use-intensity commercial buildings, particularly low-rise, when combined with passive solar design.
- Proper incorporation means that the volume of mass in a building is balanced with the area, aspect and shading of windows. The level of insulation in both walls and roof/ceiling is relevant to the climate.
- Enhanced comfort means the minimisation of greenhouse gas emissions from fuel-based heating and cooling in buildings.
- The use of mass is the only way (apart from natural ventilation) that buildings can be passively cooled without expenditure of energy.
- The thermal effect of mass is measured mainly by three parallel factors: R-value, thermal diffusivity and time lag (decrement) effect.
- Mass improperly employed can amplify the unpleasant aspect of a climate.

### Basic Strategies

*In many design situations, boundaries and constraints limit the application of cutting EDGe actions. In these circumstances, designers should at least consider the following:*

- Where possible, build on slab-on-ground. Where this is not possible, use slabs or timber floors with minimum under-floor ventilation to maximise earth-coupling effect
- In lightweight structures, consider use of lightweight steel framed concrete floors or isolated mass walls, supported by beams, to introduce mass
- Wherever possible, insulate mass walls externally or in the cavity

### Cutting EDGe Strategies

- Use second generation NatHERS software tools such as AccuRate to test the amount of mass needed for each design and climate, and to ensure a balance between glass, mass and insulation levels, and effects
- Provide summer night-time ventilation/flushing (night purging) – either manual or automated, particularly in commercial buildings to recharge the thermal mass for the following day
- Heat/cool storage in water tanks or hollow concrete floor planks; heating from active solar heat systems in winter and cooling from night-sky radiation losses in summer
- Use 'Green Roofs', (vegetated roofs) and earth integrated or insulated earth wall structures. Specify low embodied energy, high mass materials such as concrete made with cement extenders (cements made with supplementary cementitious materials e.g. fly ash, slag), rammed earth, mud-bricks, and re-cycled clay bricks. Use recycled mass products such as recycled bricks or concrete gravel to increase the ecological value of mass elements.

### Synergies and References

- BDP *Environment Design Guide*, Volume 1: Gen 12, Tec 2 and 6; Volume 2: Des 2, 20 and 23; Volume 3: Pro 8 and 12
- Hastings, SR, 1999, *Solar Air Systems*, Built Examples International Energy Agency, James and James, London
- Sunaga, N, 1999, *A Bioclimatic Design for Tropical Climates*, PLEA 99 Sustaining the Future. Energy/Ecology/Architecture, Volume 2, Passive and Low Energy Architecture Conference, PLEA International with University of Queensland, Brisbane
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## Thermal Mass in Building Design

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*This paper was originally published in August 1995. It has now been fully reviewed by the authors and republished to reflect updates to the topic since original publication.*

*Thermal mass can be effectively employed in buildings to increase occupants' thermal comfort conditions. This paper seeks to clarify the ways in which this can be achieved and specifically investigates how, why, where, when and in what way thermal mass will have the most beneficial impact.*

### 1.0 Introduction

The introduction of thermal mass elements into buildings in most climate zones assists in the reduction of energy consumed in heating and cooling, can significantly reduce the ecological impacts of burning fossil fuels for energy production, as well as reduce costs, improve comfort and reduce or eliminate the need for air conditioning.

During warm months, introducing thermal mass into lightweight structures is the only way to passively cool a structure down once the external temperatures exceed comfort levels and ventilation and insulation fail to provide comfort. Likewise, in cooler months, using thermal mass in lightweight structures is the only way daytime temperatures can be stored to keep buildings warm in the evening without introducing external energy sources. The use of thermal mass to achieve these ends has, to date, been the domain of the concept known as 'Passive Solar Design'.

However, with the introduction of the second generation National Home Energy Rating Scheme (NatHERS) software tools such as AccuRate, First Rate and NABERS Pro, the sometimes seemingly rigid precepts of passive solar design become more like guiding principles to stimulate design where ideas can be tested, simulated more accurately and endlessly finessed. However there are still some realms where even these sophisticated thermal modelling tools lack depth.

This note seeks to explain thermal mass, its benefits and limitations to enhance an understanding of mass and its uses in ordinary buildings; and provide guidance in areas where even the sophisticated second generation thermal modelling tools do not deal adequately with the thermodynamics of more innovative means such as vegetated high mass structures (e.g. green roof, earth covered, earth integrated or green wall).

#### 1.1 Low Energy Comfort

History has shown that some indigenous communities have managed to provide themselves with thermally comfortable dwellings while expending minimum amounts of additional energy. For example, the adobe Taos Pueblo in New Mexico has been in continuous occupation for over 1000 years, harnessing the diurnal temperature swing to stay comfortable throughout the year with comparatively minimal additional energy requirements, even in winter. In the 1930s, North American architects began experimenting with the

'greenhouse' effect as a means of house heating, with the Crystal House, at the 1933 Chicago World's Fair, an early example (AIA Research Corporation 1976). Since then, millions of dollars have been spent on research into solar orientated buildings in an attempt to understand how to balance the amounts of glass, thermal mass, insulation and insolation (solar access) required to produce low energy use comfortable environments.

