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Australian
Solar Energy Society
Tasmanian Branch

THERMAL MASS FOR COOL TEMPERATE CLIMATES

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Thermal mass within a building provides a more comfortable environment for both summer and winter. Thermal mass stores solar radiation entering through north facing glazing during the day, then at night re-radiates heat energy when the air temperature in the space drops below the surface temperature. Thermal mass ideally acts as a thermal flywheel, absorbing and storing excess heat energy during the day (preventing overheating) and releasing the heat energy at night, during both heating and cooling seasons.

Thermal mass should be in line of sight with the north facing glazing area (the collector) in order to obtain maximum thermal performance. During winter months heat energy re-radiates from the thermal mass keeping the building warmer. During summer months the thermal mass is flushed by cool air during the night, keeping the building cooler.

Fig. 1 Concrete floor and dark tiles serves as thermal mass in this house

Fig. 2 A feature stone wall facing a north facing glass house is used in this house as the thermal mass

Most commonly used thermal mass materials are concrete, bricks, blocks, rammed earth, stone and water. Figures 1 and 2 show the application of thermal mass in two houses in Tasmania. In Figure 1 the concrete floor covered by dark tiles serves as the thermal mass. It is important that solar radiation can directly strike the concrete floor. In Figure 2 the thermal mass is a stone feature wall situated adjacent to a sunroom. Solar radiation can strike the wall during sunny winter days warming up the thermal mass for night heating purposes.

Buildings with high thermal mass experience lower temperature swings within a 24 hour cycle compared to low mass buildings, resulting in lower maximum day time temperatures (preventing overheating) and higher minimum temperatures at night (keeping the building warmer).

THERMAL MASS PROPERTIES

To be effective as thermal mass, a material must have high heat storage capacity, high density and high emissivity. Concrete, stone, rammed earth and other masonry products are ideal, having a high capacity for heat storage, moderate conductance that allows the heat energy to be transferred deep into the storage material, and high emissivity to allow absorption of more radiation than is reflected. Conveniently, concrete, bricks and other masonry materials are commonly used in building construction and can be used as thermal mass materials, in the floors or internal walls of the building. Water is also effective as a thermal mass as it has a high heat storage capacity (specific heat content). Unlike concrete or bricks, water serves no structural purpose, but when stored in clear translucent containers can provide light and views through the (normally opaque) thermal mass. The volumetric heat capacity is a product of density of a material (kg/m^3) multiplied by the specific heat capacity of a material (KJ/m^3.K) and gives the capacity of heat storage in kilo-Joules (kJ) per 1m^3 of material per degree Kelvin (K).

Location of Thermal Mass

Thermal mass should be located within the well insulated building envelope. The better the building envelope is insulated, the more effective thermal mass will be. Locate thermal mass in north facing rooms with good solar access in winter and exposure to cooling night breezes in summer. During the summer months a wide overhang will prevent solar radiation entering the building as shown in Figure 3.

Amount of Thermal Mass

The optimal amount of thermal mass within buildings relates closely to the local climate, solar aperture or amount of northern glazing area, the amount of insulation and the sealing of the building fabric. Design guidelines recommending the amount of thermal mass required for optimal thermal performance can provide three different sizing methods given as:

- **Thermal capacitance of mass**, the measure of the amount of heat energy the thermal mass can store within the fabric of the building, given in MJ/K for the entire building, or per m^2 for easy comparisons between buildings (MJ/K.m^2). Figure 4 shows the design guideline for using the appropriate amount of thermal mass, related to the amount of north facing double glazing for 8 Australian cities located in different climates. For Hobart this figure recommends a northern glazing to floor area ratio of 17% and a thermal mass storage requirement of 95 MJ/K for optimal thermal performance (Baverstock & Paolino 1986).

- **Mass /floor area ratio**, the mass (kg) can be easily calculated, using the density and volume of the materials (kg/m^3). The mass ratio per m^2 is often used to compare the amount of thermal mass between different buildings (kg/m^2). Vale & Vale (1999) suggested that 1,200kg/m^2 of floor area will produce a zero heating house in cold European climate, while Oppenheim (2007) used 580kg/m^2 as a mass/floor area ratio in his buildings in Melbourne, Australia for optimum thermal mass storage.

- **Mass surface area to northern glazing area ratio**, the mass surface area to northern double glazing area is a convenient method of sizing thermal mass, assuming the thermal mass is evenly distributed throughout the building with an average thickness between 100 and 150mm for masonry materials. A mass surface to northern glazing area ratio between 6:1 (Your Home 2005) and 9:1 (Mazria 1982) is recommended for cool temperate climates like Tasmania. It is important to note that these guidelines only refer to thermal mass in visual contact to northern glazing.

