A COMPARISON OF THE THERMAL PERFORMANCE OF THREE TYPES OF DOMESTIC MASONRY CONSTRUCTION

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ABSTRACT The thermal performance of three types of domestic masonry construction - brick veneer, masonry core and cavity brick - is investigated by means of computer simulation of a three-bedroom dwelling, using climatic data for Melbourne, Sydney, Adelaide, Wagga and Hobart. Results are given for intermittent space heating and cooling energy requirements, and the occurrences of extreme temperatures when the house is not conditioned. They show that the wall type does not greatly affect intermittent heating requirements, and that increasing thermal mass in the wall decreases both cooling requirements and the occurrences of extreme temperatures during the waking hours in winter and summer, but tends to increase the prevalence of warm conditions in the bedroom zone at night in summer.

1. INTRODUCTION

In the decade since the oil price rises of 1973, there has been, especially in the developed countries of the northern hemisphere, a great deal of research on ways to reduce the energy consumption of all types of buildings, and in particular the heating and cooling requirements of dwellings. In the northern hemisphere, attention has been directed towards reducing dwelling heating requirements, which are large because of the whole-house, continuous (with perhaps some night setback) mode of heating common there. In the major population centres of Australia, with their relatively mild winters and warm to hot summers, there is still considerable scope for reducing heating requirements; however summer considerations must also play an important role in domestic building design, both in terms of reducing air-conditioning energy consumption if artificial cooling is necessary, and reducing the occurrences of unacceptably high temperatures, thereby eliminating some or all of the need for artificial cooling. The effectiveness or otherwise of wall thermal capacitance (or thermal mass as it is often called) in achieving good summer and winter performance is the subject of this paper.

Computer simulation has been used to examine three types of domestic wall masonry construction: brick veneer external walls with frame partitions (denoted by BV in the tables that follow), which is a very common form of construction in eastern Australia; cavity brick external walls with single leaf brick partitions (CB), which is common in Western Australia, less so in South Australia, and fairly uncommon in eastern Australia; and masonry core (MC) construction. This last type has brick veneer external walls with single leaf brick partitions. It is not in widespread use at present, but has been proposed as a useful compromise between the ease of construction and popularity of standard brick veneer, and the potential benefits of having some thermal mass inside the insulation envelope. The thermal performance of these three construction types will be evaluated in terms of the effect on the calculated annual space heating and cooling energy requirements of a typical house, and the summer and winter occurrences of unacceptable temperatures in the living and sleeping zones when the building is unconditioned. The unconditioned mode of operation in summer is particularly important for the locations considered here, since a majority of houses do not have air-conditioning.

The locations for which simulations have been done are Melbourne, Sydney, Adelaide, Hobart and Wagga (in place of Canberra, for which suitable climatic data were not available). However most of the results will be given for a subset of these five locations.

2. COMPUTER SIMULATION OF WALL THERMAL PERFORMANCE

In order to examine at a reasonable cost the effects of various construction types on the thermal performance of a building, it is necessary to resort to computer-based simulation. The program used for the studies reported here is program ZSTEP3, developed at the CSIRO Division of Building Research (1,2). It uses real hourly climatic data to calculate hourly temperatures in up to ten zones of a building, or heating space energy requirements in one zone, cooling requirements in the same or a different zone, and temperatures in the other zones. Efficient algorithms are used, so that hourly calculations for one year can be made at a reasonable cost.

The thermal performance of the three wall types described above will be examined in the context of a typical compact three-bedroom detached dwelling, of which a number have been built in Melbourne. The floor plan is shown in Figure 1, and is in fact identical to that of the Low Energy Consumption House that was built at the Division of Building Research in Highett, Melbourne, although features unique to that house, such as the under-floor rockbed thermal store and the roof-mounted solar air heaters, are not included in the simulations. The total internal floor area is approximately 100 m^2, of which the living (consisting of the lounge, dining and kitchen areas) and bedroom zones contribute about 38 m^2 each. For the masonry core construction, the area of internal masonry in the living zone is 32.7 m^2; for the cavity brick construction, an additional 23.1 m^2 of internal masonry is present in the living zone as part of the inner leaf of the external walls. For the brick veneer construction, all of the above areas appear as lightweight plasterboard. Where insulation is provided, it is to the SAA standard (3) in the ceilings, and R1.0 is added to the walls.