#### 1.2 Mass and Comfort

While the 'greenhouse' effect can trap large amounts of heat during the day, this heat can also be quickly lost unless materials that act as a storage medium for the heat – or thermal mass – are used. Thermal mass influences comfort by radiant exchanges with the skin. In fact radiant exchange with high mass surfaces is singularly the most efficient way of maintaining comfort compared with another technique as the body is more than twice as sensitive to radiant losses and gains than all other pathways combined (conduction, convection, respiration, evaporation) and more than four times as sensitive as any other single pathway.

In summer, the thermal mass effect is the most important of only three commonly possible means of passively cooling a structure without the use of externally sourced (active) energy or fuel. The others are ventilation and evaporation. As noted above, in many climatic conditions, thermal mass effects are the only means of cooling a building.

In winter, mass storage effects can create comfort by harnessing large amounts of excess solar energy to initially store and later radiate low level radiant heat via a 'thermal flywheel' effect. In doing so, thermal comfort of occupants can be maintained while achieving energy savings of up to 100% in heating and cooling loads (in some building types). This effect is dependent on the amount of mass introduced and the balance and composition of a number of key building parameters such as glass area and protection, insulation, orientation, ventilation and building usage.

However, it is important to realise that history has shown that mass must be carefully employed as it is possible to amplify the unwanted aspects of a climate by inappropriate use. Hence it is important that, from the outset and where possible, architects work with at least second generation NatHERS software tools to optimise the design effectiveness and integration

of thermal mass components. With very high mass buildings or 'added mass systems' such as sub-floor gravel bed or phase change systems, the use of specialised building services engineers who are knowledgeable in passive/active systems and use simulation software capable of modelling them (or consultants experienced in vegetated earth temperature simulation for green roofs or earth integrated buildings), to design systems in an integrated way and maximise simulation accuracy is wise.

## 2.0 Thermal Mass and Personal Comfort

### 2.1 Storage of Heat

Thermal mass is the ability of a material to store heat and is a function of its specific heat (kJ/kg.K) – the amount of heat required to increase 1 kg of material by 1°K – and its density. The thermal mass or storage capacity of a material can be measured by its volumetric heat capacity (kJ/m³.K) – the amount of energy stored in a unit volume of material (m³) for a 1°K rise in temperature. Materials suitable for thermal mass are heavy (or dense) materials with the ability to store large amounts of heat energy to provide warmth in winter and coolth (the opposite of warmth) in summer, within a relatively small volume (see Table 1).

### 2.2 Thermal Comfort

Thermal comfort exists when a body's heat loss equals its heat gain or *vice versa*. The body exchanges 62% of this heat via radiation, 15% by evaporation, 10% by convection, 10% by respiration and 3% by conduction. Hence, when considering normal comfort conditions inside a building the radiative effect of surrounding surfaces is at least as important as air temperature. Relatively small changes in mean radiant temperature have a far greater effect than similar changes in air temperatures (Ballinger 1992, p 39). This gives rise to the importance of recognising the overall Environmental Temperature [T(env)], as opposed to the dry bulb temperature.

$$T(env) = \frac{2}{3} \text{ Mean radiant surface temperature} + \frac{1}{3} \text{ Air temperature}$$

Thermal mass influences bodily comfort by providing heat source and heat sink surfaces primarily for the radiative heat exchange processes. Thermal comfort is explored in more detail in Des 12: *Perceived Comfort* (BDP Environment Design Guide, Volume 2)

Material	Density (Kg/m³)	Specific heat (KJ/kg.K)	Volumetric heat capacity thermal mass (kJ/m³.K)
Water	1000	4.186	4186
Concrete	2240	0.920	2060
AAC	500	1.100	550
Brick	1700	0.920	1360
Stone (Sandstone)	2000	0.900	1800
FC Sheet (compressed)	1700	0.900	1530
Earth Wall (Adobe)	1550	0.837	1300
Rammed Earth	2000	0.837	1673
Compressed Earth Blocks	2080	0.837	1740

**Table 1. Density, Specific Heat and Thermal Mass of a Range of Materials**

Note: Figures are based on a number of sources and include estimations and interpolations.

