SUSTAINABILITY FACT SHEET

BRANZ

TROMBE WALL DESIGN

Guidelines for Inclusion in New Zealand Homes

Introduction

The aim of this guideline is to promote and provide the information needed to design, build and make proper use of a robust solar space-heating technology that can significantly enhance your home's indoor comfort year round: Trombe walls.

The definition of a robust technology is one that provides significant comfort benefits for homes in New Zealand while also being both easy and low cost to design, build, use and maintain.

Trombe walls were shortlisted by BRANZ from a wider set of less commonly used technologies which provide a more comfortable indoor climate using natural means.

Eight less common technologies were investigated, with only three making the robust technology shortlist. If you would like more information on the process or the other technologies, see Supporting Information.

Trombe walls work best when integrated into homes which have been passive solar designed – i.e. where building elements are used to collect, store and distribute the sun's thermal energy to keep the internal spaces at a comfortable temperature all year round, with no mechanical assistance. Passive solar integration is fundamental to good home design.

What is a Trombe wall?

A Trombe wall is a heavyweight, sun-facing, glazed external wall which absorbs heat from the sun during the day in order to slowly release it to the interior at night. A typical Trombe wall cross-section is shown in Figure 1 below. The idea was developed into a workable architectural element in the 1960s by French engineer Félix Trombe and architect Jacques Michel and has been successfully used around the world.

A Trombe wall takes advantage of the natural energy characteristics of heavyweight building materials (which are also fairly conductive) that have been exposed to direct sunlight. Typically, a Trombe wall consists of a darkly coloured, northern-facing masonry external wall covered by glazing on the outside. Solar energy transmitted through the glazing heats the external face of the concrete wall. This heat slowly conducts through the wall, to be re-radiated out many hours later into the internal space, reducing the amount of conventional space heating needed. During summertime, Trombe walls need to be shaded carefully, so as not to overheat the inside.

Trombe walls are particularly well suited to homes in sunny climates that have few clouds and large day-night temperature swings in the cooler months. In New Zealand the ideal regions are all of the North Island, and Nelson and Blenheim in the South Island. However, the rest of the country, including Invercargill, will still get significant benefits from this type of technology.

There are several key considerations that must be followed to ensure the success of Trombe walls in the field. This guideline, based on the findings of four New Zealand examples, provides much of the information needed to successfully implement Trombe walls in New Zealand.

