BRANZ

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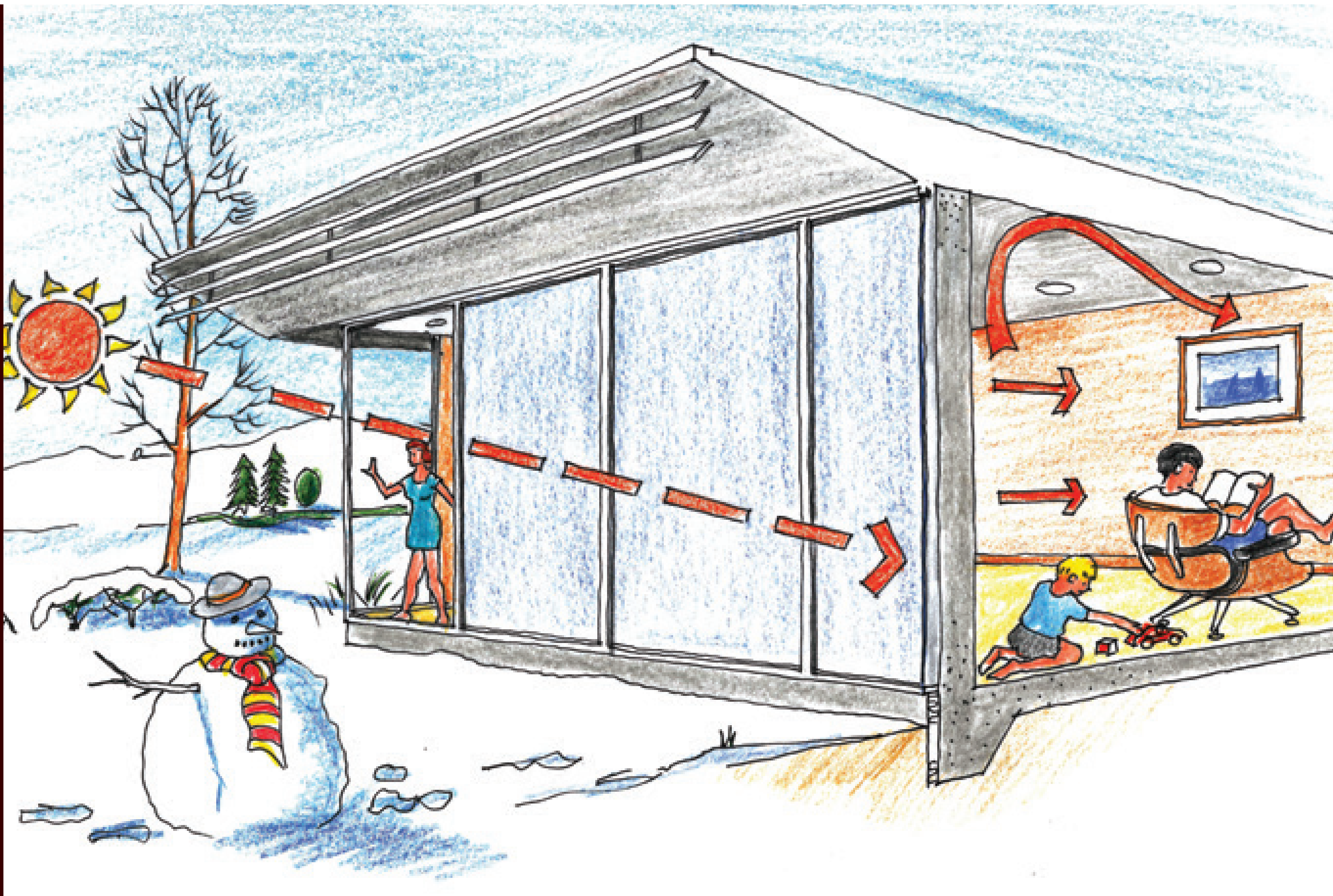

TROMBE WALLS

September 2013

- A Trombe wall is a glazed external wall with thermal mass that absorbs heat from the sun during the day and releases it inside the house at night.
- These walls reradiate free absorbed heat throughout winter, reducing the energy that needs to be purchased for space heating.
- This bulletin covers the key considerations to bear in mind when designing and constructing a Trombe wall to maximise its benefits.