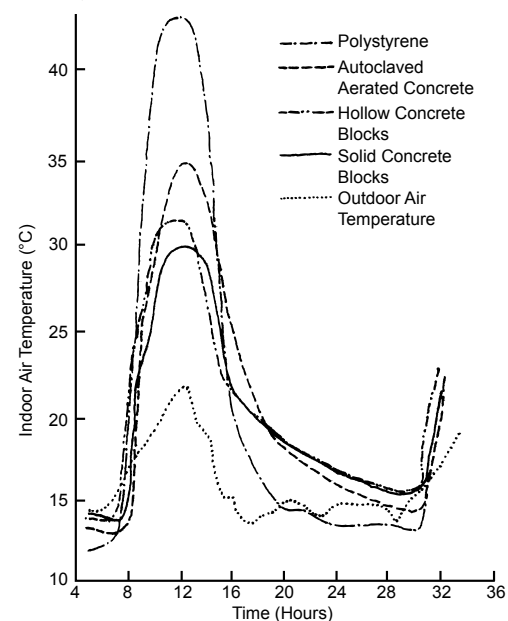
## 3.0 Thermal Mass and Internal Air Temperature

Thermal mass affects the temperature within a building by stabilising internal temperatures in three ways:

- *stabilising internal temperatures* by providing heat source and heat sink surfaces for radiative, conductive and convective heat exchange processes
- providing a *time-lag* in the equalisation of external and internal temperatures
- providing a *temperature reduction* across an external wall (the decrement factor).

### 3.1 Stabilisation of Internal Temperatures

When heat enters a space directly by penetration of sunlight, lighting, equipment losses or heating, the temperature rise will be in inverse relationship to the accessible volume of thermal mass. Therefore, the indoor temperature will rise almost immediately if there is little thermal mass in the room. Figure 1 uses an example of a simple box 1150 x 1530 x 1570 mm, with a single window 660 x 1010 mm to demonstrate the effect of thermal mass on internal air temperature using a variety of materials.



**Figure 1. Thermal Mass Effects on Diurnal Indoor Temperatures**

In situations of high thermal resistance and low levels of thermal mass, rapid heating and cooling will occur. Conversely, low levels of thermal resistance and high thermal mass significantly reduce the necessity for heating and cooling (Givoni 1981, p 144). This effect is also demonstrated in Figure 2, which compares two houses, one of lightweight construction (brick veneer, uninsulated walls, timber floor) and the other of heavyweight construction (double brick, insulated, slab on ground).

The mass effect can be enhanced with the use of insulation external to the mass and insulation of the glazed areas. In summer, thermal mass can be used in conjunction with passive solar design strategies to inhibit heat build up. In areas where there is a significant diurnal temperature range, night ventilation will cool the building by convection, leaving it ready to absorb the heat build up during the next day. Table 2 describes user shading and ventilation strategies for summer thermal comfort.

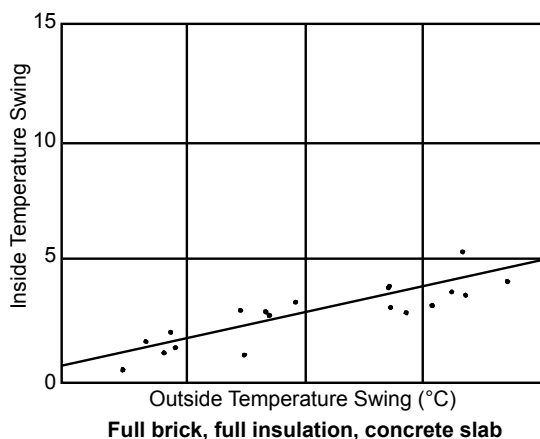
Device	Summer		Winter	
	day	night	day	night
Windows, doors	closed	open	closed	closed
Blinds (external)	closed	open	open	closed
Curtains (internal)	closed	open	open	closed

**Table 2. User Control of Shading and Ventilation Devices**

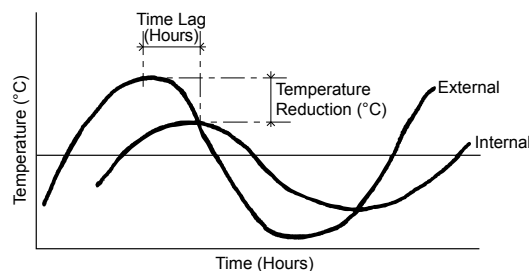
In winter, thermal mass will increase thermal comfort in a building when solar heat stored in the materials during the day is released as internal temperatures fall. Heat loss from the building after the sun has left the glazing can be prevented by drawing insulating curtains over the windows, or by using double glazing permanently in place. Table 2 describes user shading and ventilation strategies for winter thermal comfort.

### 3.2 Time Lag

The effect of using heat generated during the day to warm at night in winter and vice versa in summer is known as the 'thermal flywheel' effect. The effectiveness of the flywheel depends on the time lag introduced to a building by an external wall or other boundary element. As can be seen from Figure 3, time 'lag' is the time delay between external maximum or minimum temperatures and internal maximum or minimum temperatures respectively.



