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BULLETIN

THERMAL MASS

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High-mass materials such as concrete, brick, stone and compressed earth can absorb considerable heat energy during the day and release it at night.

When used in buildings, these materials are called thermal mass. They can decrease indoor temperature swings and reduce heating and cooling bills.

This bulletin describes the benefits of thermal mass and outlines design strategies and thermal tools for new and existing buildings.

1.0 INTRODUCTION

1.0.1 High-mass materials such as concrete, all-cells-filled concrete masonry, brick, stone, compressed earth and water can absorb considerable heat energy. Inside buildings, when exposed to the sun through glazing, these materials absorb heat during the day and release it later inside the building when the outside ambient temperature falls. This process of absorbing and releasing heat considerably reduces indoor temperature swings (Figure 1), providing a more even temperature throughout the day without the need for purchased heating.

1.0.2 High-mass materials in buildings are called thermal mass. When used correctly, thermal mass improves the thermal comfort for the occupants.

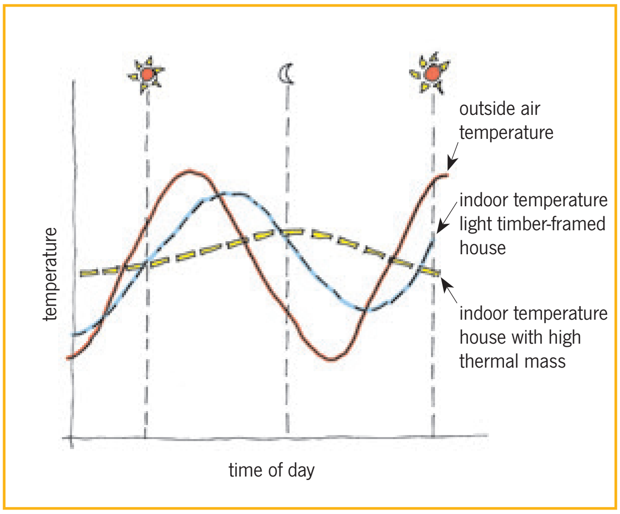

Figure 1 Use of thermal mass can reduce variations in temperature inside a building

1.0.3 Thermal mass can be best employed in buildings where there is an outside swing of at least 7°C between peak day and low night temperatures and is therefore well suited for all of New Zealand. However, it needs to be specified correctly, balancing with the other aspects of good passive design (see section 3.0). If thermal mass is not well integrated, it can reduce rather than enhance comfort and increase space conditioning-related energy use.

1.0.4 Common heavyweight building materials used in homes include concrete (in its various forms), stone, brick and compressed earth (including derivatives, such as adobe). Water (contained in a variety of enclosures) has also been used, but can be problematic to store.

2.0 BENEFITS OF THERMAL MASS

2.0.1 The key occupant benefit in homes with properly specified and used thermal mass is the internal comfort provided. The added benefits are:
- reduced heating and cooling bills
- minimal ongoing cost associated with maintenance
- it is physiologically more pleasant – our perception of warmth depends not only on the air temperature but also on the radiant heat from our surroundings.

2.0.2 These factors result in a desirable heating source that is highly appreciated by occupants. Here is a typical quote from a recent BRANZ survey of occupants of homes incorporating thermal mass walls: "The quality of the heat is really enjoyed – not stuffy like artificial heating. The subtle radiative heat of the wall seems to be better than other forms of heating."

2.0.3 Incorporating well integrated thermal mass into the design may also help the building to cope better with future changes in climate.

3.0 DESIGN STRATEGIES

3.0.1 The key to the successful use of thermal mass is integrating it into the overall passive solar design of the house – it must work in combination with window placement, summer shading, ventilation, insulation and orientation. For detail on the other aspects of passive design, see section 9.0.

3.0.2 Thermal mass should ideally be:
- dark in colour with a non-reflective (matt) surface
- near large windows so it is exposed to substantial direct sunlight
- of a volume that is appropriate for the size of the conditioned spaces it influences
- of a high density
- contained within the building's thermal envelope (fully insulated from the external climate)
- able to be shaded/exposed when needed.