1.0 INTRODUCTION

1.0.1 A Trombe wall is typically a dark-coloured northern-facing concrete or masonry external wall to provide thermal mass with removable glazing on the outside and a small airspace between (Figure 1). Solar energy transmitted through the glazing during the day heats the external face of the wall. This heat slowly conducts through the thermal mass of the wall and is reradiated out into the internal space during the evening.

1.0.2 According to Wikipedia, "The essential idea was first explored by Edward S. Morse and patented by him in 1881. In the 1960s it was fully developed as an architectural element by French engineer Félix Trombe and architect Jacques Michel."

1.0.3 During summer, Trombe walls need to be shaded and the house interior well ventilated so temperatures do not become too high.

Trombe walls (left- and right-hand sides) and solar gain glazing in Ball House, Takaka (photo courtesy of Mark Fielding, Ecotect).

1.0.4 Trombe walls are relatively simple to construct, require little on-going maintenance and are applicable in all New Zealand climates. They are useful where a portion of a home's northern view may need obscuring or the views are to other orientations. They are also useful where too much natural light or glare is a concern.

1.0.5 Trombe walls should not be confused with other types of solar heating provided through external walls. Aspirated solar thermal walls use solar heating of a wall cavity to warm indoor airspaces, for example. While these may give immediate transfer of solar heat to indoor spaces, the benefits of delayed heat transfer of a Trombe wall are not possible.

1.0.6 Use of a Trombe wall should be considered as part of an overall approach to maximise the benefits of passive design in a house.

2.0 BENEFITS OF TROMBE WALLS

2.0.1 BRANZ has modelled four existing Trombe walls in New Zealand houses using the SUNREL thermal simulation program. Comfort levels, the impact on conventional space heating and financial savings were investigated. The houses and their Trombe walls were also thermally modelled to examine the transferability of their benefits to all of the New Zealand climate zones.

2.0.2 Trombe walls were found to reduce the conventional winter space heating requirements of the house living areas by an average of 35% (ranging from a 45% reduction in Auckland to 18% in Invercargill). This equates to average savings of approximately $170 annually (based on a temperature set-point of 20°C for the hours 7–11 pm and an energy cost of