**Figure 2. Comparison of Lightweight and Heavyweight Homes**



**Figure 3. Time Lag and Temperature Reduction**

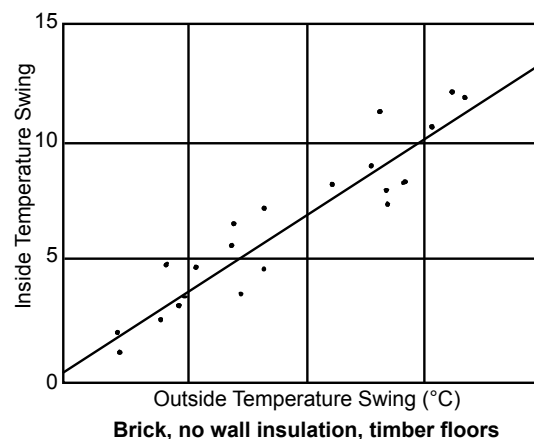
Time lag is determined mostly by the rate of heat transfer through an element or material. For most low-rise buildings in temperate climates, massive external walls which can achieve a time lag of 10-12 hours can be effectively used without the need for external insulation. Massive walls such as double brick or concrete blocks have a time lag of less than 10 hours and will need some lightweight or resistive insulation even in temperate climates. Otherwise external temperatures will 'break through' into the interior before external conditions have cooled down enough to allow ventilation cooling. Table 3 shows time lag figures for a variety of building materials. In cool climates where significant heating is necessary and adequate solar gains cannot be relied to keep overnight temperatures stable, insulation of exposed external walls is warranted.

In earth covered and earth-integrated buildings where floor levels can be 4-5 metres 'below' ground, the time lag effect can be manipulated so that instead of a *diurnal* time lag (where day heats night in winter and night cools day in summer), a *seasonal* time lag can be experienced where summer temperatures warm the occupants in winter and winter temperatures cool them in summer.

Material (thickness in mm)	Time lag (hours)
Concrete (250)	6.9
Double Brick (220)	6.2
AAC (200)	7.0
Adobe (250)	9.2
Rammed Earth (250)	10.3
Compressed Earth Blocks (250)	10.5
Sandy Loam (1000)	30 days

**Table 3. Time Lag Figures for Various Materials**

Source: Baggs, SA, JC, DB. 1991, *Australian Earth-Covered Buildings*.



### 3.3 Temperature Reduction or Decrement Factor

As heat travels through external walls constructed of massive materials, there is an overall reduction in the size or amplitude of the energy wave, resulting in less heat loss from or heat gain to a structure, thus providing an overall lower temperature swing internally than would be the case without the mass. The larger the decrement factor, the better the stabilisation of internal temperatures.

## 4.0 Design Considerations

### 4.1 Thermal Mass and Building Type

The most obvious energy efficiency benefits from the use of thermal mass accrue in low-rise buildings. Thermal mass, when used together with passive solar design techniques and natural ventilation, can effectively eliminate the requirement for air conditioning. Temperatures in such buildings can 'free-run' – that is, they do not need to be modified artificially except for small amounts of heating on extremely cold days or during extended overcast periods. Buildings in this category include single houses, medium density residential, low-rise commercial buildings and some small scale educational and industrial buildings. The internal conditions in such buildings are dominated by the influence of the climate.

In other building types including medium and high-rise commercial and educational structures, the internal conditions are generally dominated by the heat loads generated within the building envelope and these are typically cooled by other means, including air conditioning.

### 4.2 Thermal Mass and Air Conditioning Loads

Mass can be extremely useful in structures which require air conditioning. This can be achieved by night-time cooling of the mass to reduce the day-time heat loads in summer, or to even out the heat

loadings in winter and eliminate the need for cooling during winter. Baverstock (1994) has shown that mass used in this way can provide 27% of the overall building cooling benefits and 38% of the overall building heating benefits. This was in an energy efficient commercial building in Perth that was shown to be 69% more efficient than average non-low energy buildings and 79% more efficient than the recommended upper-range figures published by the Property Council of Australia for Perth. For more detailed information, refer to the BDP *Environment Design Guide* case study *Cas 2: Solar Information Centre, Perth*.

Leading edge commercial buildings use a variety of ways of engaging thermal mass cooling or pre cooling of spaces to minimise the amount of cooling needed. Examples of these systems include eliminating ceilings and exposing the underside of floor slabs, using access floors over exposed floor slabs as plenums to deliver conditioned air (pre-cooling the slabs using night time ventilation allows late start up and/or early shut down of chillers).

### 4.3 The Air/Mass, Glass/Mass Relationship

#### Air/mass

Baverstock (1994) also confirms previous authors' claims that energy savings of approximately 70-90% are achievable in air conditioned commercial buildings by using energy efficiency techniques in combination with thermal mass. He noted that for the thermal mass to work effectively at reducing air conditioning loads, the thermal mass had to be 'accessible' to the air mass within the building. Accessible spaces include exposed walls and partitions, ceilings and tiled concreted slab floors. He also found that *the required relationship between area of mass and the gross floor area of the building was 0.6 or greater* where the thermal mass was 150 mm thick structural concrete (2400 kg/m<sup>3</sup>, 2040 kJ/m<sup>3</sup> storage capacity). While Baverstock used floor area as the reference, the functional relationships are really between the internal volume of air in a room or building, and the surface area and heat storage capacity of the mass that is accessible to that air.