3.0.3 Different high-mass building materials have different heat capacities – some can store more thermal energy than others. However, all the common mass materials listed in section 1.0.1 are suitable for New Zealand climates and situations. Table 1 lists different building material heat capacities based on volume – the higher the figure the greater the capacity for thermal storage for a given volume.

TABLE 1: THERMAL MASS EFFECTIVENESS OF COMMON CONSTRUCTION MATERIALS (APPROXIMATE)

Building material	Heat capacity (kJ/m³.°C)
Water	4,200
Basalt	2,670
Schist	2,190
Concrete	2,060
Clay/ceramic tiles	1,768
Compressed earth blocks	1,700
Rammed earth	1,700
Granite	1,590
Brick	1,400

3.0.4 The glazing that lets sun onto the thermal mass should be:

- thermally broken aluminium frames with low-emissivity (low-E) insulated glazing units (IGUs) as a minimum in all climates zones – see the New Zealand Window Energy Efficiency Rating System (WEERS) for guidance on window selection
- timber or uPVC frames with low-E IGUs.

3.0.5 Some thought should be given to the future of the solar aspect – could direct sunlight be shaded by future landscaping, neighbouring foliage, fences or buildings?

3.0.6 The two most effective ways of including thermal mass in homes are:

- **direct solar gain** onto the thermal mass material (typically using a concrete floor)
- **indirect solar gain** (typically a Trombe wall).

3.0.7 Locate thermal mass elements (whether a floor or wall) where they will receive direct solar radiation. A considerable amount of direct solar radiation is needed to thermally charge the mass so that it can significantly influence adjacent spaces, so large windows are needed adjacent to the mass element. Ideally, at least a third of the mass should receive prolonged direct sunlight on a sunny day in winter. In many houses with good passive design, large north-facing windows extend from the floor to the ceiling to ensure that sunlight can shine on the thermal mass elements for long periods. Designers can use software such as SketchUp (www.sketchup.com) to quickly determine where and for how long the sun's rays will shine on a floor or wall.

3.0.8 Flexible shading of the mass elements provides occupants some control to deal with non-seasonal weather such as a cold spell in the middle of summer. Given the nature of climate change in making future weather more chaotic, this feature is increasingly desirable.

3.0.9 The design solutions provided here assume that the thermal mass is used for heating rather than for cooling, which is typical for New Zealand.

4.0 THERMAL TOOLS FOR DESIGN ANALYSIS

4.0.1 Thermal simulation tools operated by a competent professional are needed to design and assess the influence of mass on a building. The interactions between the different building elements such as insulation, window size/placement, mass and the local climate are complex, with traditional rules of thumb becoming ineffectual for any robust thermal examination of a higher-performing building.

4.0.2 Several thermal simulation tools are available, and they vary in terms of user friendliness, flexibility, cost and accuracy. BRANZ recommends using those that are based on hourly climate data and have been independently verified and tested. Ideally, only consultants with specific training should use the tools, as spurious results can be easily obtained and all require a considered approach.

4.0.3 Simulation tools are best employed at the sketch design stage where there is most flexibility to change and influence performance. Many of the better energy simulation tools are now well integrated with SketchUp.

4.0.4 GraphiSoft's EcoDesigner STAR, AccuRate NZ, SUNREL and Sefaira all provide comprehensive thermal performance examination. The user can examine a wide variety of metrics in design performance. Tool summaries are provided in section 9.0.

5.0 CONCRETE FLOORING

5.0.1 Given that most new houses today have a concrete slab, using the slab so that it receives direct solar radiation is the most cost-effective way of unlocking thermal mass in typical new homes. Therefore slabs should be uncovered or finished with (relatively conductive) materials such as stone or ceramic tiles or slate in the northern aspects of the home but can be covered elsewhere.

5.0.2 New slab finishes include polished, stained, etched (acid-washed), patterned, stencilled, surface abraded, bush hammered or shot blasted. The chip size, shape and colour can be altered.