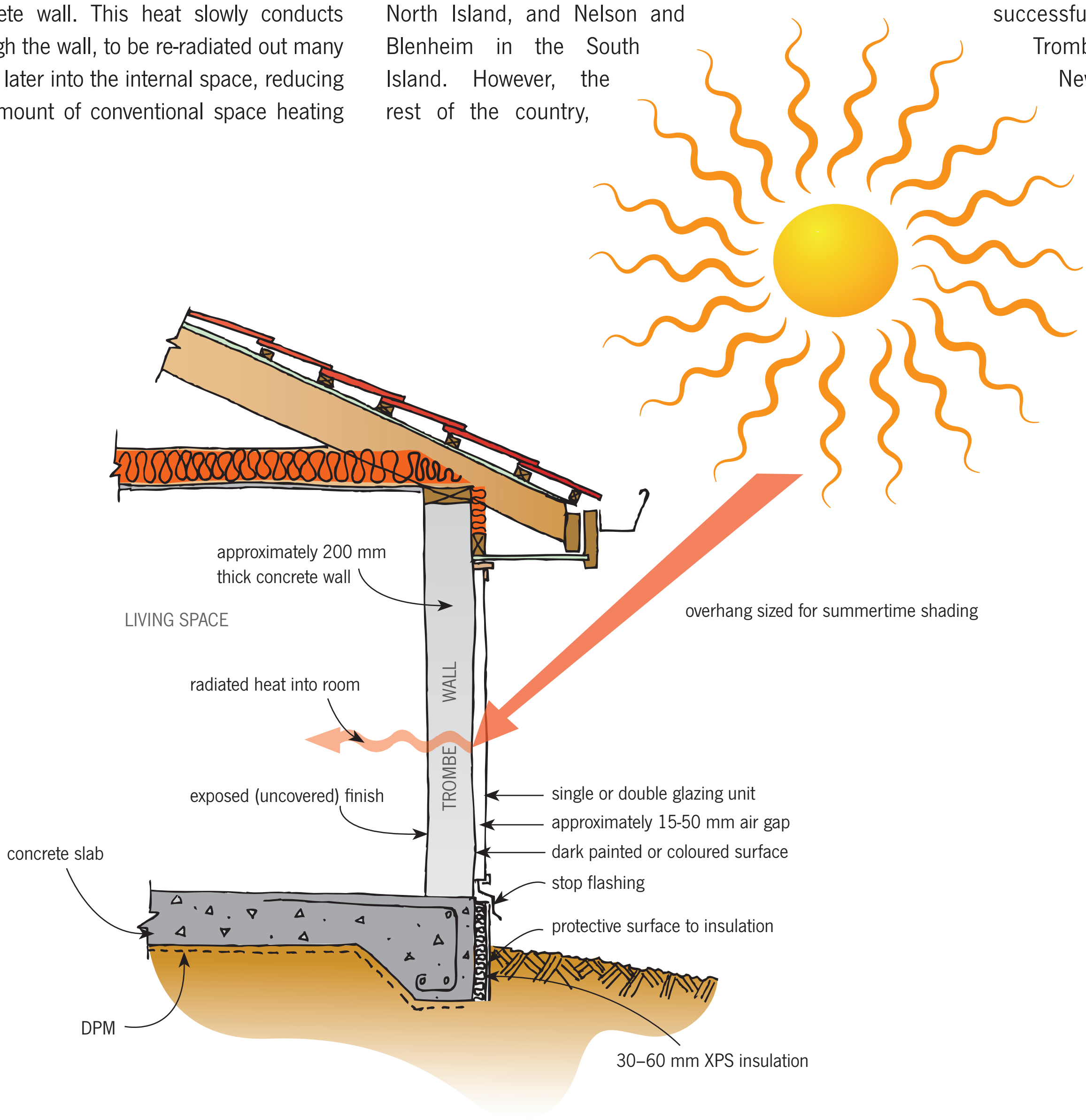

Figure 1: Schematic cross-section of typical Trombe wall, showing key components.

Why use this technology?

Trombe walls are an all-round winner – provided they are properly specified and constructed. They can greatly benefit indoor comfort by providing a very pleasant radiative heat, are very reliable and simple to construct, require very little in the way of maintenance throughout their lifetime, have a reasonable build cost, and are applicable in all New Zealand climates. They are especially good where a portion of a home's northern view may need obscuring or the views are to other orientations. In addition, they are also useful where too much natural light or glare is a concern.

User experiences

Trombe walls were recommended by all the New Zealand users surveyed by BRANZ. A typical quote:

"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"

More survey responses from New Zealand users on key performance issues are found in Table 1.

All users were asked about the extra initial installation costs. In all cases, the response was that the Trombe wall was not separately priced, as it was integrated with the rest of the house.

Table 1: Key performance indicators of Trombe walls – from BRANZ interviews in 2011–2012.

House location	Q. What do you really like about the system?	Q. What is the annual maintenance cost?	Q. How reliable is the system?	Q. Would you recommend the system to others?
Northland	It's effective and how it seasonally self-adjusts – the gradual adjustment is so perfect – the way it warms up as winter approaches.	None. Very occasional painting of black exterior concrete needed though.	It's a pretty bulletproof system. It behaves today exactly the same as it did 40 odd years ago!	Yes – have no reservations about recommending it.
Wellington	Its passivity, its robustness, and its multifunctional nature.	None.	Very reliable in providing comfortable temperatures.	Yes – because of its low dweller involvement.
Nelson	No artificial heat required. The subtle radiative heat of the wall. Seems to be better than other forms of heating.	Wash windows occasionally.	Very.	Yes, absolutely.
Nelson	Simplicity. Feeling of all-year-round comfort. Aesthetic: pebble face interior surface came out really, really well.	None really. After a couple of years, cleaning the cobwebs in the air space is needed.	Relies on the sun – so reliable as the sun!	Yes. But extra concrete and engineering calculations required.

Quantified thermal benefits

In addition to interviewing users, BRANZ modelled the Trombe walls using a thermal simulation program called SUNREL. The thermal implications of using a Trombe wall were examined in detail for four actual houses. Comfort provision, the impact on conventional space heating and the financial savings resulting were investigated. These as-built houses along with their respective Trombe walls were also thermally modelled in a range of climate zones to examine their 'transferability' to other climates.