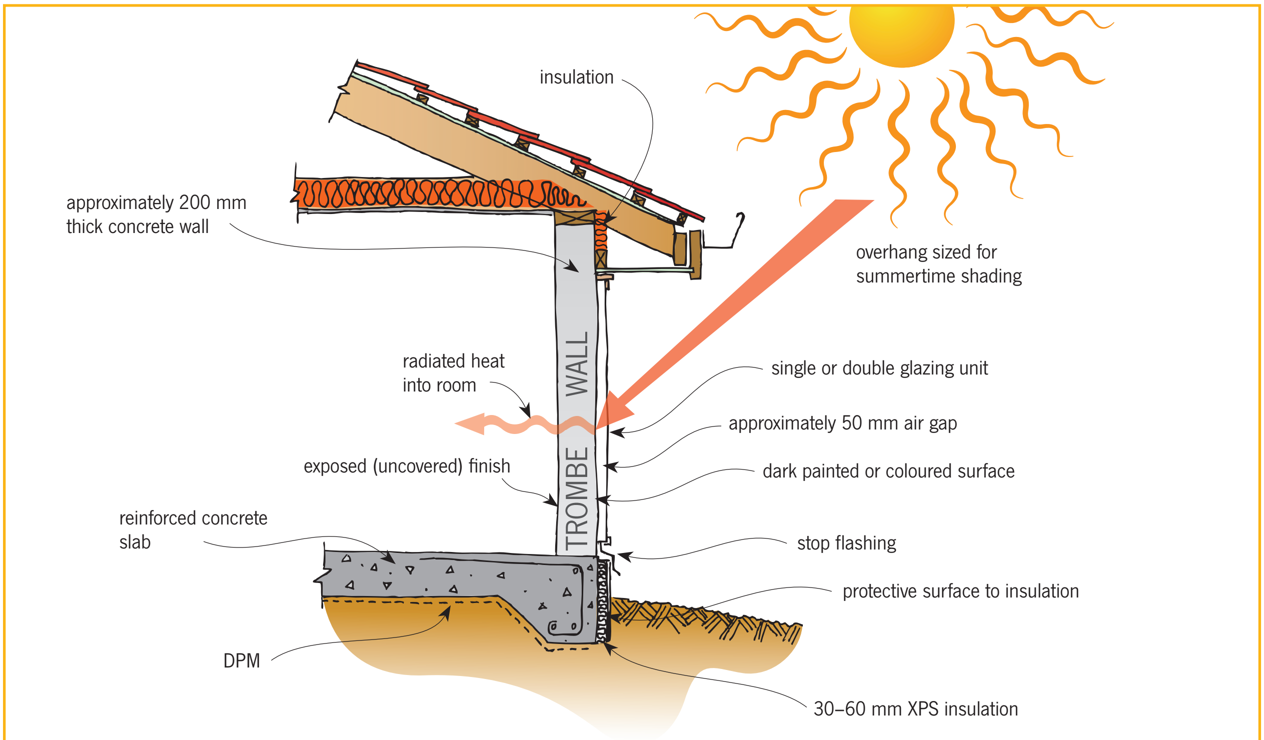

Figure 1. Schematic cross-section of typical Trombe wall showing key components

25c per kWh and replacing part of the framed wall of the room with a Trombe wall).

2.0.3 The houses had 10–15% more hours of comfortable internal temperatures (18–25°C in winter) compared to homes without these walls.

2.0.4 House occupants described the constant release of radiant heat provided by a Trombe wall as more comfortable than standard forms of convective heating.

2.0.5 A financial examination of the impact of the four Trombe walls was undertaken. On average, the benefit-cost ratio (based on a 5% discount rate over 20 years) was 2:1. Benefit-cost ratio summarises the overall value for money of a project – the higher the ratio, the better. As a rule of thumb, if the ratio is higher than 1, the project is a good investment.

2.0.6 The average simple payback period was 5.4 years. Simple payback period refers to the time required for the return on an investment (in this case, the savings in electricity) to repay the sum of the original investment.

3.0 DESIGN AND SPECIFICATION

3.1 ORIENTATION AND SOLAR ACCESS

3.1.1 A Trombe wall in New Zealand should be orientated between -30° and +30° of true north (not magnetic north) to provide maximum thermal benefit (Figure 2). True north can be measured by using either a compass (corrected for magnetic north) or by using the shadow cast by a stick in the ground at around 12 noon during wintertime (non-daylight-saving time).

3.1.2 For the operational lifetime of the wall, its external northern aspect must remain in full sunlight for as much of the day as possible in the colder months. Ideally, it should be positioned so that development or vegetation growth to the north cannot reduce the amount of sunlight it receives.

3.1.3 The use of computer tools to assist the design process is recommended. A 3D visualisation tool to examine year-round shading – such as SketchUp (which is free) – is recommended as a minimum. A thermal simulation program such as SUNREL can be used for examining the thermal aspects of the Trombe wall but needs expertise to use. There are a few energy consultancies in New Zealand that are able to provide the expertise required.

3.1.4 Solar access to the house site can also be worked out very quickly using NIWA's SolarView (Figure 3) or a variety of smartphone applications. The SolarView online tool can very easily and accurately provide quantitative information on solar access for any site in New Zealand. It can be accessed through http://solarview.niwa.co.nz.

3.1.5 Adjacent buildings and other sources of shade can be added to the SolarView diagram (which only accounts for shading from geographic features) by plotting their height and position. This helps determine the optimum location and orientation for the house and Trombe walls, including glazing and mass.

3.2 GLAZING

3.2.1 Either single or double glazing can be used as the outer component of the Trombe wall. Computer modelling indicates that, in most circumstances, double glazing gives only marginal benefits in reducing heat loss back through the glass.

