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Trombe Walls in Low-Energy Buildings: Practical Experiences

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Introduction

Since ancient times, people have used thick walls of adobe or stone to trap the sun's heat during the day and release it slowly and evenly at night to heat their buildings. Today's low-energy buildings often improve on this ancient technique by incorporating a thermal storage and delivery system called a Trombe wall. Named after French inventor Felix Trombe in the late 1950s, the Trombe wall continues to serve as an effective feature of passive solar design.

Trombe walls have been integrated into the envelope of a recently completed Visitor Center at Zion National Park and a site entrance building (SEB) at the National Renewable Energy Laboratory's (NREL's) National Wind Technology Center. The High Performance Building Initiative (HPBi) at NREL helped to design these commercial buildings to minimize energy consumption, using Trombe walls as an integral part of their design.

Trombe Wall Design and Construction

A typical unvented Trombe wall consists of a 4- to 16-in (10- to 41-cm)-thick, south-facing masonry wall with a dark, heat-absorbing material on the exterior surface and faced with a single or double layer of glass. The glass is placed from ¾ to 2 in. (2 to 5 cm) from the masonry wall to create a small airspace. Heat from sunlight passing through the glass is absorbed by the dark surface, stored in the wall, and conducted slowly inward through the masonry. High transmission glass maximizes solar gains to the masonry wall. As an architectural detail, patterned glass can limit the exterior visibility of the dark concrete wall without sacrificing transmissivity.

Applying a selective surface to a Trombe wall improves its performance by reducing the amount of infrared energy radiated back through the glass. The selective surface consists of a sheet of metal foil glued to the outside surface of the wall. It absorbs almost all the radiation in the visible portion of the solar spectrum and emits very little in the infrared range. High absorbency turns the light into heat at the wall's surface, and low emittance prevents the heat from radiating back towards the glass.

For an 8-in-thick (20-cm) Trombe wall, heat will take about 8 to 10 hours to reach the interior of the building. This means that rooms receive slow, even heating for many hours after the sun sets, greatly reducing the need for conventional heating. Rooms heated by a Trombe wall often feel more comfortable than those heated by forced air because of the large warm surface providing radiant comfort.

Architects can use Trombe walls in conjunction with windows, eaves, and other building design elements to balance solar heat delivery. Strategically placed windows allow the sun's heat and light to enter a building during the day to help heat the building with direct solar gains. At the same time, the Trombe wall absorbs and stores heat for evening use. Properly sized roof overhangs shade the Trombe wall during the summer when the sun is high in the sky. Shading the Trombe wall can prevent the wall from getting hot during the time of the year when the heat is not needed.

These Trombe wall design concepts were applied to the low-energy design of the Visitor Center at Zion National Park in Utah and to NREL's Wind Site SEB in Colorado. Figure 1 shows the Trombe wall locations in the NREL SEB (a), and the Zion Visitor Center (b).

Figure 1. a) NREL SEB, b) Zion Visitor Center

The National Park Service applied a whole-building design process to create a Visitor Center at Zion National Park that performs more than 70% better than a comparable code-compliant building at no additional construction cost (Torcellini 2004). Trombe walls were one of the many strategies included in that process and design.

The Visitor Center Trombe wall design details are shown in the cross section in Figure 2. The 6-ft-high (1.8-m) Trombe wall (740-ft^2 total area (68.7-m^2) is located on the entire length of south-facing walls of the Visitor Center. The wall is 44% of the total south facing wall area. The Trombe wall is 8-in (20-cm) grout-filled concrete masonry units (CMU) with an R-value of 2.5 hr·ft^2·°F/Btu (0.4 K·m^2/W). The other walls are 6-in (15-cm) framed walls with an R-value of R-16 hr·ft^2·°F/Btu (2.8 K·m^2/W). The Trombe wall has a single piece of high transmittance patterned glass installed on a thermally broken storefront system.

The performance of Trombe walls is diminished if the wall interior is not open to the interior zones. Based on previous experiences with Trombe walls (Balcomb 1998), the heat delivered by a Trombe wall in a residence was reduced by over 40% because kitchen cabinets were placed on the interior of the wall. The wall design at Zion includes cast-in-place concrete projections attached to the interior of the wall. These projections were included to ensure bookshelves were not placed against the Trombe wall.

The interior surface of the Zion Trombe wall was selected to maximize the heat transfer to the space. Some interior surfacing materials, such as drywall, can reduce the heat delivered by Trombe walls due to nonconductive air gaps in between the concrete wall and the interior surface (Balcomb 1998). A shotcrete wall finish was specified to provide a more continuous conductivity throughout the wall.

During the construction process, the filling of the CMU wall was monitored to ensure the concrete block cores were completely filled, which provides a consistent conductivity through the wall. The placement of the footing insulation was also verified during the construction process to ensure proper installation. The location of this insulation is critical, as Trombe wall performance can be diminished due to three-dimensional heat transfer to the ground. By thermally decoupling the footings from the ground with insulation, unnecessary heat loss is avoided and more heat from the Trombe wall is supplied to the building.