Location	Thermal mass volumes (m <sup>3</sup> )			Total heat storage required (KJ)	Air volume/mass surface area ratio for floor area of 200m <sup>2</sup> (kg of mass per m <sup>3</sup> of air)
	Concrete on ground	Brick	Other Render/timber		
Hobart	20	37	5	95000	86
Sydney	20	32	5	88500	80
Perth	20	32	5	88500	80
Adelaide	20	25	5	80000	75
Melbourne	20	13	8	66000	60
Canberra	20	13	8	66000	60
Brisbane	20	6	8	55500	50
Darwin	7	6	8	30000	27

**Table 4. Thermal Mass Requirements (for passive solar homes and small commercial buildings and spaces)**  
Source: adapted from Baverstock, G and Paolino, S, 1986, Low Energy Buildings in Australia, Graphic Systems, Western Australia.

Assuming an average commercial building ceiling height of 2.7 metres, this provides an air volume/thermal mass requirement of 1 m<sup>2</sup> of 150 mm thick concrete (or equivalent) for every 4.5 m<sup>3</sup> of air, or in other terms, (for Perth and similar climates such as Adelaide & Sydney i.e., BCA climate zone 5):

*The optimum air volume/mass ratio = 80 kg of mass per cubic metre of air*

(concrete at 2400 kg/m<sup>3</sup>, 2040 kJ/m<sup>3</sup> storage capacity and 150 mm thick).

In a building with this minimum exposed mass provided, Baverstock showed savings of up to \$24/m<sup>2</sup> pa (at 18 c/kWh) over conventional, inefficient buildings in Perth. Savings possible in other cities can be interpolated from other figures provided by Baverstock and Paolino by comparing the thermal mass requirement of Perth with other cities, as summarised in Table 4. These figures have been generated by the *TECTO Simulation Program*.

The total heat storage requirements shown in the table below are based on the volumetric heat capacity figures for various materials shown in Table 1. Furthermore, for each climate represented by the capital cities shown in Table 1, there are corresponding glass area and insulation values that need to be applied for optimum energy efficiency.

#### Glass/Mass

There are also optimum ratios for the combination of windows and thermal mass. In winter, mass needs heating to enable comfort conditions to be maintained. This heat will ideally come from solar gain provided by north-facing or other windows with appropriate summer shading. Table 5 shows the recommended area of north-facing windows for each capital city, based on the minimum thermal mass volumes shown in the previous table. The source of this data (Baverstock and Paolino 1986) also provides recommended window areas for walls with other aspects.

The inter-relationships between the information detailed in Tables 4 and 5, i.e., climatic conditions, thermal mass storage requirements and window areas can be seen in Figure 4. In general it can be seen that the more extreme the daily maxima and minima, the higher the thermal mass requirements, and the more window area needed to warm the mass in winter.

Location	North Window Area (% of overall building floor area)
Hobart	17.0
Sydney	15.5
Perth	14.5
Adelaide	14.0
Melbourne	13.5
Canberra	12.5
Brisbane	9.5
Darwin	4.75

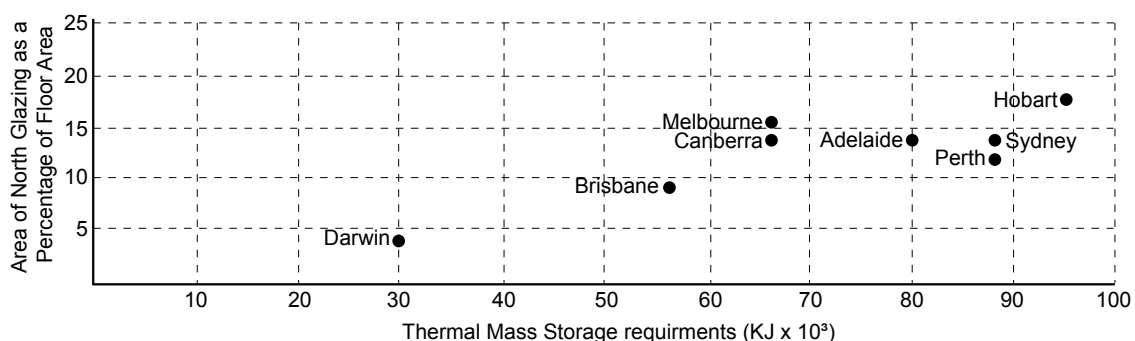
**Table 5. Recommended North Window Area (For Passive Solar Homes and Small Commercial Buildings or Spaces)**

Source: adapted from Baverstock, G and Paolino, S, 1986, *Low Energy Buildings in Australia*, Graphic Systems, Western Australia; and Ballinger, J, et al, 1992, *Energy Efficient Australian Housing*, 2nd. Edition, AGPS, Canberra.

