BRANZ

THE RESOURCE CENTRE FOR BUILDING EXCELLENCE

CONFERENCE PAPER

NO. 50 (1998)

HEATING ENERGY AND TEMPERATURES IN HEAVY MASS HOUSES

A. Pollard and A. Stoecklein

Presented at the IPENZ Conference,
Auckland, New Zealand, 1998

This paper is based on research funded by the Building Research Levy and the Cement and Concrete Association of New Zealand.

ISSN: 0111-7505

Heating Energy and Temperatures in Heavy Mass Houses

Pollard A., BSc(Hons.), MNZIP†
Stoecklein A., MSc, Dipl. Energy Management, MANZSES, MISES†

Abstract

This paper describes computer simulation results of heating energy use and temperatures levels in New Zealand houses. Simulations were conducted for houses with varying levels of thermal mass, thermal insulation and design, and the results were analysed in terms of thermal heat storage benefits and of room temperature distributions.

Keywords: Thermal Mass, Heavy Weight Construction, Thermal Comfort, Building Energy

Introduction

This paper is a summary of the results found in the research report "The Effects of Thermal Mass on Energy Consumption and Indoor Climate" undertaken by BRANZ for the Cement and Concrete Association[1].

Method

The energy consumption, heat flows inside the buildings and the indoor temperatures were investigated using the thermal simulation program SUNCODE.

SUNCODE is able to model the thermal performance of buildings with walls consisting of several layers of material, each of which is characterised by conductivity, density, specific heat capacity and thickness. Given the correct input parameters SUNCODE is therefore able to model the performance of concrete materials and construction practices as well as timber framed assemblies.

SUNCODE was the numeric tool used for the development of the new performance based energy efficiency New Zealand Building Code (NZBC) requirements for residential buildings. It should be noted that, in common with other countries[2], NZS4218:1996[3] does not permit energy use model comparisons to be made between suspended and slab-on-ground floors.

Construction types

Three residential heavy weight building designs were examined comprising a small (80m^2), medium (130m^2) and large (240m^2) design. The heavy weight buildings were modelled as having slab floors and concrete block external walls and internal timber framed walls. A number of alternate mass configurations were also considered:

- Light weight: Suspended timber floor and timber framed walls.

† Research Scientist, Building Research Association of New Zealand (BRANZ), Judgeford.

- Medium weight: Slab floors and timber framed external and internal walls.
- Heavy weight plus feature walls: Slab floors and concrete block external and internal walls.
- Medium weight plus feature walls: Slab floors and timber framed external walls and concrete block internal walls.

The insulation levels corresponded to approximately the requirements of NZS4218:1996[3]. While the standard requires particular insulation levels for particular climate zones, all the insulation levels provided in the standard were used in all four locations. Where different insulation levels are required for different construction techniques, additional simulations were undertaken using the construction with the higher level of insulation.

Four locations were considered and consequentially climate data were used from the computer files produced by the Centre for Building Performance Research, Victoria University of Wellington[4] for Auckland (Whenuapai) (NZS4218 Zone 1), Wellington (Kelburn) (NZS4218 Zone 2), Christchurch (NZS4218 Zone 3) and Invercargill (NZS4218 Zone 3).

Two different heating schedules were investigated in order to estimate the impact of different timing of heating requirements. The investigated heating schedules were:

	Schedule 1		Schedule 2	
	Living Area	Rest of House	Living Area	Rest of House
7:00 am to 9:00 am	18 °*C*	14 °*C*	18 °*C*	14 °*C*
9:00 am to 6:00 pm	18 °*C*	14 °*C*	16 °*C*	14 °*C*
6:00 pm to 10:00 pm	18 °*C*	14 °*C*	18 °*C*	14 °*C*
10:00 pm to 7:00 am	14 °*C*	14 °*C*	14 °*C*	14 °*C*

Table 1 Temperature setpoints for schedule 1 and for schedule 2.

These temperatures have been chosen to reflect the temperatures that might be expected to occur in New Zealand houses. They are somewhat colder than previous New Zealand[5,6] and Australian[7] simulations of annual heating requirements for heavy mass buildings which have had their temperatures based on comfort levels rather than what is expected to be found in houses[8,9]. The World Health Organisation recommends a minimum indoor temperature of 18 ºC, with a 2-3 ºC warmer minimal temperature for rooms occupied by sedentary elderly, young children and the handicapped[10]. NZBC, Clause G5 “Interior Environment” requires old people’s homes and early childhood centres be able to maintain the temperature at 16 ºC. It is recognised that below 16 ºC, resistance to respiratory infection can be diminished[11].