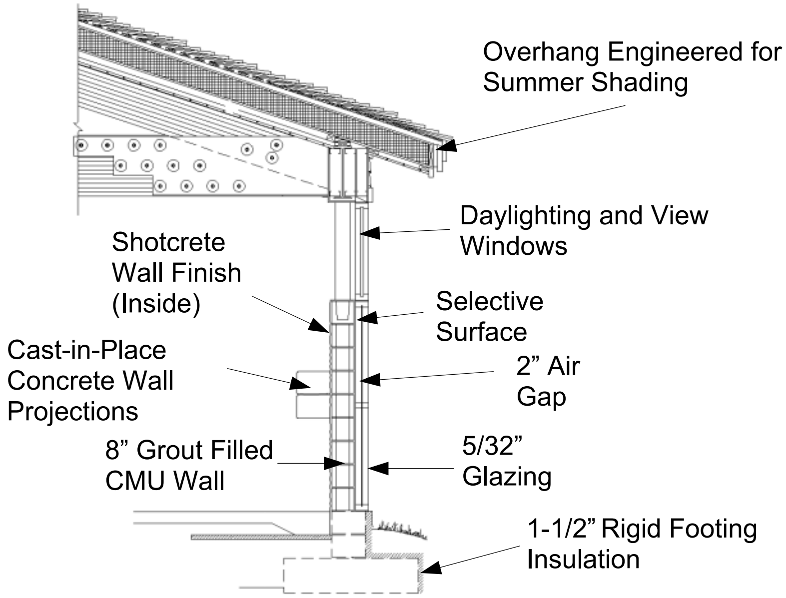

Figure 2. Cross-section details of Zion Trombe wall

NREL's Wind Site, located approximately twelve miles north of Golden, Colorado, constructed a small building at the site entrance. NREL staff designed an energy-efficient SEB that would eventually be powered completely by its onboard photovoltaic (PV) array and two wind turbines. Although small, the building is representative of many guard facilities, remote restrooms, and outposts.

A Trombe wall was an integral part of the heating system. This Trombe wall has a single piece of high transmittance patterned glass installed on a thermally broken storefront system in front of a 4-in-thick (10-cm) concrete wall with a selective surface. The other walls are 4-in-solid (10-cm) tilt-up concrete walls with an EIFS (exterior insulating finishing system). The 5-in (13-cm) exterior foam has an R-value of 25 $hr{\cdot}ft^2{\cdot}°F/Btu$ (4.4 $K{\cdot}m^2/W$). The total area of the Trombe wall is 44 ft^2 (4.1 m^2), or about 34% of the total south-facing wall. The roof overhang shades the Trombe wall for most of the summer. The interior surface is painted concrete.

Trombe Wall Energy Performance

The energy performance of the Zion Visitor Center was monitored and analyzed over a two-year period. The analysis consisted of measured electrical end uses, Trombe wall temperature profiles, and thermographic pictures to determine the performance of this Trombe wall (Torcellini, 2004). Similar measurements were taken at the SEB over a one-year period.

Figure 3 shows the thermal distribution of the Zion Trombe wall at 8:30 p.m. on December 16, 2000. The interior surface temperature is generally homogeneous, ranging from 90-96ºF (32-36ºC). The wall temperature typically peaks between 8-9 p.m. The reduced wall temperature at the far right section of Trombe wall is due to shading. The building shades a portion of the Trombe wall in the afternoon, resulting in reduced interior temperatures.

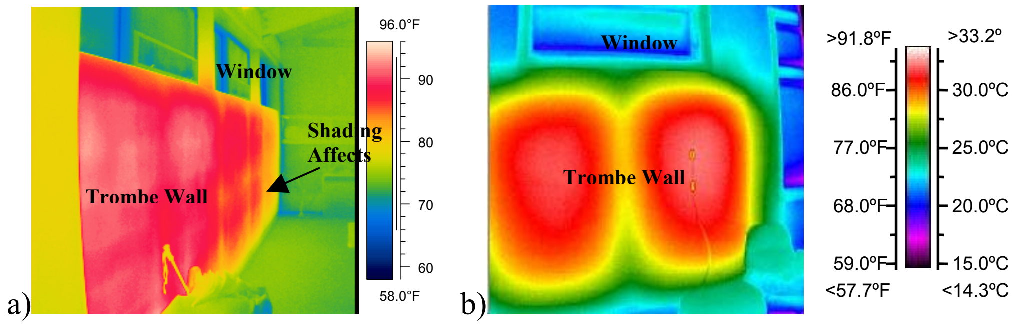

Figure 3. Infrared pictures of a) Zion Trombe wall December 16, 8:30 p.m. and b) NREL SEB Trombe Wall January 21, 8:00 p.m.