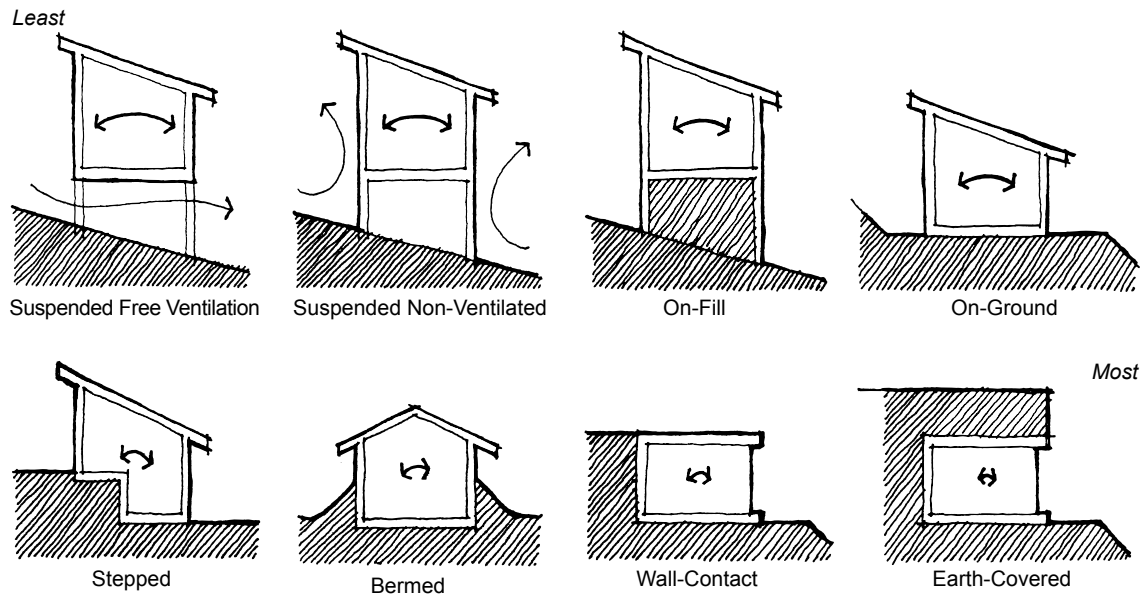
#### 4.4 Locating Mass in a Building

The most economical and effective means of locating mass within a building is to place it where it can have contact with dry earth, e.g. a slab-on-ground. As well as providing the thermal mass of the slab, this has the effect of earth-coupling the air mass inside the home to the infinite thermal mass of the ground beneath it. This coupling with the earth provides the occupants with resultant indoor temperatures which are far more stable than externally. In summer, if the slab is not insulated with carpet, a slab-on-ground provides a building with the potential for significant heat losses to the earth. In winter, a slab-on ground not only provides the potential for storage of daily solar heat gain from north windows but, even during overcast days, also provides significant stored heat from the earth below the slab. Figure 5 shows examples of construction techniques that will provide this effect (in order of increasing benefit).

The arrows inside the building indicate the diurnal internal temperature range. All options use slab floors, and all will provide more comfortable internal temperatures than a suspended timber floor. However, if none of these are possible, the next preference in locating mass within a building is the internal walls of an insulated skin structure. This can be in the form of partition walls or the internal skin of external, insulated cavity walls.



**Figure 4. The Inter-relationship Between Climate, Glass and Mass**  
(for passive solar homes and small commercial buildings or spaces)



**Figure 5. Temperature Modification by Thermal Mass**

## 4.5 Locating Insulation Relative to Mass

### Concrete Slab-On-Ground

Except in the most extreme climates, a concrete slab-on-ground does not require insulation on the complete underside, as this negates the effect of earth coupling. In extremely hot or cold climates polystyrene sheet foam insulation along the edge of the concrete slab and extending as a 'skirt' for 1.2 metres around the perimeter is preferred (Watanabe 1986).

### Suspended Concrete

Insulation is not required on the underside of suspended concrete slabs supported by fully enclosed walls. However, as the air space under the slab provides indirect 'earth-coupling', it should be isolated from the outside air by insulating the walls.

Suspended concrete slabs with the external surface exposed to the elements will require insulation located on the outside surface (i.e. underside of floor slab and top side of roof slab).

### External Walls

Because the time lag of external walls such as double brick, concrete block and stone are less than the desired 10-12 hours, they always require insulation located within the cavity where possible or preferably on the outside surface to ensure adequate thermal isolation. Current BCA 'Deemed to Satisfy' provisions require minimum levels of added insulation for all these wall types and are a good indicator of desirable insulation levels on different climates.