The use of lower temperatures in this paper is not intended to suggest that houses should be operated at these levels, but rather to better represent the ways in which New Zealand homes are used. BRANZ is conducting an extensive national investigation to measure internal temperatures.[12].

Temperature analysis

SUNCODE is capable of producing the hourly room temperatures by zone over an entire year. Figure 1 shows the lounge temperature profiles for three summer days in February for both the heavy weight and light weight cases of the medium sized building situated in Wellington. The effect of the added concrete in the heavy weight case is to increase the inertia in the room temperature so that the temperature range is less extreme than is the case with the light weight building. Figure 2 shows the lounge temperature profiles again for both the heavy and light weight cases of the medium sized building located in Wellington, but this time showing three winter days in June. The effects of the temperature setpoints is much more important for this winter period; with the temperatures within the light weight building frequently at the temperature setpoint levels of 14°C and 18°C.

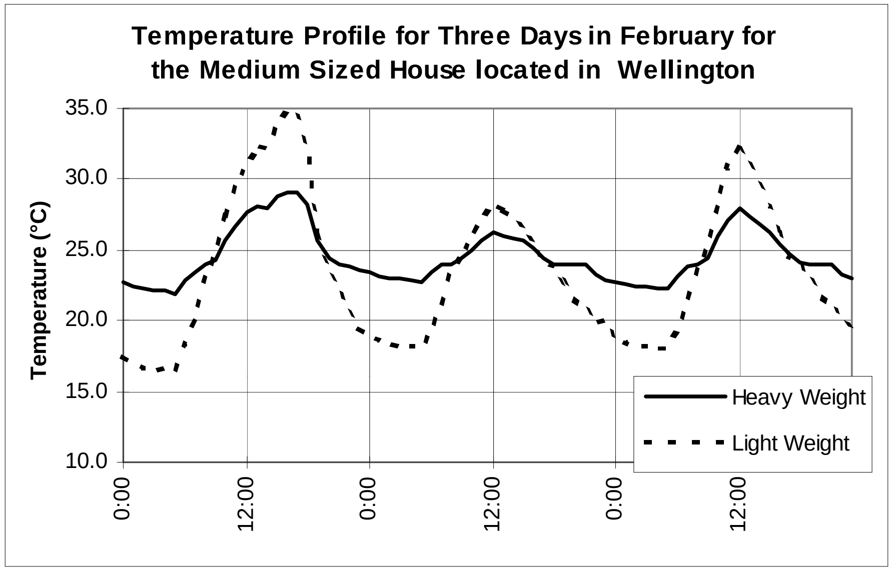

Figure 1 Temperature profile comparison for February.

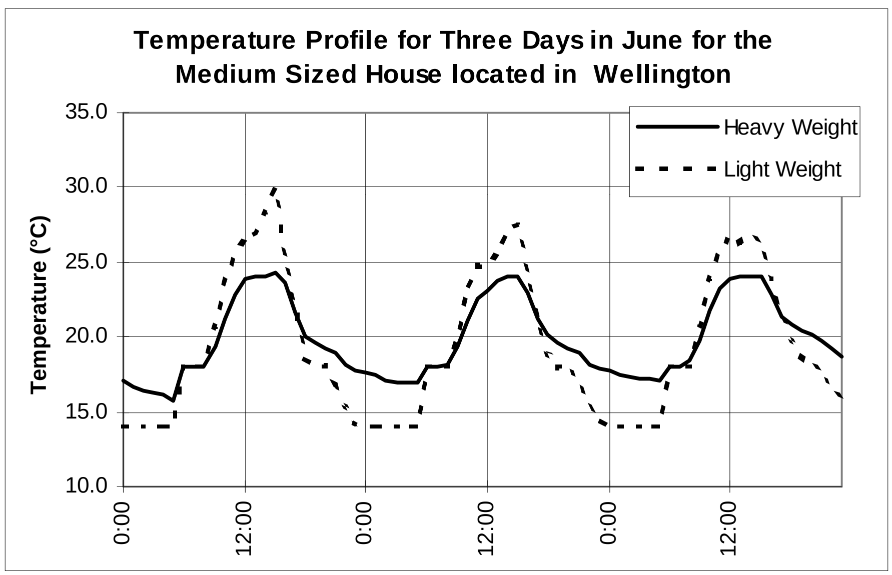

Figure 2 Temperature profile comparison for June.