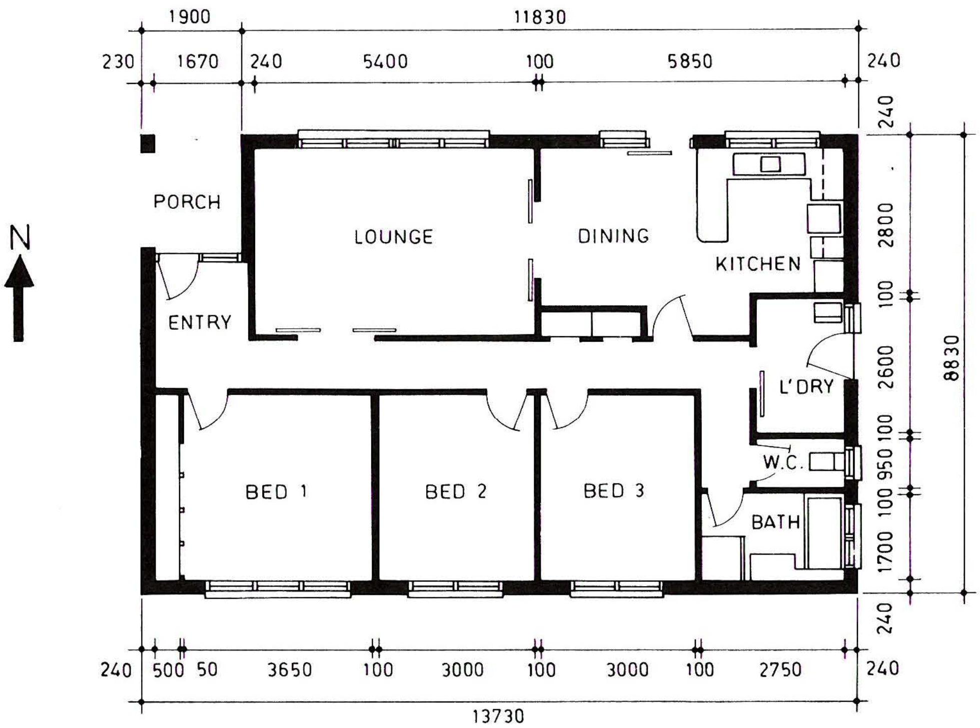

Fig. 1 Floor plan of the house examined in this paper. Dimensions are in mm.

The house is assumed to be occupied by a four-person household, whose various activities generate the heat inputs to the living, bedroom and service zones shown in Table 1.

Table 1. Daily profile of internal heat inputs arising from the activities of a four-person household. "Time" is the starting time for the indicated input, which applies for one hour.

Time	Living zone (W)	Bedroom zone (W)	Service zone (W)
0000	75	225	0
0100	75	225	0
0200	75	225	0
0300	75	225	0
0400	75	225	0
0500	75	225	0
0600	75	225	0
0700	400	450	800
0800	325	0	325
0900	100	200	0
1000	150	0	0
1100	150	0	0
1200	225	0	0
1300	150	0	0
1400	150	0	0
1500	150	0	0
1600	800	200	0
1700	1200	200	0
1800	800	100	0
1900	800	100	0
2000	800	100	0
2100	800	100	100
2200	500	150	0
2300	75	225	0

When the house is conditioned the living zone is heated or cooled from 0600 to 2200, to temperatures derived from the work of Humphreys (4). This work derived a correlation betwen the mean monthly outdoor temperature and the preferred or neutral temperature, t_p. Using the coldest month to obtain the winter preferred temperature gives 20°C for Melbourne, Sydney and Adelaide, and 19°C for Hobart and Wagga; similarly, using the hottest month to obtain the summer preferred temperature gives 24°C for Melbourne and 25°C for Sydney, Adelaide and Wagga. Cooling requirements for Hobart are small and are not considered. These temperatures are used as the heating and cooling thermostat settings. Heating is available throughout the year, but cooling is not available from May to October inclusive. The energy quantities calculated are heating and cooling space energy requirements only; these are to be divided by an appropriate seasonal coefficient of performance to obtain estimates of actual energy consumption.