The modelled thermal impacts were assessed quantitatively across a range of useful indicators. The results showed that:

- Trombe walls reduced the winter-time space-heating requirements of the living areas of the individual homes by an average of 35%, which equates to savings of approximately $170 annually. This was based on a temperature set-point of 20°C for the hours between 7pm and 11pm and an energy cost of 25c per kilowatt hour (kWh).
- Trombe walls worked well in different climate zones. The space-heating reduction percentages for Auckland, Wellington, Christchurch and Invercargill walls were 45%, 21%, 20%, and 18% respectively.
- Homes with Trombe walls installed had 10%, 12%, 14% and 15% more hours of comfortable temperatures in Auckland, Wellington, Christchurch and Invercargill respectively, compared to those homes without the technology. Comfortable temperatures were defined as those between 18°C and 25°C for the winter-time.

Financial implications

Finally, a financial examination of the Trombe wall technology was undertaken. Two common economic indicators were chosen: benefit-cost ratio and simple payback period.

Benefit-cost ratio summarizes the overall value-for-money of a project: the higher the ratio, the better the investment. As a rule of thumb, if the ratio is higher than one, then the project is a good investment.

Simple payback period refers to the time required for the return on an investment to 'repay' the sum of the original investment. Although it doesn't account for the risk or the financing of money, it is a useful indicator when used carefully to compare similar investments.

On average, for the four Trombe walls examined:

- the benefit-cost ratio is 2.1, making for a very good investment indeed. This is based on a 5% discount rate over 20 years, which is the rate that is typically used for these types of energy-saving technologies.
- the simple payback period is 5.4 years. This is very appealing and far better than the expected return if that money were to be invested in stock, shares or in the bank.

The assumptions made and details of the equations applied are all listed in the BRANZ conference paper by Jaques (refer to Supporting Information).

Strategies

This section provides the detail required for a Trombe wall to be planned, designed, specified, constructed and utilised correctly in a home. Both the way in which the Trombe Wall is constructed and the occupants' behaviour will impact on the effectiveness of the system.

Planning

Talking the client through the **benefits of the walls**, especially in terms of the quality of the heat provided, is suggested. The low-intensity radiative heating which is provided over a very large surface is found to be a considerably more pleasant form of heating than fan forced heating such as from electric heaters/heat-pumps. Emphasising its very low maintenance requirements, reliable performance over time and its 'safeness' as a space heater are all good selling points.

The Trombe wall will need to be **orientated** between 330° and 30° of true north (rather than magnetic north) to provide a reasonable amount of thermal benefit. This accounts for both the practicalities of shading non-north facing walls as well as the reduction in their effectiveness. To understand how the benefit reduces with non-ideal orientation, see Figure 2.

For the operational lifetime of the Trombe wall, the external northern aspect of the wall will need to **remain unobstructed** in the colder months – from landscaping, hard-scaping and vegetation. Ideally, it should be positioned so that even the neighbours cannot obstruct it in any way.