In the case of the various kinds of earth walls such as adobe, rammed earth and compressed earth blocks, with their time lags of 10-11+ hours, their apparent performance is enhanced if they are either left unsealed or finished with a 'breathable' paint. This is to take

advantage of the thermal energy which can also be absorbed or released by the processes of latent heat of water vaporisation or condensation. These processes are believed to provide earth walls with actual thermal performance characteristics which exceed the theoretical or calculated thermal performance. Research currently being undertaken at the *Cra' Terre* Institute of France has indicated that favourable winter thermal performances seem to rely heavily on this yet to be fully quantified effect. Nonetheless in cold temperate and cold climates the thermal performance of even earth walls can necessitate the introduction of insulation if inadequate solar heat cannot be stored from daytime gains.

### Australian Climate Zones and Types

The main characteristics of the Australian capital cities or major centres in the eight climate zones cited in the Building Code of Australia are summarised below. Thermal mass is important in Zones 3-8 and useful in Zones 1 and 2 when used correctly.

## 4.6 Impact of Room Shape

The mass walls within a passive solar building receive most of their heat from internal air. If the house has high cathedral ceilings, when the heated air stratifies, the absorbed heat is located too high up the walls to be effective for the comfort of the occupants (the use of ceiling fans can reduce this stratification to some extent). With horizontal plaster or concrete ceilings the rising hot air will stratify closer to floor level and the heat energy passing into the walls is more effective due to its proximity to occupants. In rooms with the same floor areas and solar access but with different ceiling configurations, and without additional heating or air movement techniques being employed, environmental temperature variations of up to 3-4°C can occur.



Zone	Climate Type	Characteristics	Examples
1	Tropical	Hot humid summer, warm winter	NT: Darwin, Katherine; WA: Broome, Karratha; Qld: Cairns, Townsville
2	Sub-Tropical	Warm humid summer, mild winter	Qld: Mackay, Rockhampton, Brisbane; NSW: Byron Bay, Coffs Harbour
3	Hot Arid	Hot dry summer, warm winter	WA: Shark Bay, Halls Creek NT: Tennant Creek, Alice Springs Qld: Mount Isa, Birdsville, Charleville
4	Hot Dry	Hot dry summer, cool winter	WA: Meekatharra, Kalgoorlie SA: Oodnadatta, Tarcoola, Whyalla NSW: Bourke, Tamworth, Dubbo Vic: Mildura, Swan Hill
5	Warm Temperate	Warm summer, cool winter	WA: Perth, Geraldton, Esperance NSW: Sydney, Wollongong, Newcastle
6	Mild Temperate	Mild to warm summer, cool winter	Vic: Melbourne, Orbost, Warnambool SA: Mt Gambier WA: Albany, Pemberton
7	Cool Temperate	Mild to warm summer, cold winter	ACT: Canberra NSW: Cooma Tas: Hobart, Launceston
8	Alpine	Warm summer, cold to very cold winters	NSW: Thredbo Vic: Mt Hotham Tas: Breona

**Table 6. Australian Climate Zones and Types**  
(Source: Australian Building Codes Board)

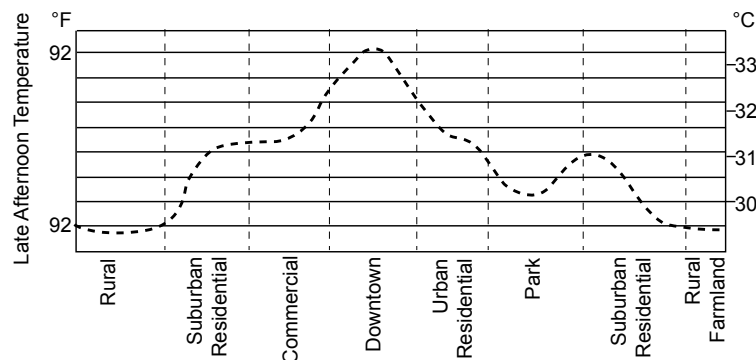
#### 4.7 Impact of Mass on Ventilation Heat Loss

From a health point of view, it is desirable to provide some ventilation to internal spaces to remove internal pollutants. Off-gassing of hazardous chemicals such as formaldehyde, plasticisers and radon gas ordinarily tend to build up in the indoor environment if left unchecked. The polluted internal air requires replacement with outdoor air by flush ventilation (short sharp flushes are recommended). While the period of ventilation can be short, it is important (particularly in the case of radon) that a significant volume of air is exchanged. The provision of thermal mass to a space allows this ventilation to occur with the loss of only a small amount of stored heat energy or 'coolth', compared to a lightweight structure, which would lose the majority of its stored heat under these conditions.