Infiltration rates to each zone are assumed to be one air change per hour (ac/h), but the occupants increase this to 10 ac/h in the living and bedroom zones when the zone temperature is greater than the summer preferred temperature, t_{ps}, and greater than outdoors, until the temperature is less than or equal to t_{ps} - 3K or outdoors. The living zone window shading coefficient is set to 0.9 in the unshaded mode and reduced to 0.3 whenever the daily maximum temperature exceeds t_{ps} + 6K, in which case the shading coefficient is set to 0.3 all

day, or whenever the living zone temperature is greater than t_{ps}. These measures are designed to improve summer conditions; to reduce heat losses at night, the occupants draw heavy drapes across the living zone windows from sunset until 0700 or sunrise, thereby reducing the window U-value from 7.1 $Wm^{-2}K^{-1}$ to 2.5 $Wm^{-2}K^{-1}$.

Before proceeding to examine the thermal performance of the three wall types, it is of interest to examine briefly the effect of increasing wall thermal mass on the response of the living zone temperature. Program ZSTEP3 calculates the response of each zone (called the total zone response factor) to temperatures or heat flows acting on the building. For example, the response factor for convective heat flow gives the change in zone temperature per watt of heat flow to the zone (say from heating equipment). Table 2 gives the living zone convective heat flow response factors for the three wall types.

Table 2. Living zone response factors for convective heat flow for suspended timber floor construction. Walls and ceilings insulated.

Wall type	Living zone response factor to convective heat flow (K/W)
Brick veneer	0.0019
Masonry core	0.0015
Cavity brick	0.0013

These illustrate the progressively slower response that results when thermal mass is added to the walls. This slower response is desirable on summer days, since the zone temperature will not rise as much for a given heat input. By the same token however, this effect is undesirable on warm summer nights, where the zone temperature will not fall as quickly in response to the cooling effect of night ventilation. Furthermore, the slower response of the more massive walls may not necessarily be beneficial in winter for intermittent heating, since more heat will be required in the morning to bring the zone temperature up to the thermostat setting in a given time (say one hour). This is counterbalanced to some extent by the fact that overnight the temperature in the more massive structure would not have fallen as far as in the less massive one. These effects will be examined in the next section.

3. RESULTS FOR THE CONDITIONED MODE

The simulations for the conditioned mode have been done for an intermittent mode of heating and cooling, from 0600 to 2200, as described above. This period was chosen as being representative for a household in which some members are at home all day. Tables 3a and 3b give the heating and cooling energy requirements for a variety of building types and insulation levels for five locations. Note that comparisons between locations should be made with caution, because of the different thermostat settings and levels of ceiling insulation.

Two main conclusions may be drawn from these results. Firstly, for the intermittent regime under consideration, heating requirements are not very dependent on the wall type: for the cooler winters of Melbourne, Wagga and Hobart there is some tendency for increasing wall thermal mass to increase heating requirements, whereas in the milder winters of Sydney and Adelaide, increasing wall thermal mass tends to decrease heating requirements slightly.

An examination of monthly requirements can shed further light on the interaction between wall thermal mass and the season of the year. Table 4 gives the monthly heating requirements for a selected building in Wagga.

Table 3a. Annual heating space energy requirements for various construction types. Walls and ceilings are insulated unless otherwise indicated. TFU denotes uninsulated suspended timber floor; CC denotes carpeted concrete slab-on-ground; BV denotes brick veneer, MC masonry core, and CB cavity brick construction.

Building type	Heating Requirements (GJ)				
	Melbourne	Sydney	Adelaide	Wagga	Hobart
BV, TFU, no insulation	18.6	13.3	14.2	19.3	21.9
MC, TFU, no insulation	20.6	13.3	15.5	21.6	24.7
CB, TFU, no insulation	20.1	12.6	15.1	21.5	24.7
BV, TFU	9.0	6.5	6.5	9.5	10.3
MC, TFU	9.6	6.2	6.6	10.5	11.2
CB, TFU	9.1	5.6	6.2	10.5	11.1
BV, CC	6.7	4.9	4.5	7.3	7.6
MC, CC	6.9	4.5	4.3	7.8	7.9
CB, CC	6.6	3.9	3.4	7.7	7.6

Table 3b. As for Table 2a, but for cooling requirements.