The contour charts in Figure 3 and Figure 4 show the indoor air temperature distribution for one year for each hour of the day for the Medium sized house located in Wellington. The hourly temperatures are average temperatures for the month during the particular hour. In these plots, the temperatures are indicated by shading. Temperatures between 19°C and 21°C are shown in white. As the temperatures become more extreme the shading darkens. Therefore extended periods with dark colours are not desirable. Figure 3 gives the contour plot for the heavy weight building while Figure 4 gives the contour plot for the light weight building.

As a general pattern, the winter temperature fluctuations across one day are greater in the light weight houses than in the heavy weight houses. The winter temperatures in the heavy weight house fluctuate between approximately 15°*C* and 22°*C*, in the light weight house they are between 14°*C* and 23°*C*. Only the Auckland climate shows significantly higher indoor maximum temperatures in the winter time (up to 26°*C*) in the light weight houses.

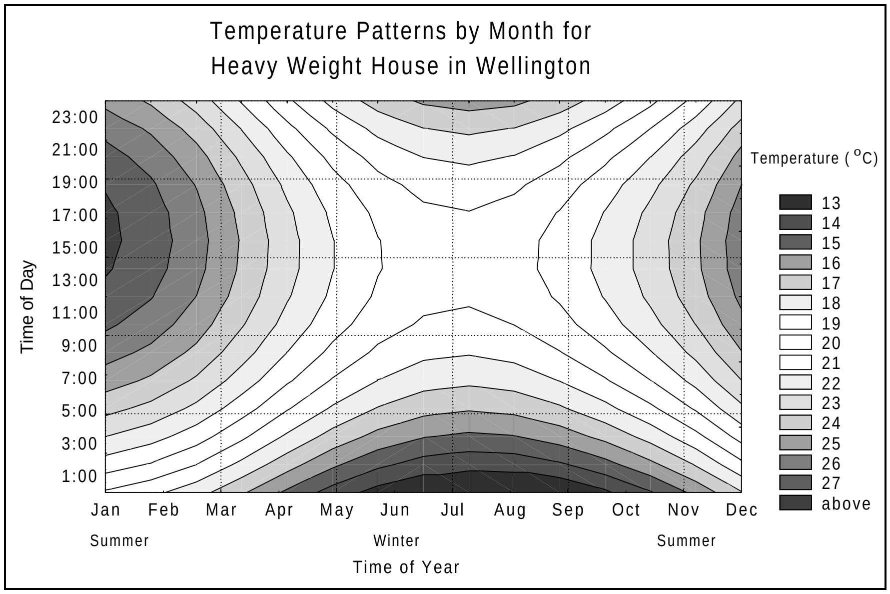

Figure 3 Average monthly temperature profiles for the heavy mass house.

It is expected that the minimum night-time winter indoor temperatures would fall further in the light weight building but this is prohibited by all heating schedules which set a 14°*C* minimum. The summer temperature profiles are less influenced by the night time setpoint. Light weight houses in all climates show living room temperatures exceeding 31°*C* during the early afternoon hours. The thermal mass in heavy weight buildings reduces the maximum summer indoor air temperatures to under 30°*C* even in Auckland.