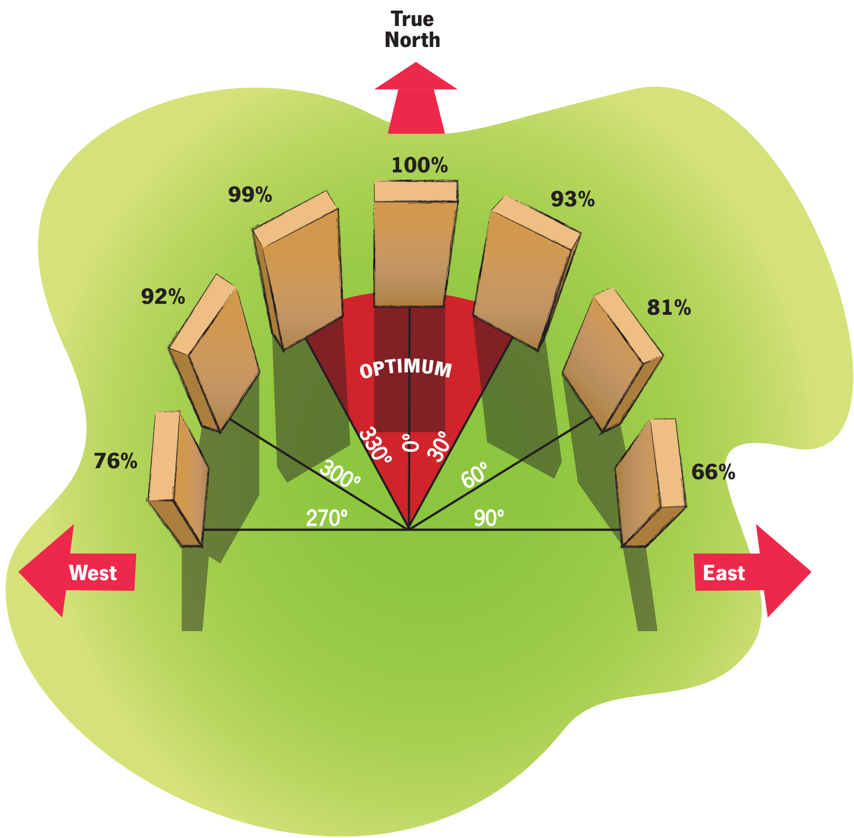

Figure 2: Percentage thermal effectiveness for differently orientated Trombe walls.

The use of **computer tools** to assist the design process is recommended. A 3D visualisation tool to examine year-round external 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 (see Supporting Information for possible providers).

Design and specification

The **glazing used** can either be single or double. Computer modelling shows that there are only marginal benefits to be gained by double glazing (in terms of heat loss) for most circumstances. More important is to look for high transmission glass – i.e. glass with a 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 on to the wall surface. If the glazed wall is difficult or inaccessible to reach from the outside, consider self-cleaning glass for long-term transparency.

The **size of the airspace** between the outer wall surface and the glazing should be between 15 mm and 50 mm, and can be either vented or unvented to the outside. Keeping the gap to around 20 mm means that the convective losses will be minimised. The benefit in venting is to reduce the risk of overheating during the warmer months – by allowing for a breeze to exhaust the heated air outside.

Thermally decoupling the footing from the ground using **insulation** is highly recommended in order to reduce heat loss. See Figures 3 and 4 below for one solution. Using extruded (XPS) insulation rather than expanded (EPS) on the external face of the footing will reduce the amount of moisture that can be absorbed. Additionally, XPS insulation provides better insulation for a given thickness. Both polystyrene types need some form of surface protection though " – for example, protective plaster.

The material chosen for the Trombe wall mass has implications for how much heat can be stored and therefore later released to the adjacent internal living area. This heat storage ability is commonly called **thermal inertia**. The higher the thermal inertia of a material is, 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. Alternative building materials, such as rammed earth and adobe, are thermally different. Rammed earth/compressed earth blocks can store about 25% more heat than concrete does even though it is less dense for a given volume. Adobe can store considerably less than even concrete, for a given volume. If concrete blocks are used, they all need to be fully grouted – the less air gaps the better, to provide consistent conductivity. Autoclaved aerated concrete does not have sufficient density to warrant being used as a Trombe wall.

The **size of the thermal inertia** must be in proportion to the living space which it is heating – a very small Trombe wall will not be beneficial to a very large room. The ratio of the Trombe wall's volume (in m^3) to the adjacent affected living area volume (in m^3) should be a minimum 1:80 for concrete-based materials. These figures assume that the home is an otherwise lightweight construction.

The **thickness** of the Trombe wall determines the time delay for the heat to conduct through from the exterior wall to the interior, which is proportional to its thermal conductivity. The rate at which the heat travels through concrete is about 25 mm/hour. Thus, for a 200 mm thick Trombe wall, heat absorbed by the exterior will take about eight hours to reach the interior space of the building. A thickness of around 200 mm is usually used for concrete-based wall materials, as the time delay means that the occupants will benefit from it in the evening. The thermal time delays for rammed earth/compressed earth blocks is around 40 mm/hour, while for adobe it is about 35 mm/hour. Exact figures are very dependent on composition.

Some early passive solar references suggested **vents** top and bottom of the wall to vent warm air from the front of the wall into the room for early morning heat gain. It is now recommended that Trombe walls aren't vented to the interior so they heat up more during the day to provide more heat at night when needed, and that early morning heat gains are harvested from direct sunlight entering windows adjacent to Trombe walls. To assist the ability of the external wall to absorb the sun's radiation, it should be a mid-dark colour.

Summertime and shoulder season shading is strongly recommended. This is especially important where good summertime whole-house ventilation is either difficult or not possible. **External shading** for mid-day direct summer sun is critically important, but mid-morning and mid-afternoon shading is important as well. Ideally, shading and ventilation should be employed in the warmer months. However, shading is more beneficial than ventilation. Fixed shading, where users don't have to do anything, will be more reliable than movable shading devices. For directly true north facing Trombe walls, extend horizontal fixed shading beyond the wall edges for at least the same distance as its depth. 3D shading studies can easily be carried out using SketchUp or similar 3D design tools to ensure appropriate shading year-round.