#### 5.0 Urban Heat Island Effects

One thermal mass effect that is having significant deleterious impacts in cities around the world including Australia is known as the Urban Heat Island (UHI) effect. This is a function of high mass surfaces in the city such as concrete roofs, roads and to a lesser extent walls, absorbing daytime heat and re-radiating it at night. This re-radiated heat forms a heat 'halo' around the city and subjects all residents to significantly hotter night time conditions.

Melbourne University recently measured average summer night temperatures 3.4-4.5 degrees Celsius above the long term mean and on still nights, increases of 10 degrees Celsius were experienced. Similar studies in Brisbane, Tokyo and many other cities worldwide have confirmed this phenomenon is common to all cities to some extent. This will have obvious impacts in decreased comfort and increase air conditioning loads. It may also have serious consequences for increased global warming and climate change if left unchecked.



**Figure 6. Urban Heat-Island Profile**  
Source: Heat Island Group

## 6.0 'Green Roof' Revolution

Urban heat islands have become such a phenomenon worldwide that vegetated green roofs on conventional buildings offices now account for 20% of the new roofs in Germany. In Tokyo it has been mandated on all new commercial buildings over 1000m<sup>2</sup> and massive projects are appearing throughout the United States, such as the 40,000 square metre green roof on the Ford Motor Company's Detroit manufacturing plant.

Green roofs provide significant energy savings via insulation, thermal mass, evaporation and evapotranspiration pathways as well as major water and visual quality outcomes.

They are being promoted for use in Australia also and were recently the subject of a book by NSW Government Architect Chris Johnson entitled *Greening Sydney*.

Green roofs are one form of earth integrated buildings that are the subject of the author's book *Australian Earth Covered Buildings* (see references at the end of this paper). Both of these books set out the benefits of earth integration and show that thermal mass effects combined with evapotranspiration and vegetative shade create thermal comfort, energy efficiency and other synergistic benefits well beyond the potential of ordinary structures (see references for further benefits).

## 7.0 Limitations of Software Tools

The second generation NatHERS tools such as AccuRate, First Rate and BERS Pro are significant improvements over first generation tools and they are effective at providing simulations of ordinary buildings. However they still have limitations that impact on their ability to accurately simulate (or in some cases simulate at all) certain building types, features and climates such as:

- Passive/Active add on systems;
- Inner city areas impacted by Urban Heat Island effects that are not included in the temperature data (normally taken at airports away from inner urban areas)
- Earth wall structures where the full thermal effects of these structures is still not fully understood and practical experience indicates that conventional understanding is inadequate to explain the full thermal effects of earth structures
- Vegetated green roofs and earth covered buildings where software that simulates shade cover, evapotranspiration and moisture dependent thermal diffusivity of soil is required.

More sophisticated commercial modelling tools such as DOE2, TAS and IES Virtual Environment are required to undertake these types of assessments in combination with specialised vegetated earth temperature simulation programs such as TCAL (see references).

## 8.0 Embodied Energy

There is a tendency to design high mass buildings with much reinforced concrete and clay fired bricks which tend to be high in embodied energy. This is particularly the case with deep earth covered buildings where in the past deep section in-situ concrete has been the preferred structure. However, in today's greenhouse gas emission (GGE) aware world, the GGE of the energy embodied in the structure needs to be compared against the savings due from the building's energy efficiency and the 'payback' analysed as to whether it is 'worthwhile'. If a structure takes 50 years to pay back its GGE of construction does this warrant the initiative even if the structure lasts 500 years? Given the imminence of global warming, probably not, so structures that use low embodied energy materials to provide access to mass need to be employed wherever possible e.g. any technique that provides access to the free mass of the earth by coupling either directly or indirectly as in Figure 5 where sketches 2-8 are easily made GGE efficient. Structures represented in sketches 9-11 need to be carefully considered to ensure low GGE profile structures and systems are used to minimise the 'payback' period. Obviously impacts such as urban heat island effect minimisation need to be taken into account in this process.

There are options available in some locations and markets to introduce low-embodied energy cement into some concrete products. Up to a fifty percent or higher embodied energy saving can be achieved by specifying cement blended with cement extenders (supplementary cementitious materials) such as fly-ash and granulated blast furnace slag. These products are commonly available and with larger projects and more complex concrete structures have the added advantage of resulting in a higher strength (MPa) concrete (albeit with longer setting times). Also, Tec-eco in Tasmania is researching and developing a magnesium based cement (and some products are already available from pilot projects) which actually absorb CO<sub>2</sub> during production.

## 9.0 Conclusion

Mass is an essential aspect of energy efficient design. However, mass alone will not create a thermally comfortable building. The inclusion of thermal mass has to form part of an integrated approach to the thermal design of buildings, incorporating correct orientation, appropriate areas and treatment of windows, insulation (when required), site integration considerations, appropriate use of natural and/or mechanical ventilation and appropriate back-up heating or cooling sources. It is important that designers consider energy efficiency techniques such as thermal mass as an inherent part of design and architectural expression and that they be included conceptually from the outset.

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## Biography

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