Building Type	Cooling Requirements (GJ)			
	Melbourne	Sydney	Adelaide	Wagga
BV, TFU, no insulation	10.8	24.9	18.5	21.0
MC, TFU, no insulation	8.9	22.9	16.5	18.2
CB, TFU, no insulation	7.5	19.0	14.9	15.7
BV, TFU	4.0	8.9	8.2	6.8
MC, TFU	3.1	7.1	7.2	5.4
CB, TFU	2.5	6.2	6.5	4.3
BV, CC	3.8	8.3	7.8	6.3
MC, CC	3.0	6.8	7.0	5.2
CB, CC	2.6	5.9	6.4	4.4

Table 4. Monthly heating space energy requirements for an insulated house with suspended timber floor in Wagga

Month	Mean Temp.	Heating requirement (MJ)		
		BV	MC	CB
Jan	23.5	16	1	0
Feb	22.5	2	0	0
Mar	21.7	2	0	0
Apr	16.6	182	104	64
May	10.7	1027	1081	988
Jun	7.2	2023	2350	2394
Jul	6.0	2163	2486	2530
Aug	7.3	2128	2546	2646
Sep	10.9	987	1104	1122
Oct	13.1	725	716	665
Nov	16.7	222	151	103
Dec	20.5	30	5	0
Total		9507	10544	10512

This shows that when the mean outdoor temperature is well below the comfort range, increasing the wall thermal mass tends to increase heating requirements, whereas in the other months, when the mean outdoor temperature is closer to the comfort range, increasing wall thermal mass tends to decrease heating requirements. The annual heating requirement reflects the balance between these two opposing tendencies, so that in locations where the mean monthly temperatures are closer to the neutral range, increasing wall thermal mass would tend to decrease annual heating requirements, or at least increase them by less, compared to locations where mean monthly temperatures are further from the neutral range.

The second conclusion that may be drawn from Table 3 is that increasing wall thermal mass decreases cooling requirements for all the locations considered, so that brick veneer consistently has higher cooling requirements than does masonry core, which in turn has higher requirements than does cavity brick. Again, for these locations the mean outdoor temperatures for the cooling months are close to the comfort range of temperatures.

It should be emphasized that the above remarks on the effect of wall type on heating requirements apply to an intermittent heating regime. For a continuous regime, the work of Walsh et al. (5) shows that heating requirements decrease with increasing wall thermal mass. However, since a continuous heating regime would be uncommon for the locations considered here, it will not be considered further.

4. RESULTS FOR THE UNCONDITIONED MODE

For the locations considered here, the unconditioned mode of operation is very common in summer, and it is therefore important to examine the effect of wall type on the frequency of occurrence of unacceptable temperatures in summer. Furthermore, although most houses have some form of heating, this is often confined to part of the house, so that unheated rooms in winter are also common.

The output from program ZSTEP3 gives for each month the total number of hours for which the zone temperature is in a given temperature bin: for these simulations each bin is 1K wide, ranging from 10°C to 34°C, plus bins for temperatures greater than 34°C or less than 10°C. The summer (December, January, February) and winter (June, July, August) periods will be considered. Taking the preferred temperatures t_p given in section 2 above as the midpoints of the winter and summer neutral ranges respectively (taken to be 6K wide, i.e. $t_p \pm 3K$ are the limits of the neutral range) and taking the limits of acceptable conditions to be $t_p \pm 6K$, then for Melbourne, for example, the lowest acceptable temperature in winter is found to be 14°C, and the highest acceptable temperature in summer is found to be 30°C. Accordingly for each construction type, the number of hours for which the zone temperature falls below the lowest acceptable temperature in winter or rises above the highest acceptable temperature in summer has been calculated. This will be expressed as a percentage of the total number of hours in the period.

4.1 Summer conditions

Most of the results will be given here for the two major population centres, Melbourne and Sydney. Table 5 gives the occurrences of unacceptable temperatures in the living zone during the summer months, for the waking hours 0600-2200.

Table 5. Occurrences of unacceptable temperatures in the living zone during the waking hours 0600-2200 for summer, as a percentage of the total number of hours for that period. Walls and ceilings are insulated unless otherwise indicated.