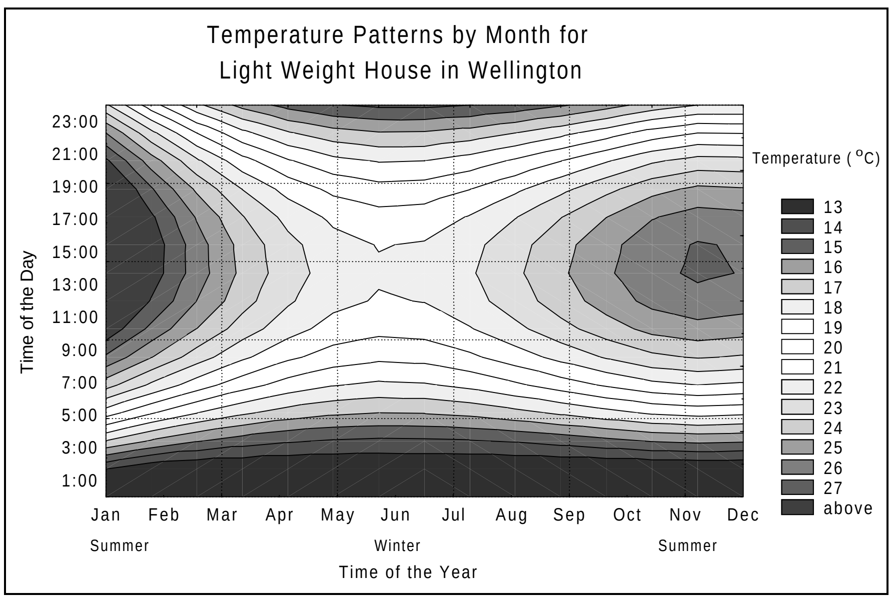

Figure 4 Average monthly temperature profiles for the light mass house.

As a simple measure of comfort the annual number of degree hours above and below the comfort level will be used. This index is calculated by adding the difference in temperature between comfort and actual mean monthly indoor temperature for all hours in which the actual temperature is larger/smaller than the comfort temperature. As the house is only "uncomfortable" when being used by the inhabitants for non-sleeping activities, the index is calculated only for the period 7 am to 10 pm. Outside this time, the winter temperature fall is limited by the heating regime, while in summer the building's temperature is floating. The index for overheating discomfort is defined as:

$$DC^{+} = \sum_{Month=1}^{12} \sum_{Hour=7}^{21} (\overline{T}_{actual}(Month, Hour) - T_{Comfort}) \text{ for all } T_{Comfort} < \overline{T}_{actual}(Month, Hour)$$

The respective Index for underheating is:

$$DC^{-} = \sum_{Month=1}^{12} \sum_{Hour=7}^{21} (T_{Comfort} - \overline{T}_{actual}(Month, Hour)) \text{ for all } T_{Comfort} > \overline{T}_{actual}(Month, Hour)$$

The larger the discomfort index the more uncomfortable the building. This measure is a simple index only. Comfort and discomfort are determined by rather complex relationships including relative humidity, clothing level, climate zone, cultural setting, general climate and other conditions. For this simple approximation we have selected 21°C as the optimum comfort temperature $T_{Comfort}$. This temperature is probably above the level generally seen in New Zealand, however, it is still at the lower end of the comfort level suggested in the ASHRAE guidelines (20°C to 29°C)[13]. Figure 5 and Figure 6 show that the heavy weight buildings have improved indoor climate conditions particularly in terms of reduced overheating. The differences between the two construction types is smaller for the underheating discomfort. This can be explained by the applied heating schedule which requires a minimum temperature of 18°C during the hours for which the thermal discomfort index is calculated (7am to 10pm).

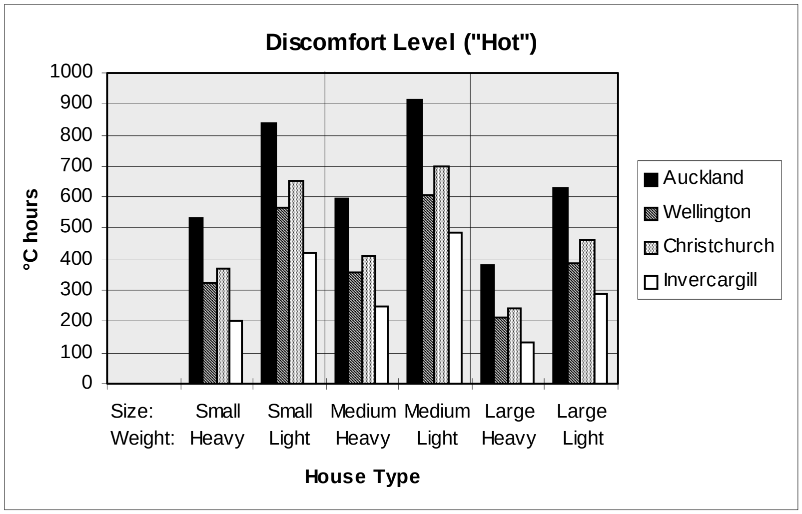

Figure 5 Discomfort level ("Hot") as expressed as the number of degree hours above 21°C.