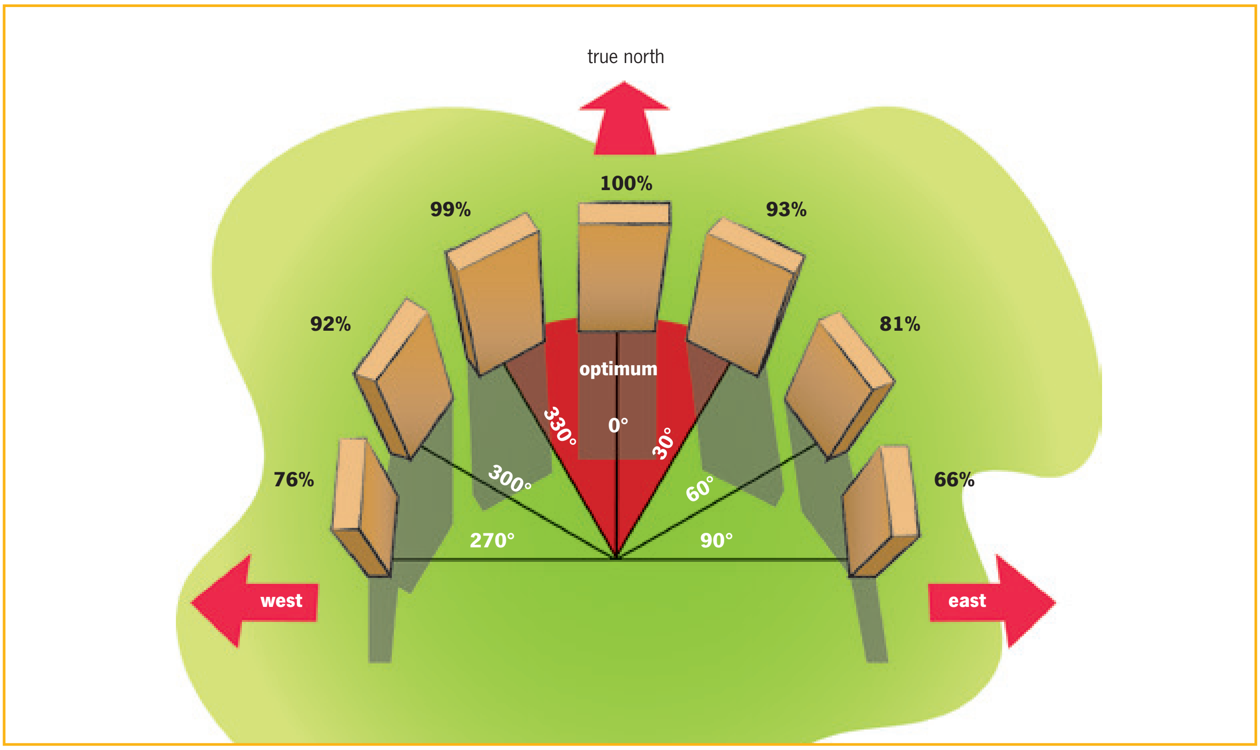

Figure 2. Percentage thermal effectiveness for differently oriented Trombe walls.

