Thermal performance of concrete-walled homes: A research update

By Dr Larry Bellamy and Don Mackenzie
Natural Resources Engineering, Lincoln University

Concrete has become the preferred floor material for most new houses in New Zealand but concrete-based products have only a small share of the house wall market. There are a number of reasons for this, but inferior thermal performance is not one of them.

A key finding from the thermal mass research project being undertaken at Lincoln University is that concrete walls can provide significant benefits to the homeowner. In this research update we outline these benefits and consider the implications of the research for the cement and concrete industries.

The experimental approach

Previous investigations of the thermal performance of concrete walls in New Zealand houses have been based on computer simulation. The experimental nature of the current project is unique. Measurements are being made in side-by-side test buildings that are nearly identical, apart from the amount of thermal mass[1] in the walls. One building has concrete walls and the other has timber-framed walls. These buildings were described more fully in an earlier report in the September 1998 issue of *New Zealand Concrete Construction.*

The main reason for deciding to use an experimental approach was the continued questioning concerning the reliability of computer simulation. The concern being voiced at the time this project was being planned was that the models were not showing the true benefits of concrete walls. It became clear that a ‘real building’ approach was required in order to make progress in understanding and quantifying the benefits of heavy mass walls.

The Cement & Concrete Association and BRANZ are funding four trials in the side-by-side test buildings. The first two have been completed. In both trials[2] the buildings were heated to maintain a minimum dry resultant temperature of 16°C from 10pm-7am and 20°C from 7am-10pm[3].

In the first trial (June-Dec 1998), the test buildings were not vented for temperature control. In the second trial (Jan-June 1999), the buildings were fan-ventilated[4] to try to avoid uncomfortably high temperatures. Only the results from the second trial are discussed here, as this trial is arguably closer to reality for most households than the first trial.

The main criteria being used to evaluate the effect of wall thermal mass on the thermal performance of the test buildings are:

Heating energy Heater capacity	} the heating cost is directly related to these
Overheating frequency	a measure of discomfort
Heating load profile	may affect the heating energy cost for an electrically heated house

Only the first three criteria are covered here, as they should be of greatest concern to new homeowners.

Energy savings

The concrete walls provided modest savings in heating energy use. Over the three heating months of this trial, the savings were greater than 10% (see Table 1). The percentage energy savings were greatest in April (14.4%) and least in June (8.4%). However the greatest absolute energy savings were in June.

The principal reason for the savings in heating energy was the difference in the buildings' ventilation requirements for cooling. The connection between energy savings and ventilation seems obvious. The concrete-walled building needed less ventilation because the concrete walls absorbed more energy, and cooled the building more effectively, than the timber-framed walls. The greater heat flow from the concrete walls during the night led to the energy savings.

The concrete walls 'captured' and stored the solar energy entering the building more effectively than the timber walls. Even during June, which is not that warm or sunny in Christchurch, the timber-walled building needed a lot more ventilation than the concrete-walled building (Table 2). This was surprising because the test buildings are insulated only to a modest level and the north-facing window, with an area approximately equal to 13% of the floor area, is not large.

Not all of the additional energy stored in the concrete walls on sunny days contributed to the energy savings. During the night the heat from the concrete walls often kept the temperature in the concrete-walled building higher than the temperature in the timber-walled building. Some homeowners may value this extra warmth, but the higher night temperatures were treated as 'surplus comfort' and a waste of energy in this research project. 'Surplus comfort' was observed on nights following both sunny and overcast days.

On overcast days the concrete-walled building tended to use more heating energy than the timber-walled building. The reason for this is related to the 'surplus comfort' effect noted above. The energy used to maintain the higher night temperatures had to come from somewhere – if not from the sun then from the heater.

The poorer performance of the concrete-walled building on overcast days has some implications for designers. Building sites with poor solar access may not be well suited to heavy-mass homes. Windows need to be designed (in conjunction with thermal mass and insulation) to ensure there is adequate solar gain in the buildings so that the benefits of thermal mass are captured. House designers need to address these issues early in the design process – our concern is that the design information they need to do this is not available.

Table 1: Monthly Auxiliary Heating Energy Use in the Test Buildings during the 2nd Trial (Jan-June 1999)

	Auxiliary Heating Energy Use[1] (kWh.m^{-2} (floor))		Heating Energy Savings due to Heavy Walls (kWh.m^{-2} (floor)) ± Experimental Uncertainty (kWh.m^{-2} (floor))	Percentage Energy Savings due to Concrete Walls (%)
Month[2]	Timber	Concrete		
April	3.89	3.33	0.56 ± 0.26	14.4
May	6.37	5.58	0.79 ± 0.31	12.4
June	12.71	11.63	1.08 ± 0.48	8.5
Total	22.97	20.54	2.43 ± 1.02	10.6

Table 2: Thermal Energy Lost from the Test Buildings due to Cooling Ventilation during the 2nd Trial (Jan-June 1999)

	Energy Loss in Ventilation Air[1] (kWh.m^{-2} (floor))		Difference between the Timber and Concrete Test Buildings[2] (kWh.m^{-2} (floor))
Month[2]	Timber	Concrete	
April	1.51	0.52	0.99
May	1.51	0.34	1.17
June	1.01	0.16	0.85
Total	4.03	1.02	3.01

Table 3: Hours When the Test Buildings Overheated During the Second Trial (Jan-June 1999)
Number of hours that the Hourly Mean Dry Resultant Temperature in the Test Building Exceeded:[1]

	28°C [2]		30°C [3]	
Month	Concrete-walled Test Building	Timber-walled Test Building	Concrete-walled Test Building	Timber-walled Test Building
Jan	10	113	0	21
Feb	34	139	7	39
Mar	36	126	16	46
Apr	7	29	0	11
May	2	15	0	5
Jun	0	4	0	1
Total	89	426	23	123

Note:

1. The data should be treated as preliminary results.
2. A significant percentage of the population feel uncomfortable when the dry resultant temperature exceeds 28°C.
3. A majority of the population feel uncomfortable when the dry resultant temperature

Heater capacity

The peak-heating loads of the two buildings were essentially equal for this trial. This is an important result because it indicates that a bigger heater is not needed if thermal mass is added to the walls of a house.

