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Thermal Mass Integrated into Passive Solar Homes

Summary

A house building company in Pueblo, Colorado, has combined the "thermal mass" concept with passive solar design to create energy-efficient homes that are comfortable, sustainable and more affordable than many other types of solar home.

The US Department of Energy's National Renewable Energy Laboratory (NREL) helped to design and monitor energy use in two of the first homes built by the company. As a result, the company, Tierra Concrete Homes, has developed Tierra III, which is around 63% more energy efficient than conventional homes constructed to the US 1995 National Model Energy Code.

Highlights

- **Energy consumption for heating about 48% lower than comparable homes**
- **No conventional cooling system normally required**
- **Costs only 2% more than a standard house design**

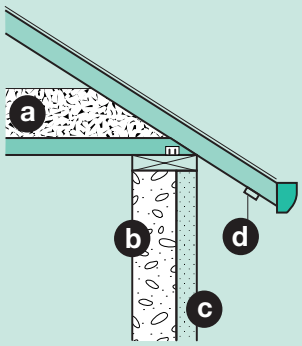
One of the affordable energy-efficient houses.

Photograph: Dwight Smith

Project Background

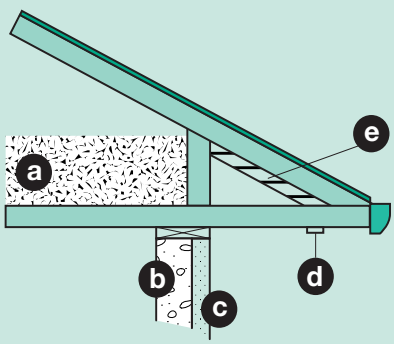
The concept of thermal mass involves using building material(s) that can absorb, store and release heat and coolness into the building. The idea is not new. Thousands of years ago, early civilisations were using earth as thermal mass to maintain moderate temperatures in their homes.

Conventional Truss



a Insulation
b 10.2 cm Concrete
c 5.1 cm Polyisocyanurate
d Vent

Raised-heel Truss



a Insulation
b 10.2 cm Concrete
c 5.1 cm Polyisocyanurate
d Vent
e Baffle

Pueblo is situated in the southern part of Colorado at 1,463 m above sea level. It experiences some extreme weather conditions, with temperatures reaching above 36°C in the summer and dropping below –22°C during winter. Bearing this in mind, local house builder Tierra Concrete Homes decided to combine traditional thermal mass and passive solar concepts with modern, innovative building technologies to create highly energy efficient homes, which would be comfortable to live in all year round.

Each home has insulated concrete wall panels and floor slabs, creating a thermal mass which is an envelope for the living space from the sides and below. Passive solar design features include many south-facing windows and overhangs for shading. During winter, the concrete walls and floor absorb and store the sun's heat, gradually releasing it into the home as temperatures fall. On summer nights, open windows allow air in to cool the concrete, which then holds the coolness through much of the following day.

NREL assisted with the computer modelling and energy analysis of Tierra I and Tierra II, two early designs built by Tierra Concrete Homes. NREL analysts also helped to design Tierra I using SUN-REL computer simulation software. Energy analysis included tests on short-term energy flow and the use of blower door and infrared camera monitoring. Both homes compared favourably with the 1995 US National Model Energy Code reference home, reducing the heating load by one-third and eliminating the cooling load.

The infrared camera, however, identified significant energy losses at points where the wall corners met the roof. This occurred as a result of using conventional trusses, which compress the insulation and push it away from the wall.

These test results were used to improve energy efficiency still further in the next generation of the company's home design. Tierra III incorporates these improvements together with other energy efficient and solar design features.

The Project

As with the earlier houses, Tierra III's passive solar energy features were considered at the predesign stage. Designers balanced all the building's elements, including site, envelope, windows and thermal mass, in order to maximise comfort and energy efficiency.