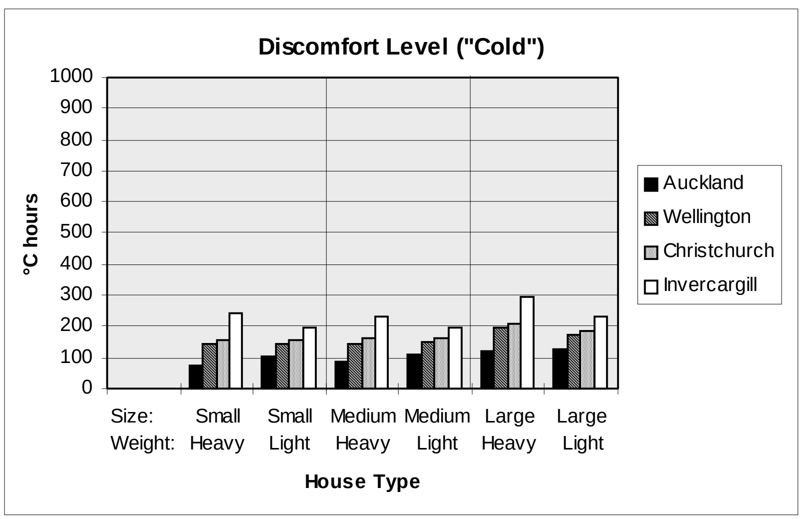

Figure 6 Discomfort level ("Cold") as expressed as the number of degree hours below 21°C.

Two main benefits can attributed to the increased thermal mass and the reduced temperature fluctuations: Firstly human temperature comfort levels are achieved more frequently in the heavy weight houses than in the light weight counterparts; and secondly the temperature swings are reduced in heavy weight buildings reducing the time with very low temperatures and consequently reducing the risk of indoor condensation and mildew growth.

Energy analysis

Isolation of thermal mass

The houses considered in this paper all have their mass exposed to the room air. No carpet is used and the wall insulation is placed on the outside of the concrete blocks. As has been found in earlier studies[5,6] the location of the exterior insulation plays an important role. Placing the insulation internal to the blocks significantly alters the behaviour of the building, as the thermal storage of the walls is isolated from the internal zones, making the building behave more like a light weight building.

A series of modelling runs were undertaken on the medium sized heavy weight house where the order of the insulation and mass layers were reversed for one particular wall orientation. For all the cases examined, placing the insulation on the inside resulted in increased the heating energy required for the house. The heating energy increase for Auckland is between 0.6% and 3.4% while for Wellington, Christchurch and Invercargill is less than 1% for each wall. While the increase for each wall is small, the walls are taken in isolation so that heat is still able to be stored in the other walls and the floor. Reversing the insulation and mass layers in each of the walls results in progressive energy savings.

The inclusion of carpeting in the design has a similar effect to the reversal of the wall insulation, in that resistance is placed in the path of the heat flow from the building zone into or out of the thermal mass. For the SUNCODE modelling in this paper the carpet was modelled as a pure resistance layer of R 0.4. For Auckland when carpets were used in the slab on ground buildings they resulted in increased heating energy requirements of between 70% and 128%. For Invercargill the increase in heating energy requirements was between 9% and 22%. The level of increase was dependent on the amount of additional mass present in the building. The increase was highest the buildings which had mass only in the slab on ground (all the walls were timber framed) while the increase was the least for buildings with a large amount of additional mass in concrete block external walls and concrete block internal feature walls.

Building orientation

Solar effects play a major role in the performance of heavy weight buildings. The heavy weight building and the light weight building for all three house designs were studied with the buildings being rotated in steps of 90°.

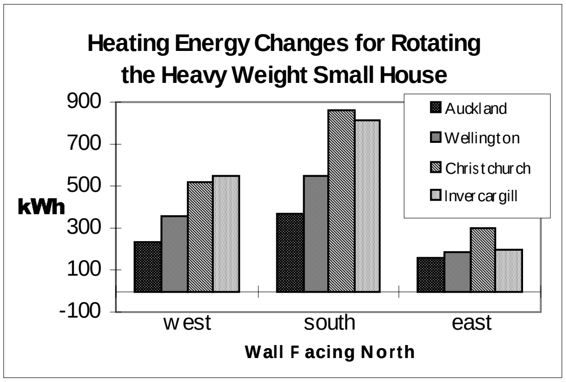

Figure 7 Change in the heating energy required for the heavy weight case of the small house design with different walls facing north.