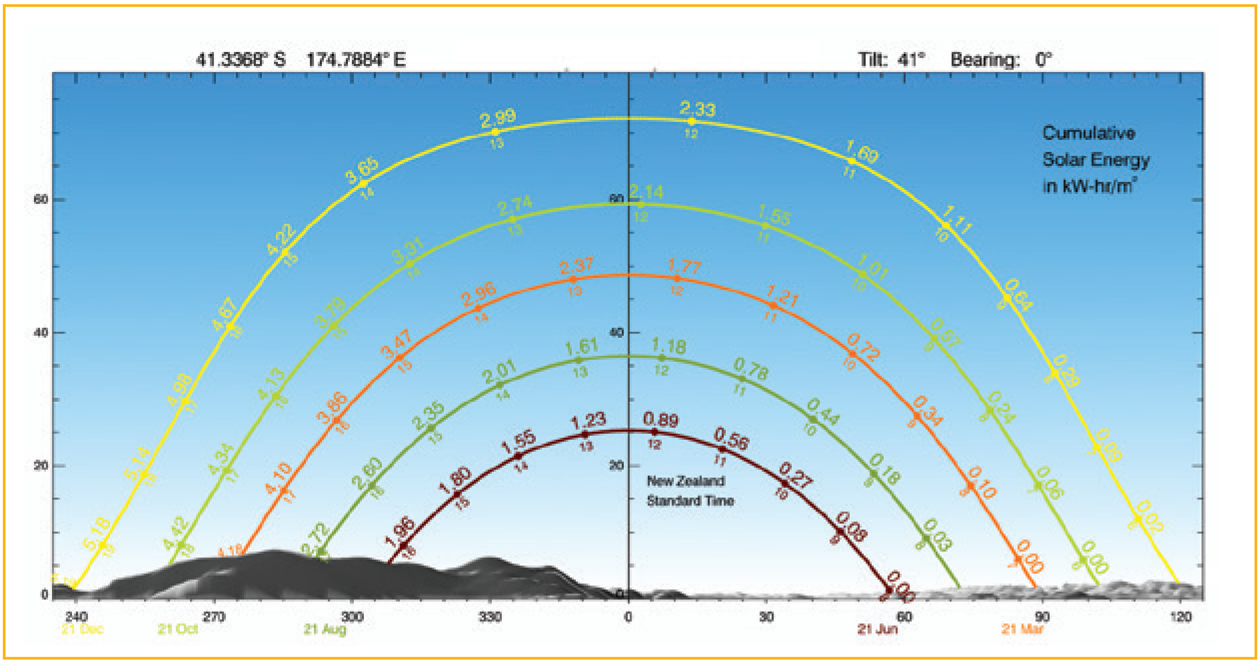

Figure 3. SolarView diagram for one Wellington house (courtesy NIWA).

3.2.2 More important is to specify high transmission glass – glass with a high solar heat gain coefficient (SHGC) of 0.7 or more. SHGC is the total fraction of available solar radiation that is transmitted through the window as heat gain. Having a high SHGC ensures that a high percentage of solar energy gets transmitted through the glazing to the wall surface.

3.2.3 If the glazed wall is difficult or inaccessible to reach from the outside, consider self-cleaning glass for long-term clarity because the SHGC can be markedly affected by the build-up of dirt on the outside of the glazing.

3.2.4 The size of the airspace between the outer wall surface and the glazing should be between 15–50 mm. Keeping the gap to 20 mm or less minimises convective losses.

3.3 THERMAL MASS WALL DESIGN AND CONSTRUCTION

3.3.1 Trombe walls can be constructed on site or, for concrete, be precast and then installed (Figures 4 and 5). In one Blenheim house recently, a precast wall with a polished concrete finish was craned into place and propped before the slab floor was poured.

3.3.2 Thermally decoupling the wall footing from the ground with insulation is recommended to reduce heat loss into the ground – where this is done, the foundations will need to be specifically designed by a chartered professional engineer.

3.3.3 Using extruded polystyrene (XPS) insulation rather than expanded (EPS) on the external face of the footing will reduce the amount of moisture that the insulation can absorb. Both polystyrene types need some form of surface protection to ensure durability.

3.3.4 The material chosen for the wall mass determines how much heat can be stored and released. This heat storage ability (Table 1) is commonly called thermal inertia (and more formally known as volumetric heat capacity). The higher the thermal inertia of a material, the longer the time needed to change its temperature. The thermal inertia values for poured/tilt concrete and grout-filled concrete blocks are similar to cast concrete. (If blocks are used, they all need to be fully grouted – the fewer air gaps the better to provide consistent conductivity.)

3.3.5 Alternative building materials such as rammed earth and adobe are thermally different. Rammed earth/compressed earth blocks can store more heat than the same thickness of adobe. While water can store more heat than concrete, it is difficult to incorporate into a wall construction.

TABLE 1: THERMAL MASS OF COMMON TROMBE WALL CONSTRUCTION MATERIALS

Material	Estimated minimum thermal mass (volumetric heat capacity, kJ/m³.K)
Basalt	2670
Schist	2190
Concrete	2060
Sandstone	1800
Compressed earth blocks	1700
Rammed earth	1700
Granite	1590
Brick	1400

3.3.6 Table 1 uses a measure of the effectiveness of the thermal mass of a material called volumetric heat capacity – a material's capacity to store heat relative to its volume. Volumetric heat capacity is measured in $kJ/m^3.K$