The temperature gradient in the wall was measured during the 2001-2002 heating season. With internal temperature measurements, the Trombe wall energy supplied to the building was calculated based on published heat flux calculation methods (Balcomb 1980). The Visitor Center Trombe wall daily performance during the 2001-2002 heating season is shown in Figure 4. The electric radiant heating system used 22,680 kWh (81.6 GJ) over the year, with the Trombe wall contributing 20% of the total heating to the building. The Trombe wall imposed a heating load on the building for only two of the 151 days of the 2001-2002 heating season. For the other 149 heating days, the wall was a net positive. The peak heat flux through the wall was 11.2 W/ft^2 (89 W/m^2), or 8.3 kW over the entire Trombe wall area. The average efficiency of the wall (defined as the heat delivered to the building divided by the total solar radiation incident on the exterior of the wall) was 13%.

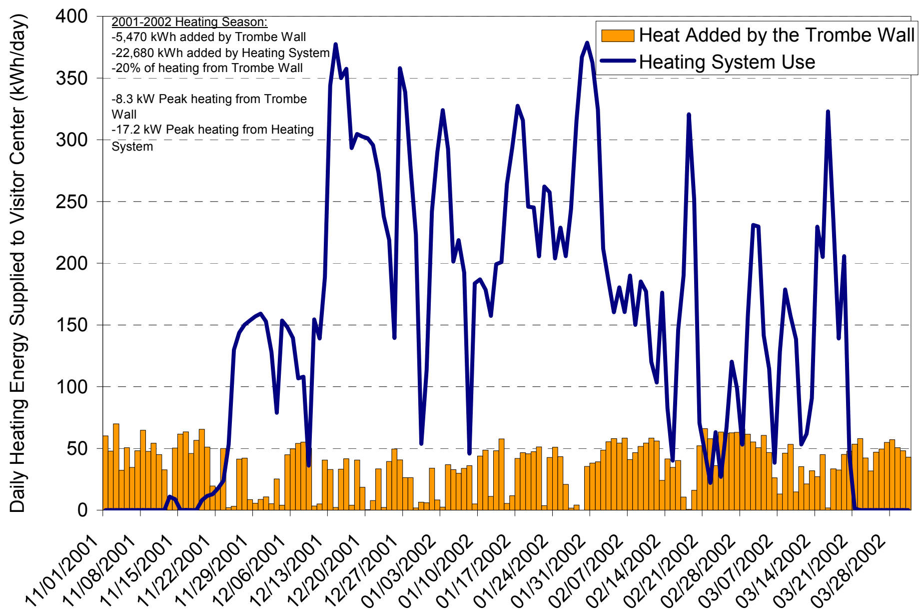

Figure 4. Zion Visitor Center Trombe wall and heating system performance, 2001-2002 heating season

The interior surface temperature of the SEB Trombe wall typically peaks at 120-130ºF (49-54ºC) at 3:30-4:00 p.m. during the heating season. The interior temperatures of the SEB wall are generally higher, but earlier in the day than the Zion wall. This difference is due to the 4-in (10-cm) SEB wall that releases the heat quicker than the 8-in (20-cm) Zion wall. During good solar days in the heating season, the Trombe wall typically provides all of the necessary heating throughout the afternoon and evening.

A potential design issue to consider in any passive solar building is overheating in the summer and swing seasons. The overhangs in both the Zion and NREL SEB were designed to shade the Trombe walls during the cooling season. Even with the Trombe walls shaded during the summer, the walls impose an additional cooling load on the buildings. This is because early morning and late afternoon radiation is not shaded, and diffuse and reflected radiation is not negligible. Additionally, the insulation values of these walls are low. At Zion, any additional cooling loads are not a significant issue, as the passive direct evaporative cooling system provides an abundance of cheap cooling. The additional cooling loads at the SEB are an issue, as a heat pump has to provide extra cooling to account for the hot Trombe wall. On average in July, the SEB Trombe wall reaches 100ºF (38ºC) in the afternoon. When the Trombe wall was completely covered for four days in August 2003, the interior surface temperature was never above 87ºF (31ºC). A summer shading blind has been recommended for the SEB Trombe wall to reduce the cooling impact of this wall.

Conclusions

Trombe walls have been integrated into the envelope of a recently completed Visitor Center at Zion National Park and a SEB at NREL's Wind site. A Trombe wall can enable a building envelope to go from a net-loss feature to a net-gain feature. The Trombe wall provides passive solar heating without introducing light and glare into theses commercial spaces. Overhangs are necessary to minimize the summer gains; however, additional means would be helpful to minimize summer cooling impacts. In both walls, edge effects were minimized with appropriate ground insulation.

The Trombe walls in both the Visitor Center and the SEB provide significant heating to the buildings. In the Visitor Center, 20% of the annual heating was supplied by the Trombe wall, and the SEB afternoon and evening heating loads are typically met by the Trombe wall. The annual net effect of the wall has to be considered when designing a Trombe wall, as the additional cooling loads can affect the cooling system performance.

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Low-energy buildings today improve on passive solar design by incorporating a thermal storage and delivery system called a Trombe wall. Trombe walls were integrated into the envelope of a recently completed Visitor Center at Zion National Park and a site entrance building at the National Wind Technology Center located at the National Renewable Energy Laboratory. NREL helped to design these commercial buildings to minimize energy consumption, using Trombe walls as an integral part of their design.

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