5.0.3 There is some resistance from consumers to exposed concrete floors. These are the main apprehensions:

- Cracking that may occur will be unsightly. This risk can be minimised through good concrete design, specification and curing. See BRANZ Bulletin 372 *Durability and crack control in domestic concrete floor construction*. If cracking does occur, micro-toppings offer the ability to hide cracks under a smooth new surface that can accept a wide array of decorative treatments.
- They can be slippery. Any smooth surface is slippery – including vinyl, linoleum, marble and ceramic tile.
- They are cold. Since concrete is a comparatively conductive material, it will feel cool to the touch even at room temperature. Embedding radiant heating (electric cables or hot water pipes) into the slab to provide supplementary heat is an option for back-up in the depth of winter.
- They are too costly. They are comparable in cost to carpet of a reasonable quality, yet far more durable and easier to keep clean, so are actually more economical over their lifetime.

5.0.4 To maximise the thermal performance of exposed concrete slabs, insulation is required under the slab to minimise heat losses to the ground and around the perimeter (to minimise losses to the external air). These are the main solutions available for insulated slabs:

- Insulation applied to the outside face of the foundation (Figure 2).

- Fully insulated systems. There are a few proprietary products on the market that insulate both the underside and the perimeter of concrete slabs. Some of them have the ability to eliminate all thermal breaks by having a continuous polystyrene enclosure of the slab, covering all but the top surface. Insulation under areas of larger loading – such as the footings under perimeter and internal loadbearing walls – are made of high-density polystyrene to ensure adequate structural strength and good load transference. (Note that this will require specific engineering design.)

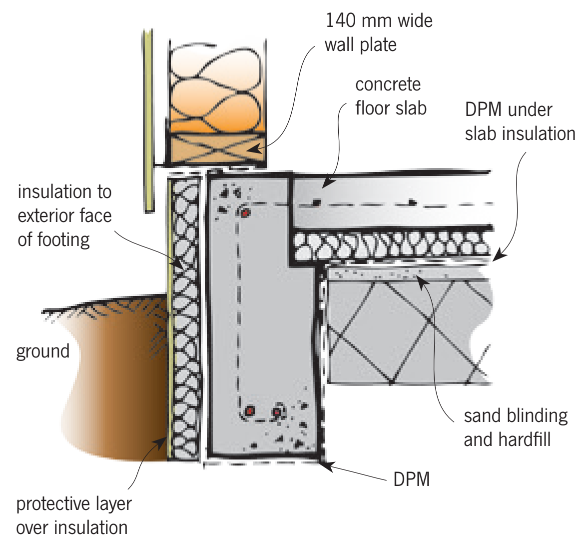

Figure 2 BRANZ detail for slab perimeter insulation

6.0 WALL SOLUTION

6.0.1 Exterior walls that are thermal mass walls should always be insulated on the outside so the thermal mass layer is inside the insulation plane and exposed to the interior. Heavyweight materials on the outside of the insulated envelope do not provide thermal mass benefits to the interior. Only when thermal mass is exposed internally can it interact with the interior space. If the mass is a wall, it will not work if it is strapped and lined or when the insulated concrete formwork has an internal layer of insulation. The thermal mass layer must be exposed to the passive heat source – preferably it has the sun shining on it.

6.0.2 One of the most effective construction elements that can provide substantive thermal benefit is the Trombe wall (Figure 3), a heavyweight, north-facing, glazed, uninsulated external wall. Solar energy transmitted through the glazing heats the dark, concrete external face of the Trombe wall. This heat slowly conducts through the wall, to be reradiated out many hours later into the internal space, reducing the amount of conventional space heating needed.

6.0.3 An alternative to the Trombe wall is a north-facing thermal wall. To be effective, this type of wall needs to be at least 100 mm thick (200 mm is preferable to maximise storage and ensure the heat is reradiated to the adjacent space over a longer period) and located close to large north-oriented glazing and part of the space being heated. The optimum area of the wall will depend on its length and the size of the space it services, as well as the other passive-related features of the house. This is where thermal simulation is needed to determine suitable dimensions.