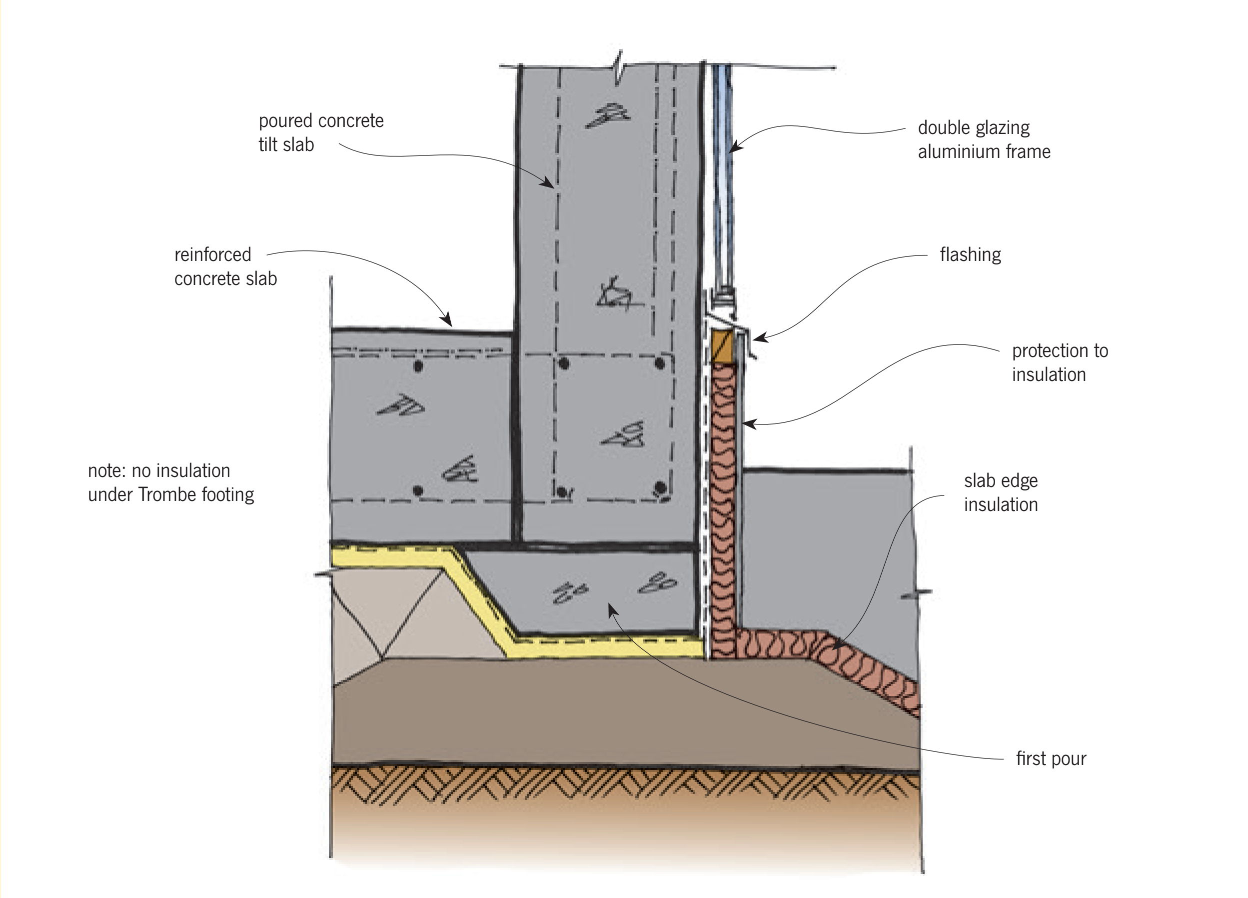

Figure 4. Cross-section of Trombe wall (based on plan provided courtesy of Peter Olorenshaw ANZIA).