The Trombe wall interior surface must not be covered with plasterboard or insulation of any type to ensure that its radiative properties are not compromised. If it does need to be covered, then use a conductive surface – like shotcrete or solid plaster/stucco. Alternatively, the surface can be painted, plastered in cement-based plaster, or even tiled as long as the material is directly fixed. If painted, the colour is incidental to its thermal performance – the same amount of heat will be emitted whether the wall is white or black. Finishes such as gypsum-plastering, lining with timber, cork, wallpaper, or felt and/or objects – pieces of artwork, flatscreen TVs, whiteboards and the like – should be avoided.

Living

One of the real benefits of Trombe walls is their low need for user adjustment to function well. The only **control needed** is for shading and venting in the warmer seasons, if the glazed wall incorporates adjustable vents. There are many other ventilation options beyond the simple ones suggested in this guide, which are expanded on in the paper *Trombe walls: A review of opportunities and challenges in research and development* (see Supporting Information).

In terms of maintaining the integrity of the wall, very little is required. The occasional coating (whether painting or staining) of window mullions/framing may be necessary. Ideally, the occasional accessing of the air-space should be provided for, to clear out any spiderwebs or repaint the dark wall surface. The operation of the vents will need to be checked, and lubrication and maintenance provided as necessary.

Questions

for the homeowner and designer to discuss

1. It is extremely important that the exterior northern aspect of the Trombe wall remains unobstructed. What implications will this have for landscaping and vegetation over the next 10 years, 20 years, and 30+ years? What is the risk from neighbouring buildings (or gardens) causing obstructions during this time, and how can the risks be successfully mitigated or managed?
2. How has the seasonal shading of the external wall been addressed – shading in the summer to reduce overheating, and full exposure in winter to maximise heating gain? What about the shoulder seasons – i.e. autumn and spring?
3. What implications does ensuring an unobstructed internal wall have on the circulation routes and furniture layout adjacent?
4. What are the possible surface finishes to the internal wall to ensure good looks which last a long time and are easy to clean while complementing your adjacent internal walls? (Due to cleaning difficulties, uncoated concrete block is not recommended.) What opportunities does this present, in terms of polished concrete, exposed aggregate, painting or other methods of surface treatment finishes?
5. What strategies have been adopted to ensure that good ventilation is possible within the house, for the warmer months? For example, are there substantial openings available on both the windward and leeward side of the house to promote cross-flow ventilation?
6. Although Trombe walls are usually constructed of concrete (whether tilt slab, poured in-situ or block), other massive materials such as brick, rammed earth and adobe can be used. What opportunities do these other materials present in terms of aesthetics, cost, flexibility of construction and maintenance?
7. Although maintenance requirements are minimal, can the outside of the glazing be cleaned easily? If the glazing isn't fully sealed, access to the wall for cleaning cobwebs should be considered.

Minimum criteria checklist
for designers

For this technology to work properly, some key design issues need to be addressed. These key issues are set out in the checklist below, which are minimum requirements for the viable application of Trombe walls in New Zealand homes.

EXTERNALLY

- [ ] Trombe orientation between -30° and +30° of true north (not magnetic north). 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 12 noon during wintertime (non-daylight-saving time).
- [ ] Wintertime shading: no shading of the external Trombe wall for at least 70% of the wintertime day compared to an unobstructed horizontal skyline, so that sunlight is falling directly on the wall.
- [ ] Summertime shading: external Trombe wall fully shaded for at least 70% of the day, preventing almost all direct sunlight.
- [ ] Single glazing units installed, with solar heat gain coefficient (SHGC) ≥ 0.7
- [ ] A cavity space between the glazing and the external wall surface of between 15mm and 50mm.
- [ ] A darker-coloured external face.
- [ ] The ratio of the Trombe wall's volume (in m^3) to the adjacent affected living area volume (in m^3) should be a minimum 1:80 for concrete-based materials.
- [ ] The wall thickness to be around 200 mm, depending on time lag required and construction material desired.
- [ ] The foundation footing must be insulated from the ground with at least edge insulation.

INTERNALLY

- [ ] A wall which is at least 90% uncovered by items such as: flat screen TVs, artwork, internal linings, etc.
- [ ] A minimal (≤10% wall area) amount of furnishings (e.g. couches, shelving units) pushed up against the wall.
- [ ] Located within the living areas or even bedrooms.