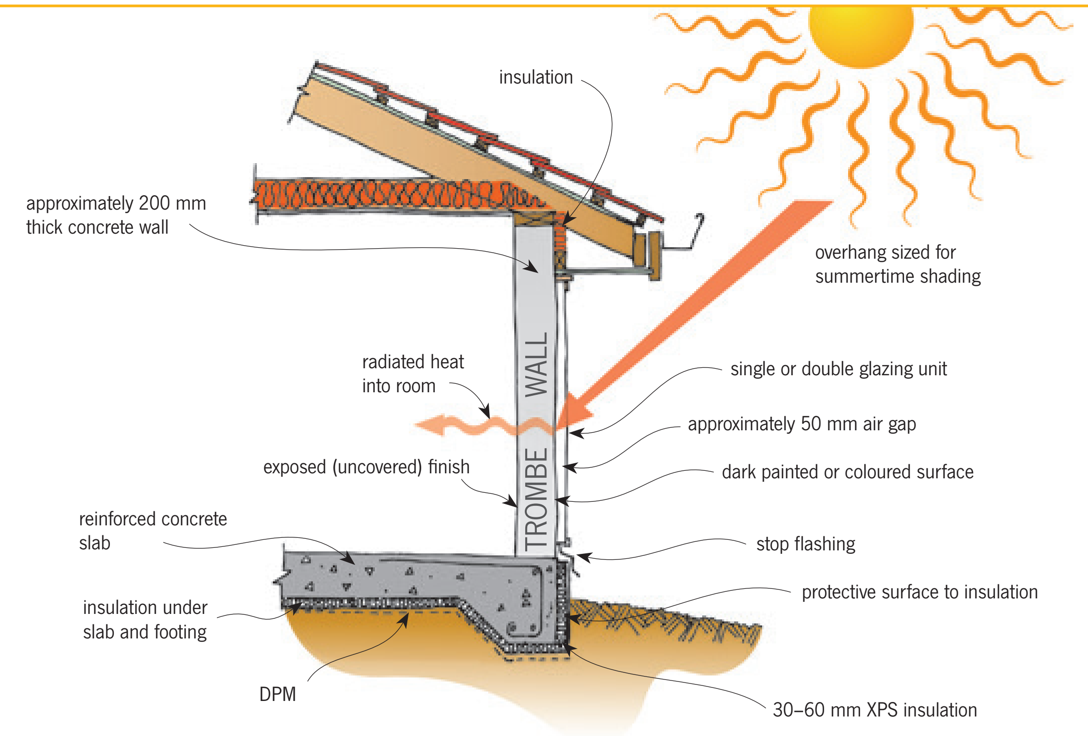

Figure 3 Schematic cross-section of typical Trombe wall showing key components

6.0.4 During summer, Trombe walls need to be shaded carefully so as not to overheat the interior. Ideally, there should be flexible shading to ensure unseasonable weather can be responded to easily and quickly.

6.0.5 Trombe walls are suited to homes in all New Zealand climate zones.

6.0.6 Trombe wall planning, design and specification are provided in the BRANZ Sustainability Fact Sheet *Trombe Wall Design* (see section 9.0). The fact sheet includes sample construction details, user experiences, a minimum design checklist and questions for the designer to discuss with the homeowner.

7.0 MODELLED NEW ZEALAND EXAMPLES

7.0.1 To show how exposed mass (in this case, a slab floor) influences space heating and cooling needs over an average year, BRANZ carried out hourly thermal simulations. The simulated 130 m^2 single-storey, slab-on-ground house has living spaces well oriented for the sun, has approximately 20% better than NZ Building Code insulation, has thermally broken windows and was timber-framed. The north-oriented floor was adjacent to large double glazing. The following comfort levels set were:

- living zones (lounge, dining and kitchen): 20°C between 9 am–11 am and 5 pm–11 pm
- bedrooms: 18°C between 5 pm–11 pm
- all other areas – no heating.