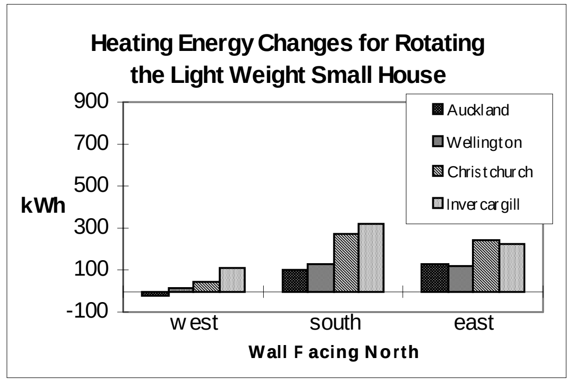

Figure 8 Change in the heating energy required for the light weight case of the small house design with different walls facing north.

From Figure 7 it can be seen that reorienting the north facing wall for the heavy weight small building required considerably more heating energy (for Auckland between 29% and 42%, and for Invercargill between 3% and 15%). Figure 8 shows that the light weight design of the same building required an increase in heating energy in all but one case. The relative increases in heating energy for Auckland are between -1% and 5%, and for Invercargill between 1% and 4%. The increase in heating energy, both in absolute and relative terms, is greater for the heavy weight building than the light building.

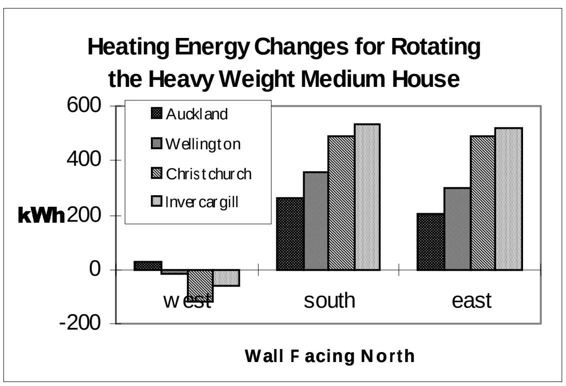

Figure 9 Change in the heating energy required for the heavy weight case of the medium house design with different walls facing north.

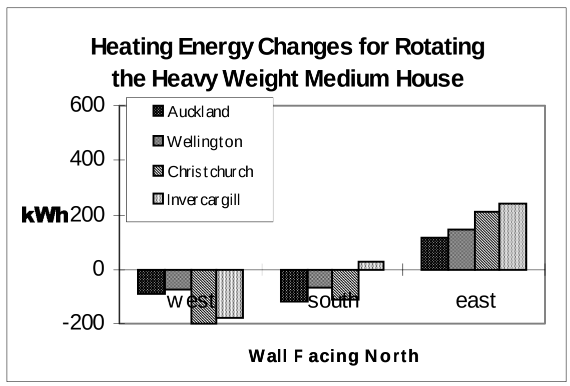

Figure 10 Change in the heating energy required for the light weight case of the medium house design with different walls facing north

Figure 9 and Figure 10 show the situation for the medium size building. Again the increase in heating energy for rotating the heavy weight building is larger when the south or east walls face north, however when the west wall of the design is aligned to north there is a decrease in the heating energy. The design of the medium size house has a large amount of glazing on the west wall providing solar gains into the lounge. Thus when this wall is orientated to the north, an increase in the useful solar gains reduces the heating energy. For the heavy weight building the relative increases in the heating energy for Auckland were between 2% and 23% and for Invercargill between -1% and 6%. For the light weight building the relative increases in heating energy for Auckland were between -3% and 3% and for Invercargill were between -1% and 2%.

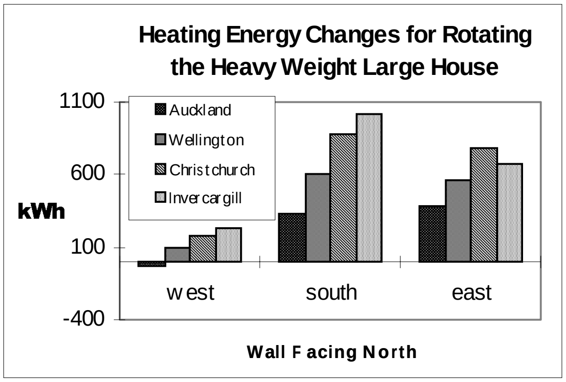

Figure 11 Change in the heating energy required for the heavy weight case of the large house design with different walls facing north.