OTHER CONSIDERATIONS

- [ ] The Trombe wall is part of a wider passive solar design strategy which encompasses the whole house.
- [ ] Use a 3D visualisation tool to examine year-round external shading of the Trombe wall.
- [ ] Use the opportunity presented by the large wall for decorative purposes, such as: exposed aggregate, unusual aggregate types, coloured concrete, painted, etc.
- [ ] Consider the use of computer thermal modelling to better understand the year-round comfort implications of the whole house.

Construction details

The construction drawings in Figures 3 and 4 detail a Trombe wall which has successfully been providing free space-heating for a number of years to its very satisfied owners.

The house uses a concrete tilt slab Trombe wall, covered with double glazed windows. The external face is cast and painted flat black, while the interior face is finished with an exposed aggregate. This is one viable solution of many, and is provided courtesy of architect Peter Olorenshaw.

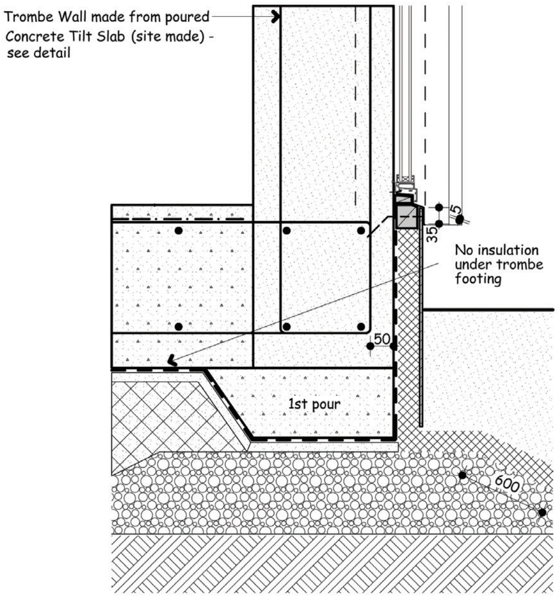

Figure 3: Cross section (not to scale)

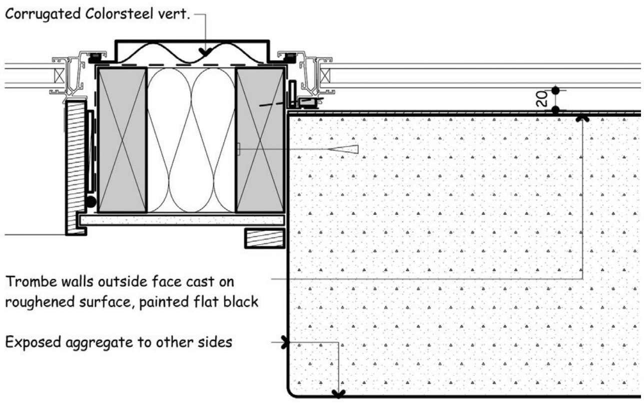

Figure 4: Plan (not to scale)

Supporting information

These references are specifically chosen to ensure that the designer and user can gain independent and relevant information on Trombe walls and passive design strategies.

1. Torcellini, P. and Pless, S. 2004. *Trombe walls in low-energy buildings: Practical experiences*. Presented at the World Renewable Energy Congress VIII and Expo Denver, Colorado August 29–September 3, 2004. National Renewable Energy Laboratory. Colorado, USA. NREL/CP-550-36277.
2. Computer tools: SUNREL (www.nrel.gov/buildings/sunrel), AccuRateNZ, and SketchUp (www.sketchup.com). Thermal modelling providers include: www.snughome.co.nz, www.settlement.co.nz and www.righthouse.co.nz
3. On the principles and strategies of passive solar design: www.level.org.nz (more technical focus) and www.smarterhomes.org.nz (more general focus); BRANZ Bulletin's #540 *Solar gain in housing* and #494 *Thermal insulation of new houses* available www.branz.co.nz ; the free *Designing comfortable homes*, by CCANZ and EECA at www.ccanz.org.nz/files/DCH_Book_WEB.pdf
4. Jaques, R. 2013. *Uncommon energy technologies in NZ homes.* Conference paper for 4th International ASA Conference, Hong Kong, November 2013.
5. 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.

This factsheet is part of a BRANZ series on the best performing, unusual space conditioning and micro-renewables technologies for the New Zealand situation.