7.0.2 Mechanical cooling of the zones was introduced when the indoor temperature exceeded 25°C.

7.0.3 Three concrete flooring scenarios were examined:

- Carpeted and uninsulated: uninsulated 100 mm thick concrete slab, mostly carpeted (except kitchen, bathroom and entry).
- Carpeted and insulated: fully insulated 100 mm thick concrete slab (80 mm thick EPS under and 25 mm thick EPS perimeter), carpeted floor.
- Partially exposed and insulated: fully insulated 100 mm thick concrete slab with exposed floor on the north-facing rooms and carpet or linoleum everywhere else.

7.0.4 Three performance metrics were used:

- Yearly conditioning cost is the cost for both heating and cooling the conditioned spaces within the building. This was based on $0.30/kWh.
- Savings/year is the energy savings in dollars when compared to the traditional uninsulated and carpeted slab.
- % savings is the energy savings as a percentage when compared to the traditional uninsulated and carpeted slab.

7.0.5 The heating and cooling requirements to meet the scheduled comfort temperatures are shown in Table 2. It should be noted the figures represent an average year with standardised occupant behaviour in a thermally well designed, single-storey medium-weight home.

TABLE 2: SPACE HEATING AND COOLING COSTS FOR VARIOUS SLAB CONFIGURATIONS IN EIGHT NEW ZEALAND CLIMATES

		Carpeted and uninsulated	Carpeted and insulated	Partially exposed/partially carpeted and insulated
Whangarei	Yearly conditioning cost savings/year % savings	$273 $0 0%	$185 $88 32%	$108 $165 60%
Auckland	Yearly conditioning cost savings/year % savings	$326 $0 0%	$224 $102 31%	$133 $193 59%
Tauranga	Yearly conditioning cost savings/year % savings	$415 $0 0%	$306 $109 26%	$193 $222 53%
Hamilton	Yearly conditioning cost savings/year % savings	$621 $0 0%	$455 $166 27%	$322 $299 48%
Wellington	Yearly conditioning cost savings/year % savings	$582 $0 0%	$394 $188 32%	$322 $260 45%
Nelson	Yearly conditioning cost savings/year % savings	$714 $0 0%	$531 $183 26%	$389 $325 46%
Christchurch	Yearly conditioning cost savings/year % savings	$1,164 $0 0%	$907 $257 22%	$778 $386 33%
Invercargill	Yearly conditioning cost savings/year % savings	$1,475 $0 0%	$1,154 $321 22%	$1,057 $418 28%

7.0.6 Table 2 shows that:

- an exposed concrete slab is beneficial in well designed, well insulated, medium-weight homes for all tested New Zealand climate zones
- the largest benefit is when the slab is both fully insulated and exposed internally
- in terms of dollar savings, the colder the climate, the better
- in terms of percentage savings, the warmer the climate, the better.
- heating and cooling energy requirements can be reduced by between 28% and 60% by effectively using the thermal mass of the slab for the assessed house.

7.0.7 Other thermal benefits of unlocking the mass – such as the amount of time the internal temperatures remain comfortable without purchased space heating or cooling – are not shown.

7.0.8 In typical houses, simply exposing an uninsulated slab will increase space heating requirements in almost all climate zones.

8.0 DESIGN STRATEGY FOR EXISTING BUILDINGS

8.0.1 The opportunity to place significant thermal mass within existing buildings is limited due to the resultant weight imposed on the existing structural foundation. One option that has the potential to provide similar performance via a different process is the use of phase change materials (PCMs).

8.0.2 Phase change is the chemical transformation of a substance from one physical state (solid, liquid or gas) into another.

8.0.3 PCMs have the ability to store/release large amounts of energy while maintaining near-constant temperatures, via chemical bonds. The energy is either absorbed or released as heat, depending on the direction of the change of state. Figure 4 shows the varying responses of wax impregnated into plasterboard when energy is added at a constant rate.