Thermal Performance Prediction of Thermal Mass

The heating/cooling requirements star rating and thermal performance of three building types have been simulated for climate zone 26 (Hobart) and compared in table 1.

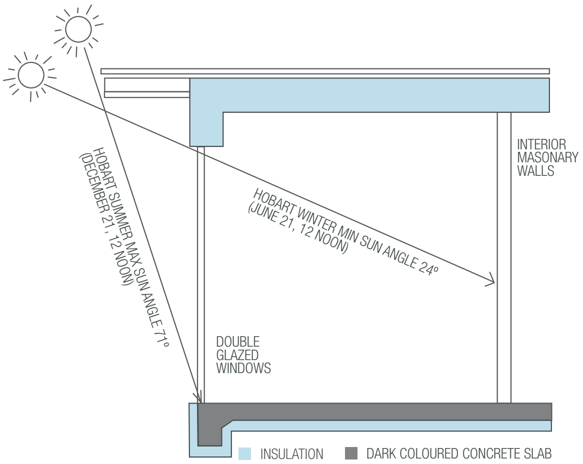
- A low-mass building, a timber framed light weight house with interior timber stud walls and plaster board finish and timber floors (36kg/m^2);

- A mid-mass building, a timber framed house with interior timber stud walls and plaster board finish with a 130mm concrete slab floor (382kg/m^2);

- A high-mass building, a timber framed house with 140mm concrete block walls (grout filled) interior thermal mass walls and a 130mm concrete slab floor with dark surface finish (1082kg/m^2).

All three houses have the same size, floor plan, levels of insulation and the same north-facing window area. The floor plan of the case study house is shown in Figure 5. Note that the majority of thermal mass of the houses is in direct visual contact with the northern glazing.

The star ratings and predicted heating and cooling requirements have been simulated with the House Energy Rating Software



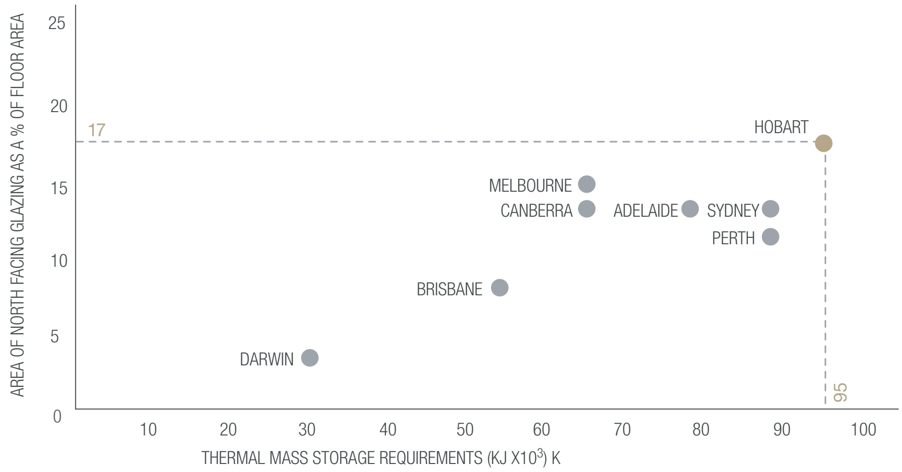


Fig. 3 Location of Thermal Mass in a Solar Passive Direct Gain System

Fig. 4 Inter-relation ship between climate, northern glass are and thermal mass
Source: Baverstock & Paolino 1986)

Table 1 Comparison of heating and cooling requirements and star ratings for a low-mass, mid-mass and high-mass building

	Low-Mass Building Mass/Floor Area 36kg/m^2	Mid -Mass Building Mass/Floor Area 382kg/m^2	High-Mass BuildingMass/Floor Area 1082kg/m^2
North Window Area to Floor Area Ratio	0.21	0.21	0.21
Floor Construction and Insulation Value	Timber, R 3.0	130mm dark coloured Concrete Slab R 3.0	130mm dark coloured Concrete Slab, R3.0
External Wall Construction and Insulation Value	Timber Framed, Plaster Board R 5.0	Timber Framed, Plaster Board R 5.0	Reverse Block Veneer, 90 Concrete Block Wall Grout filled to Inside of External Building Fabric R 5.0
Internal Wall Construction	Timber-Framed, Plaster board	Timber-Framed, Plaster board	140 Concrete Blocks Grout filled
Roof Construction and Insulation Value	Timber, R 8.0	Timber, R 8.0	Timber, R 8.0
AccuRate Star Rating	7.0	9.3	9.6
Heating Requirement	106.1MJ/m^2.year	16.6MJ/m^2.year	9.2MJ/m^2.year
Cooling Requirement	17.9MJ/m^2.year	6.1/m^2.year	2.2 MJ/m^2.year
Total Heating/Cooling Requirements	124.0MJ/m^2.year	22.7MJ/m^2.year	11.4MJ/m^2.year
% Improvement		+78.6	+90.8

AccuRate and results are shown in Table 1.