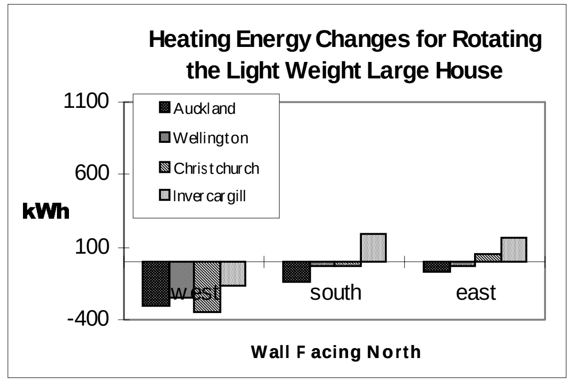

Figure 12 Change in the heating energy required for the light weight case of the large house design with different walls facing north

The situation for the large house again illustrates that heavy weight and light weight buildings do respond differently. The heavy weight building (Figure 11) shows large increases in the heating energy required in all except one case, whereas the light weight building (Figure 12) shows decreases in heating energy in all but three cases. The relative change in heating energy for the heavy weight case for Auckland are between -2% and 17% and for Invercargill are between 2% and 7%. For the light weight case the change in heating energy ranges from -5% to -1% for Auckland and -1% to 1% for Invercargill.

As found by a previous study[5] the correct orientation is more important for the heavy weight buildings than for the light weight buildings. The location of the living areas appears to be a crucial factor in the amount of heating energy purchased for these temperature schedules.

Properties of the concrete slab and the ground beneath It

With the importance of the slab on ground floor and the ground beneath illustrated by the dramatic change in heating energy requirement when carpeting is added, further analysis was undertaken to explore the inter-dependence.

The SUNCODE program models heat flow through building components in one-dimensional way. A building component is characterised by a thermal resistance, a thermal capacitance and the number of nodes within the component.

Heat flows from the building through the concrete slab and ground are strongly three dimensional. Heat flowing through the centre of the slab has to travel a lot further to travel than heat flowing through the slab close to the edge. Isaacs and Donn[5] found that the thickness of the ground modelled beneath the slab is important in modelling energy usage. The concrete slab here is modelled as two components. One component is the core of the concrete slab (everything excluding a 0.75 metre edge) and a 5.9 metre ground path beneath it, the other component being the remaining 0.75 metre edge of the concrete slab and a 1.4 metre ground path beneath that. The path lengths of ground beneath the concrete slab were chosen so that the R-value for the core path was 4.0 $m^2 °CW^{-1}$ and the R-value for the edge path was 1.0 $m^2 °CW^{-1}$. The ground temperature was taken as the average seasonal ground temperature at one metre depths as recorded by the New Zealand Meteorological Service[4]. SUNCODE simulations were performed on the medium sized heavy weight house with a variety of other ground path lengths for both the core path and the edge path.

As the path length is increased both the thermal resistance and thermal capacitance of the ground is increased. Reducing the path length so the overall R value is 2.0 $m^2 °C W^{-1}$ (half its original value) increased the heating energy by 12% to 28%, depending on location. An increase in the path length so that the overall R value is 8.0 $m^2 °C W^{-1}$, decreased the heating energy by between 7% and 9%.

Changing the length of the edge path heat flow has a similar effect to the changes to the core path length. Reducing the R value for the edge path by half to 0.5 $m^2 °C W^{-1}$ increased the heating energy between 7% and 14% while increasing the path length to give 2.0 $m^2 ° C\ W^{-1}$, decreased the heating energy by between 5% and 11%. The high sensitivity of the heating energy on the path lengths of the ground beneath the slab, makes comparison between slab on ground and suspended flooring difficult to interpret.

Values for the heat capacity for the ground and slab are always fairly approximate, as the actual value for the heat capacity depends heavily on the composition and water content of the ground and concrete slab. The ground heat capacity was taken as 0.84 $kJ \cdot kg^{-1} \cdot °C^{-1}$ and for the earth beneath the slab as 0.88 $kJ \cdot kg^{-1} \cdot °C^{-1}$. A number of SUNCODE simulations were performed on the medium sized, heavy weight house. The effect of varying the ground thermal capacitance by reducing the heat capacity to 1% of its originally modelled value results in increased heating energy requirements between 5% and 13%. Varying the value of the heat capacity of the concrete slab to 1% of its original value produced the increases in heating energy required by between 1% to 2%. The difference in magnitude between variations in the heat capacities for the ground and the concrete slab is partly explained by the difference in overall thermal capacitance of the ground and the slab. The ground has a considerably larger overall thermal capacitance (260 $kJ \cdot kg^{-1} \cdot °C^{-1}$) than the overall thermal capacitance of the concrete slab (7.2 $kJ \cdot kg^{-1} \cdot °C^{-1}$) so reducing the heat capacity of ground reduces the overall capacitance of the ground-slab system more than reducing the heat capacity of the concrete slab by an equivalent percentage.