8.0.4 When PCMs change state at around room temperature, they have the potential to be used like ordinary thermal mass. Typically, they are wax-based materials that are impregnated into plasterboard or provided as plastic mats to be placed within ceilings. In both cases, the PCMs are installed within the building's thermal envelope.

8.0.5 By using PCMs that change at the right temperature (for example, around 23°C), a more consistent indoor temperature can be maintained at a fraction of the weight of traditional thermal mass materials.

8.0.6 Although PCMs are uncommon in New Zealand currently, this is likely to change as their benefits are more widely understood and costs reduce.

9.0 MORE INFORMATION

Thermal modelling tools for designers:

- **Sefaira**: very fast, very user friendly, iterative, intuitive, customised reports, SketchUp-compatible, flexible cloud-based validation and exploratory design tool. www.sefaira.com. Medium ongoing cost.
- **GraphiSoft EcoDesigner STAR**: building information modelling integrated, fast, highly flexible, customised reports, stand-alone. Medium ongoing cost (but free if using ArchiCAD 17+ already).

Tools for building technologists:

- **AccuRate NZ**: New Zealand-tuned, reasonably fast and intuitive, stand-alone, requiring transfer to a spreadsheet for detailed thermal and energy interrogation. Relatively low cost.
- **SUNREL**: Requires considerable upskilling, models slower to build, not very intuitive, stand-alone, requires transfer to a spreadsheet for detailed thermal and energy interrogation. Free.

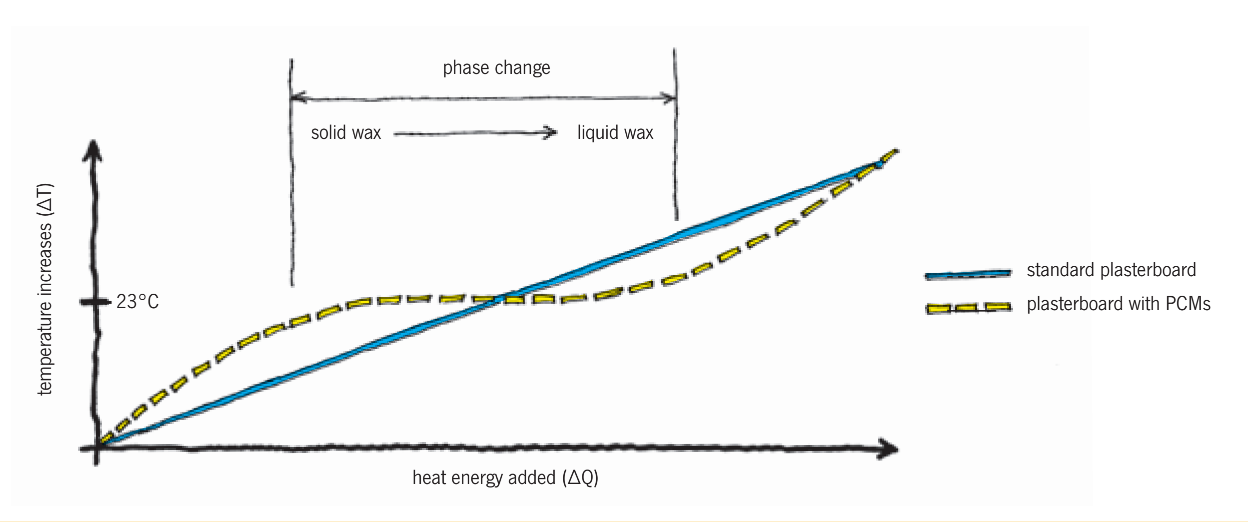

Figure 4 The changing phases of wax impregnated into plasterboard

BRANZ PUBLICATIONS:

- Good Practice Guide: *Concrete Slabs and Basements*. Second Edition, February 2012.
- Bulletin 541 *Concrete floor slabs*
- Bulletin 543 *Concrete finishes*
- Level Design Guides – www.level.org.nz/other-resources/design-guides/
  - BRANZ Sustainability Fact Sheet *Passive Solar Design*
  - BRANZ Sustainability Fact Sheet *Trombe Wall Design*

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