It is important to note that the simulated buildings employ a north window to floor area ratio of 21% and all thermal mass in the mid-mass and high-mass buildings are in visual line contact with the northern glazing area, providing radiative coupled access to the concrete floor and mainly convective coupled access to the internal thermal mass walls. All three building types are well insulated, the low-mass timber building rating showing as 7.0 stars, the mid-mass building as 9.3 stars and the high-mass building rating as 9.6 stars. There is a significant reduction of heating/cooling requirements for the mid-mass building compared to the low-mass timber building, amounting to 102.3MJ/m^2.year, a reduction of 78.6%. The reduction of heating/cooling requirements for the high-mass building compared to the low-mass timber building amounts to 112.6MJ/m^2.year, a reduction of 90.8%

The reduction of both the mid-mass and the high-mass building compared to the low-mass timber building is significant showing the great potential of the application of thermal mass in cool temperate climates of Australia. It must be pointed out that the simulation predictions are only valid with the majority of thermal mass in visual contact to the north double glazing. Predicted temperature profiles for the three building types for a typical winter month in August are shown in Figure 6.

Figure 6 shows similar maximum temperatures for all three building types, however minimum temperatures are significantly higher in the mid-mass and high-mass house, with the low mass house showing slightly higher maximum temperatures. While the minimum temperature in the low-mass building is 8.1ºC the minimum temperature in the mid-mass building is 13.8ºC and the minimum temperature in the high mass building 17.0ºC. The value of thermal mass is primarily achieving warmer temperatures at late afternoon and during the night, with the lowest temperatures showing at 7am in the morning. The overall predicted temperature profiles for August are summarized in the Table 3.

Predicted temperatures in the high-mass building of 17ºC to 23ºC provide a significant increased thermal comfort compared to the temperature profile in the low-mass building of 8.1ºC to 24.8ºC and shows the importance of thermal mass in building design.

Table 2 Comparison of predicted temperature profiles during August for the low-mass, mid-mass and high mass buildings

Low-mass timber building	8.1ºC - 24.8ºC
Mid-mass building	13.8ºC - 23.3ºC
High-mass building	17.0ºC - 23.0ºC

Table 3 Comparison of predicted temperature profiles during February for the low-mass, mid-mass and high-mass buildings

Low-mass timber building	16.2ºC - 32.0ºC
Mid-mass building	19.5ºC - 27.5ºC
High-mass building	20.0ºC - 25.2ºC

Fig. 5 Floor plan of the case study house for estimating heating/cooling energy and star ratings to compare the heating/cooling energy requirement, star rating and thermal comfort of three construction types

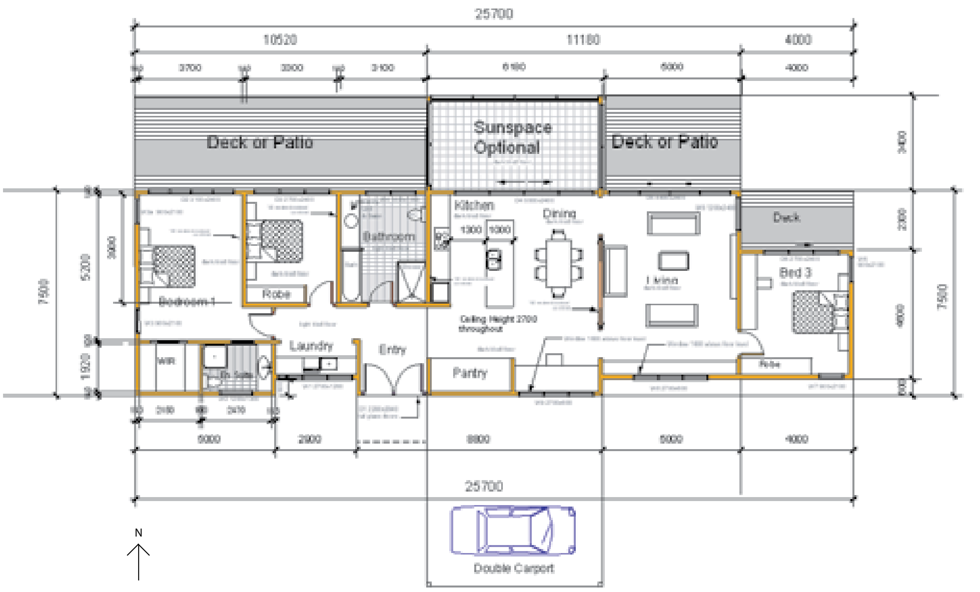


Fig. 6 Expected temperature profiles for the low-mass, mid-mass and high-mass building type for August. (AccuRate, climate zone 26, Hobart)