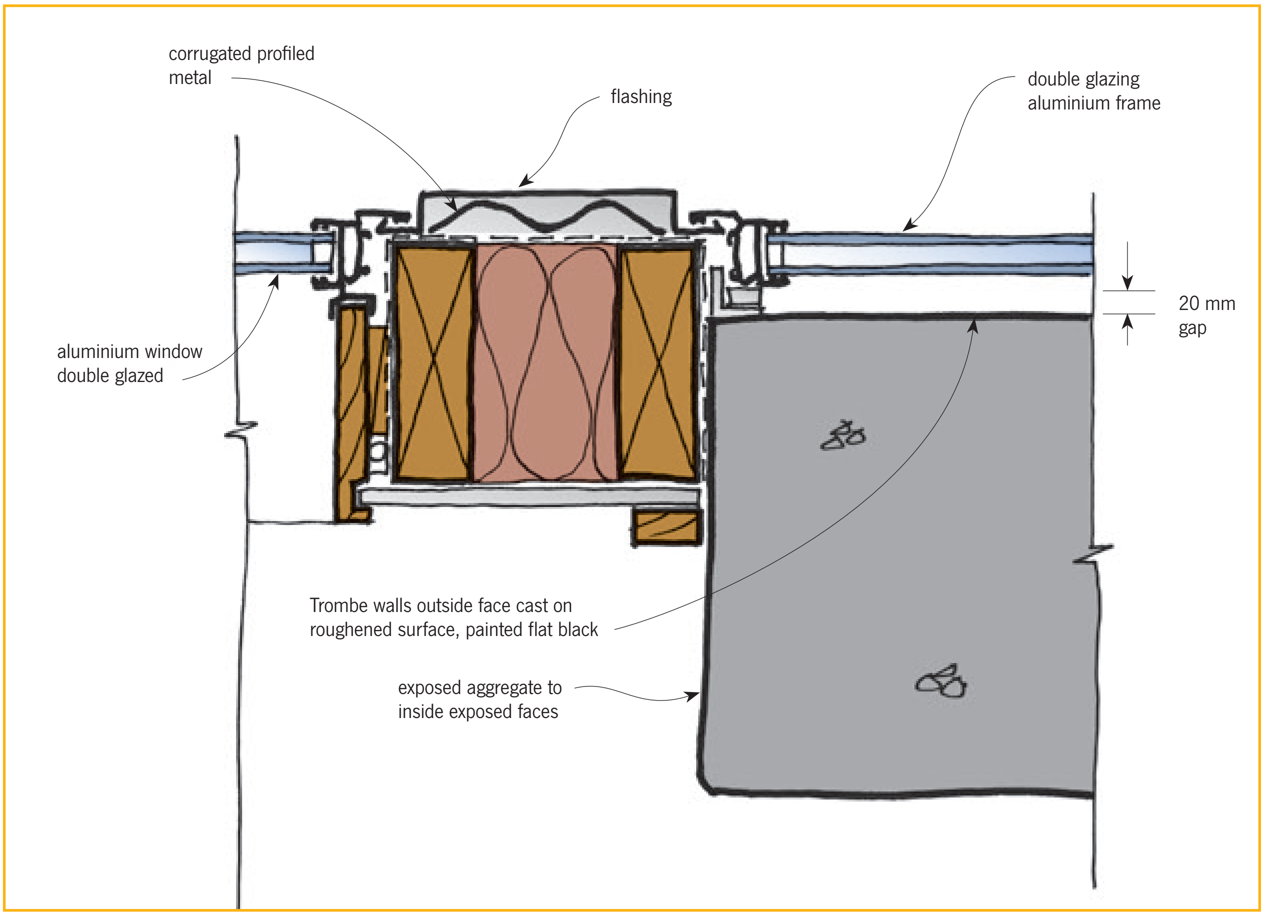

Figure 5. Plan section of Trombe wall (based on plan provided courtesy of Peter Olorenshaw ANZIA).

3.3.7 The thickness of the Trombe wall determines how long it will take for heat absorbed from the sun to conduct through the wall from the exterior to the interior. The time is proportional to the material's thermal conductivity. The rate at which heat travels through concrete is approximately 25 mm/hour. Therefore, heat absorbed by the exterior of a Trombe wall that is 200 mm thick will take about 8 hours before it is reradiated to the interior space of the building. A thickness of around 200 mm is usually used for concrete-based materials, as the time delay means that the occupants will benefit from the radiated heat in the evening. The thermal time delay for rammed earth/compressed earth blocks is around 40 mm/hour while it is about 35 mm/hour for adobe.

3.3.8 A small area of Trombe wall will not provide sufficient heat for a very large room. The ratio of the Trombe wall's volume (in m^3) to the volume of the adjacent affected living area (in m^3) should be a minimum 1:170 for concrete-based materials for the wall to be a significant heat source. These figures assume that the home is an otherwise lightweight insulated construction.

3.3.9 Finishing the mass wall in a dark colour will increase the amount of heat absorbed.

3.3.10 Thermal blinds installed between the glazing and the mass wall can be specified to reduce overnight heat loss. However, enclosing them in a sealed space creates potential issues regarding control and maintenance.