Overheating

On sunny days the concrete-walled building was up to 3-4°C cooler than the timber-walled building (Table 1). As a result, the concrete-walled building overheated less frequently and was significantly more comfortable than the timber-walled building (Table 3).

The timber-walled test building was sometimes so warm that it was barely habitable (Table 1). Reducing the solar gain (smaller windows; window overhangs; blinds and curtains; tinted glazing; reflective films) and/or increasing the ventilation rate would have reduced its overheating problem. However, these strategies would have increased the heating energy requirements of the timber-walled building.

Pulling blinds or curtains, to reduce the heat of the sun, is a ritual in some homes. The results indicate that concrete walls can largely relieve the household of this chore.

Overheating and daytime comfort are probably not given much, if any, consideration by most designers. These results indicate that it is a significant issue and one that should be considered in conjunction with energy efficiency.

Insulation

The results support the notion that exterior insulated heavy mass walls require less insulation than a timber-framed building in order to achieve equivalent energy performance. What reduction in insulation is justified is not clear.

Recall that the test buildings were insulated to just meet the minimum requirements of NZS4218:1996, for a home in the South Island. Had the timber-walled test building been insulated to a higher level, the energy use would have been reduced but the overheating problem would have been worse. It is not uncommon, at least in Christchurch, for new homes to be insulated well above the Standard in order to make them more energy efficient. While maybe well intentioned, ad-hoc sizing of insulation may not be in the best interests of the homeowner if the solar gain through the windows is not adequately controlled.

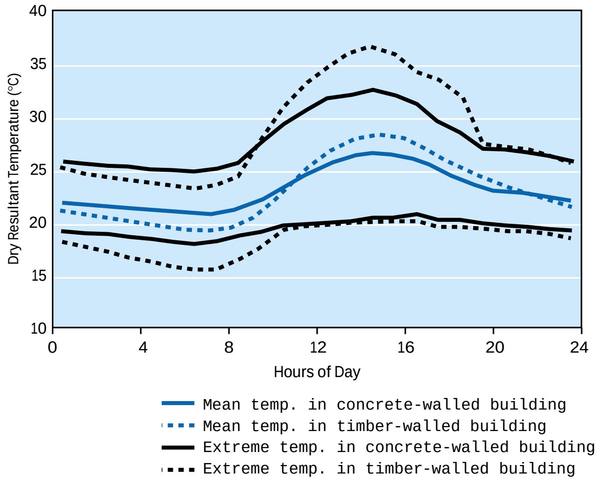
While we can only speculate on how the concrete-walled building would have performed had it been insulated more, we believe the comfort levels would not have been significantly changed and the energy use would have reduced. Further research is needed to prove this. But if this is true then concrete walls will enable the design of low-energy and comfortable homes, without having to compromise on house styling (eg small windows) or require the occupants to actively control temperature (eg pulling shades or curtains).

When the Insulation Standard is next revised, any increase in the insulation requirements will create more overheating problems in new homes, unless they are intelligently designed to avoid this. Concrete walls offer an effective solution to the overheating problem and new marketing opportunities would arise should building energy performance legislation tighten.

Climate

The cooling and comfort benefits of concrete walls should apply to all the main centres. The results show that the energy savings from wall thermal mass are dependent on climate. The percentage energy savings during the trial were greatest for April, indicating that wall thermal mass should work better (in terms of percentage energy savings) at locations with warmer climates.

Figure 1: Hourly Mean Dry Resultant Temperature and Temperature Extremes in the Test Buildings During March 1999



Design

For most new houses thermal design is limited to ensuring that the insulation meets the minimum requirements of the Insulation Standard, or some ad-hoc level above it. The potential benefits of thermal mass are unlikely to be realised with this approach, or worse, a cold and hard-to-heat home may be created.

Designers need to consider the combined effect of the main factors affecting the thermal performance of a heavy-mass home – thermal mass, insulation and windows. If concrete walls are going to increase their share of the house wall market, designers need appropriate information and design tools so that they can take this ‘systems approach’ to thermal design. This research project is one step towards providing these.

If houses should be designed to perform well in the local climate, then the results from this trial indicate that heavy-mass homes are appropriate for New Zealand. We ask if lightweight timber-framed homes are the most suitable for our temperate, sunny climate – perhaps the time for concrete walls has arrived.

Footnotes

1. *Thermal mass relates to the thermal energy storage, absorption and release characteristics of a material.*
2. *In these trials the floors of the buildings were carpeted and the windows were Ï0.5 air changes per hour. For temperature control there was additional ventilation.*
3. *Dry resultant temperature was the temperature measured at the centre of a 100 mm diameter black globe. It is a better indicator of thermal comfort than air temperature. During sunny periods, the dry resultant temperature was up to several degrees greater than air temperature, even though the globe was not in direct sunlight. During the night, the dry resultant temperature was slightly greater or less than the air temperature depending on the temperature of interior surfaces of the building.*
4. *The fans vented the buildings at approximately 5 air changes per hour when the dry resultant temperature exceeded 27°C.*