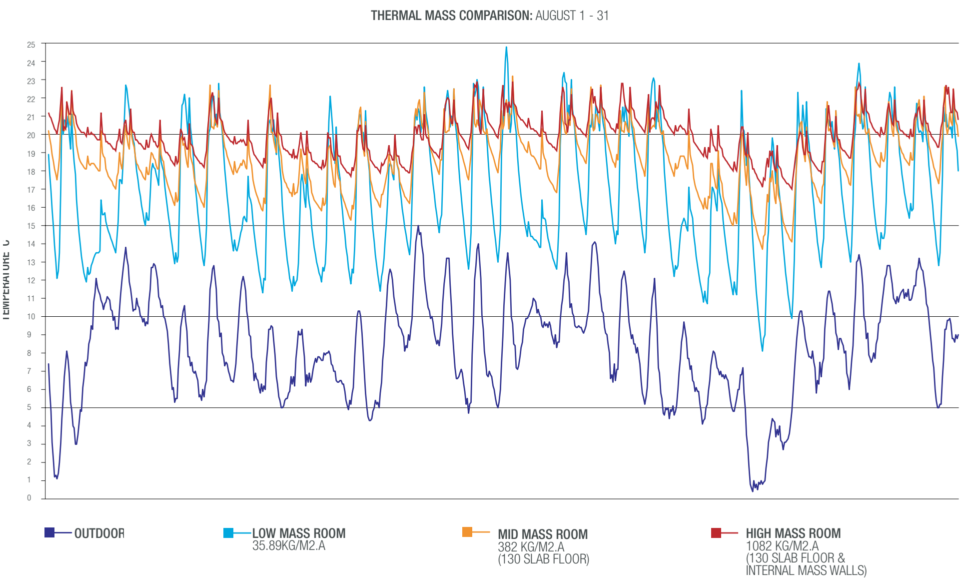
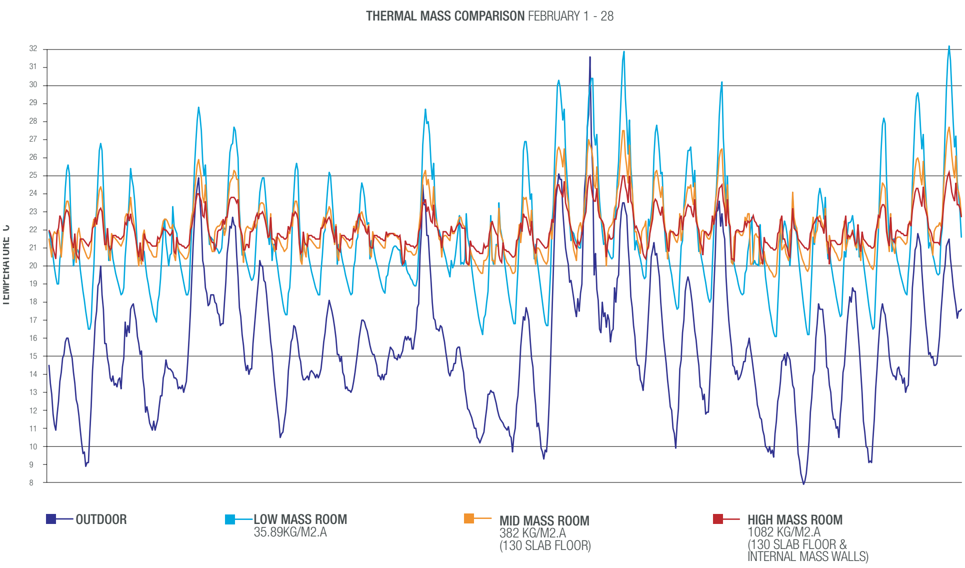


Fig. 7 Expected temperature profiles for the low-mass, mid-mass and high mass building type for February. (AccuRate, climate zone 26, Hobart)



Expected temperature profiles for the three different building types for a typical summer month in February are shown in Figure 7.

Figure 7 shows much wider temperature variations in the low-mass building compared to the mid-mass and high mass building. The predicted maximum temperature in the low-mass building is 32ºC, in the mid-mass building 27.5ºC and 25.2ºC in the high-mass building.

The temperature profile in the high-mass building of 20.0ºC to 25.2ºC provides a superior thermal environment in summer compared to the low-mass building temperature profile of 16.2º to 32.0ºC. The use of thermal mass in summer is also of great significance, lowering the maximum temperature in the low -mass building of 32.3ºC to a comfortable temperature of 25.2ºC in the high-mass building.

It is important to note that the mid-mass house with a dark coloured concrete slab finish achieved a 0.4 higher star rating when compared to a light coloured concrete finish.

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Further Information

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