Conclusion

In all the houses and locations modelled, the presence of mass within the building had the effect of moderating the variations in room temperatures. Light weight buildings had a much greater variation in temperatures.

Thermal mass plays an important role in determining the annual heating requirement for buildings. For the buildings simulated in this report the most important controllable factor was whether or not the buildings had a slab on ground floor or a suspended timber floor. The thermal capacitance of the buildings simulated is determined largely by the ground beneath the concrete slab, adding additional thermal mass to the building by adding concrete block walls has a lesser effect so With the ground providing the larger part of the thermal capacitance of the building, the manner in which the ground is modelled becomes a crucial factor.

Insulation and thermal mass levels can not be considered separately when determining heating energy use due to their interaction.

Factors that influence the availability of the thermal mass to the room air of the building, such as the presence of carpet or internal insulation produce an effect on the heating energy requirement of the building. With the ground being the dominant source of thermal mass, the presence of carpet is the more important factor.

The absolute amount of thermal capacitance of a building is not a reliable indication of the useful storage of the building. Placement and orientation of mass is important at the design stage to ensure that heat can be stored within the mass. Factors such as the proper solar orientation of the building can produce large variations in the heating energy requirement due to the better uptake of solar gains. These reductions in energy use are largely dependent on appropriate thermal design.

This study, along with previous studies of the role of mass is creating thermal comfort conditions, is based on thermal simulations. There is a lack of information on the actual conditions found in heavy mass New Zealand homes. This should now be a priority for future research.

References

1. Pollard, A. and Stoecklein, A. 1997. "*The Effects of Thermal Mass on Energy Consumption and Indoor Climate*", BRANZ Report for the Cement and Concrete Association, Wellington.

2. Isaacs, N., et al. 1995. *"A SENSIBLE STEP TO BUILDING ENERGY EFFICIENCY: 1995 Revision of NZBC Clause H1"*, Centre for Building Performance Research for Building Industry Authority (BIA) and Energy Efficiency & Conservation Authority (EECA).

3 Standards Association of New Zealand (1996) NZS4218:1996 "*Energy Efficiency - Housing and Small Building Envelope*", Wellington.

4. Amor, R., Donn, M. and Rollo, J. 1993. "*New Zealand Weather Data for DOE2 and SUNCODE*", Centre of Building Performance Research, Victoria University of Wellington.

5. Isaacs, N. and Donn, M. 1994. "*Effects of Thermal Mass on House Energy Use and Internal Temperatures*", Centre for Building Performance Research, Victoria University of Wellington.

6. Leslie, S. F. 1976. "*Annual Heating Energy Demand of Heavy Buildings*", NZERDC Report No. 16.

7. Walsh, P. T., Gurr, T. A. and Ballantyne, E. R. 1982. "*A Comparison of the Thermal Performance of Heavyweight and Lightweight Construction in Australian Dwellings*", Division of Building Research Technical Paper (Second Series) No. 44, Division of Building Research, CSIRO

8. Department of Statistics 1976. "*Survey of household energy consumption 1971-72, Report on the Temperature/Insulation Study*", Wellington.

9. Breuer, D. R. 1988. "*Energy and Comfort Performance Monitoring of Passive Solar, Energy Efficient New Zealand Residences - Volumes One and Two*" NZERDC Report No.171.

10. World Health Organisation 1987. *"Health Impact of Low Indoor Temperature"* , Copenhagen: World Health Organisation

11. Collins, K. J. 1993. *"Cold- and Heat- Related Illness in the Indoor Environment. In Unhealthy Housing: Research, Remedies and Reform"*, (R. Burridge and D. Ormandy, eds) London : E & F.N. Spon

12. Stoecklein, A., et al. 1997. "*ENERGY USE IN NEW ZEALAND HOUSEHOLDS - Report on the Household Energy End Use Project (HEEP) - Year 1*", Wellington : EECA

13. ASHRAE 1992. "ASHRAE Standard 55-1992, Thermal Environmental Conditions for Human Occupancy", Atlanta, Georgia, USA.