The floor plan measures 20.7 m by 8.5 m for a total of 167 m^2 conditioned and 200 m^2 finished space. A northwest-facing garage provides winter weather protection. The long rear elevation faces due south, creating more space for south-facing windows and allowing direct sunlight and heat into most of the rooms. The south-facing window area totals about 24.5 m^2, representing 15% of the entire floor area.

The windows are vinyl-clad, dual-pane and low-emissivity, which reduces heat loss. They have 0.6 m overhangs, including gutters, which provide total shade in June and July to keep the house cool. In August and September, bottom-mounted

Table 1: Energy performance of Tierra III			
	Reference home	**Tierra III**	**Reduction**
Auxiliary heating load	261 million joules/m^2/year	136 million joules/m^2/year	48%
Auxiliary cooling load	102 million joules/m^2/year	0 joules/m^2/year	100%

shades in the windows are pulled up just enough to keep out the sun's heat, whilst preserving daylight. Minimal north-, east- and west-facing windows help prevent heat loss during winter and heat gain from the east and west in summertime.

Tierra III's substantial thermal mass helps it to accommodate a large, south-facing window area without suffering the effects of overheating. The thermal mass consists of 10.2 cm thick concrete wall panels and floor slabs. Interior wall partitions are also made of concrete. The precast concrete walls are made locally; during manufacture, the electrical outlet boxes are positioned with conduits reaching to the top of the walls. Rigid insulation is attached to the exterior before the wall panels are cut out.

Both walls and floor are insulated to retain heat or coolness. The walls have 5.1 cm of polyisocyanurate foam-board insulation on the outside and are finished with stucco. There are no wood studs to break the continuity and allow temperature transfer to the outside. The slab is insulated underneath with 2.5 cm of extruded polystyrene. To prevent energy loss through the ground, such as that detected in Tierra I and Tierra II, the frost-protected shallow foundation was insulated on the outside with 5 cm of extruded polystyrene.

The only part of the building envelope not made of concrete is the ceiling/roof. The builder installed 31 cm of blown-in cellulose in the attic. Instead of conventional trusses, raised-heel trusses were used for the roof framing to maximise insulation (see the illustration far left); potential air leaks in the roof were sealed.

The combination of passive solar design and thermal mass works so well to heat and cool the house that only a thermostatically-controlled, gas-fired log fireplace is needed for back-up heating, with an electric space-heater occasionally being used in the north bedroom. Back-up cooling is not required.

Performance

NREL provided an energy analysis of Tierra III based on computer simulations of the US 1995 National Model Energy Code reference home and actual utility bills (see Table 1). Tierra III uses about 48% less energy than a comparable new home in the Pueblo area.

Economics

Tierra III cost about \$734/m^2 (where \$ is the US dollar) to build and was sold for \$189,000, a price only 2% than comparable homes in the Pueblo area. Table 2 shows the estimated additional expenditure on its energy efficiency and solar design aspects, with the savings from the home's energy saving features shown in brackets.

In terms of running costs, Tierra III offers substantial advantages (see Performance above).

Table 2: Cost breakdown for the energy-efficiency and solar design features	
Feature	**$**
Raised-heel trusses	1,000
Extra slab and wall insulation	3,000
Windows (added area, low-emissivity)	1,500
Concrete wall construction/delivery	2,500
(Savings on heating/cooling system)	(2,500)
(Eliminated drywall)	(1,000)
(Savings on floor furnishings)	(1,000)
Total	**3,500**

Environment

In Colorado, 94% of electricity consumed is generated from coal-fired power plants. By eliminating the cooling load and reducing electricity consumption in houses, use of fossil fuels is reduced. Heat savings also reduce the environmental impact of natural gas production and combustion. The annual emissions avoided by the Tierra III homes are estimated at 4,218 kg of carbon dioxide, 14.5 kg of sulphur dioxide, and 13.6 kg of nitrogen dioxide. More than 97% of this reduction is due to cooling load reduction.

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