3.3.11 Other factors related to Trombe walls:

- Design and construction of concrete masonry or concrete Trombe walls must comply with NZS 4229:2013 *Concrete masonry buildings not requiring specific engineering design* or NZS 4230: 2004 *Design of reinforced concrete masonry structures*.
- Autoclaved aerated concrete does not have sufficient density to be used as a Trombe wall.
- While materials such as water (4200 kJ/m^3.K) and fibre-cement (1530 kJ/m^3.K) have a higher volumetric heat capacity, they are not typically used in the construction of a Trombe wall.

3.4 VENTING FOR HEAT FLOW

3.4.1 It is recommended that Trombe walls are not vented to the interior, so they can heat up more during the day to provide more heat at night when needed, and that early morning heat gains are taken from direct sunlight entering east/north-east windows adjacent to Trombe walls.

3.4.2 It was common for Trombe walls to be designed with ventilation openings to the building interior at the top and bottom of the wall. These use the stack effect to pull cold air from the room through the bottom vent into the space between the Trombe wall and the glazing, while pushing warmer air out of the top vent into the living space. One advantage of this is that it provides heat earlier in the day. Flaps on the ventilation openings are used to stop the convection at night and during the summer months.

3.5 DESIGN TO AVOID SUMMER OVERHEATING

3.5.1 External shading (determined using SolarView or one of the variety of smartphone applications) of the whole wall is recommended for at least 70% of the day during summer months, especially where good whole-house ventilation is difficult. Shading from midday direct summer sun is crucial, but mid-morning and mid-afternoon shading is also important.

3.5.2 Fixed exterior shading will be more reliable than movable shading devices that require action from house occupants. For directly true north-facing Trombe walls, extend horizontal fixed shading beyond the wall edges for at least the same distance as its depth to prevent early morning and later afternoon sun striking the wall.

3.5.3 Shading generally gives greater benefits than ventilation, but ventilation is still an option. An exhaust vent near the top of the Trombe wall can be opened on hot summer days, moving fresh air through the house even in the absence of wind.

3.6 FINISHING AND MAINTENANCE

3.6.1 The interior surface of the mass wall must be left exposed to retain its capacity to radiate heat to the inside. Polished concrete with exposed aggregate is one popular finish. If it does need to be covered, use a conductive material such as solid plaster or ceramic tiles. It can also be painted. Uncoated concrete block is not recommended because it is difficult to clean. If painted, the colour of the inside-facing wall does not affect the amount of heat that will be emitted.

3.6.2 The benefits of the wall will be reduced if large pieces of artwork or big flat screen televisions are placed on the wall or if furniture is located close to it.

3.6.3 Little maintenance of the wall itself is required – the dark outer surface may need recoating occasionally. The glazing will need cleaning, and the space between wall and glazing may need occasional cleaning if it is not sealed.

4.0 REFERENCES AND FURTHER READING

Saadatian, O., Sopian, K., Lim, C. H., Asim, N. & Sulaiman, M. Y. (2012). Trombe walls: A review of opportunities and challenges in research and development. *Renewable and Sustainable Energy Reviews*, *16(8)*, 6340–6351.

Torcellini, P. & Pless, S. (2004). *Trombe walls in low-energy buildings: Practical experiences*. Presented at the World Renewable Energy Congress VIII and Expo Denver, Colorado 29 August–3 September. National Renewable Energy Laboratory, Colorado, USA. NREL/CP-550-36277.

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Level: www.level.org.nz
Bulletin 540 *Solar gain in housing*
Bulletin 500 *Optimising energy-efficient design of houses*
Bulletin 494 *Thermal insulation of new houses*

STANDARDS
NZS 4229:2013 *Concrete masonry buildings not requiring specific engineering design*
NZS 4230: 2004 *Design of reinforced concrete masonry structures*

OTHER RESOURCES
CCANZ and EECA, *Designing Comfortable Homes*.
www.ccanz.org.nz/files/DCH_Book_WEB.pdf

Computer tools
SUNREL (www.nrel.gov/buildings/sunrel)
AccuRateNZ (www.csiro.au/AccuRate)
SketchUp (www.sketchup.com)

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