House type	Melbourne % occurrences > 30°C			Sydney % occurrences > 31°C		
	BV	MC	CB	BV	MC	CB
TFU, no insulation	17.7	13.6	10.2	38.7	33.5	27.7
TFU, ceiling insul. only	10.3	5.6	1.8	23.1	14.1	9.0
TFU	8.8	3.2	0.7	19.1	10.1	5.8
CC	7.7	1.7	0.6	15.8	8.8	4.2

It clearly indicates the effectiveness of thermal mass in walls (either as part of the external walls or as partitions between and within zones) in reducing the occurrences of unacceptable temperatures. It also shows that wall thermal mass is effective regardless of whether insulation is present, or of the floor type.

When examining the figures in Table 5, it should be borne in mind that they have been calculated by assuming that blinds and ventilation rates are adjusted by the occupants in a sensible way. To illustrate the importance of good occupant management in achieving tolerable summer conditions, Table 6 shows, for an insulated house with suspended timber floor, the effect of no management (that is, the ventilation rate is fixed at one ac/h, and blinds are never drawn) on the performance of the three wall types in Melbourne.

Note that although the occurrences of unacceptable temperatures increase considerably, the superiority of the more massive walls is maintained, and is in fact even more evident.

Table 6. As for Table 5, suspended timber floor, Melbourne only. Walls and ceilings insulated

	% occurrences > 30°C		
	BV	MC	CB
With good occupant management	8.8	3.2	0.7
With no occupant management	21.2	12.6	9.5

A common criticism of heavyweight construction is its tendency to maintain uncomfortably high temperatures on warm summer nights, when the quicker response of a lightweight structure might be expected to take better advantage of cooler ambient air temperatures, and so improve sleeping conditions. To examine this effect, the occurrences of temperatures greater than 24°C in the bedroom zone for the sleeping hours (2200 to 0600) are given in Table 7 for Melbourne, for two ventilation strategies: one where the rate is fixed at one ac/h, and the other where the rate is increased to 10 ac/h whenever the zone temperature is greater than 24°C and greater than outdoors, until the temperature drops to 21°C or outdoors.

Table 7. Occurrences of temperatures greater than 24°C in the bedroom zone for the sleeping hours 2200-0600 in summer, for two ventilation strategies. Melbourne, suspended timber floor, walls and ceilings insulated

	% occurrences > 24°C		
	BV	MC	CB
1 ac/h only	26.2	40.2	41.9
1 ac/h plus extra ventilation when required	11.1	15.4	16.3

Clearly the lighter wall is always superior, particularly if extra ventilation is not available. However, if extra ventilation is available, the differences between the three wall types are considerably reduced. Of course in practice the natural ventilation rate will depend on wind speed and other factors; however the figures in Table 7 serve to highlight the importance of providing good cross ventilation where heavyweight walls are used. One possibility to be considered for use on still, warm nights is the use of a whole-house fan to assist ventilation.

4.2 Winter Conditions

Although living rooms in winter will generally be heated for some part of the day, some houses will have unheated north-facing rooms that have daytime uses, so that it is of interest to examine the occurrences of unacceptable temperatures in the unheated living zone during the waking hours for the winter months. These are given in Table 8 for Melbourne, which also gives the occurrences of unacceptable temperatures in the bedroom zone during the sleeping hours.

Table 8. Occurrences of unacceptable temperatures in winter in the living zone during the waking hours and in the bedroom zone during sleeping hours for Melbourne. Walls and ceilings insulated unless otherwise indicated.

Building type	% occurrences < 14°C	
	Living zone 0600-2200	Bedroom zone 2200-0600
BV, TFU, walls and ceiling uninsulated	32.1	90.1
MC, TFU, walls and ceiling uninsulated	33.3	80.6
CB, TFU, walls and ceiling uninsulated	33.4	78.5
BV, TFU	22.2	73.2
MC, TFU	19.0	59.6
CB, TFU	16.5	58.7

Note that in the living zone of the uninsulated structure, the wall type does not have much effect on the occurrences of unacceptably cool temperatures during the waking hours, whereas for an insulated structure, the addition of thermal mass to the walls does reduce the occurrences significantly. In the bedroom zone, we see that the more massive wall type is able to maintain higher temperatures at night than the lighter type; whereas this effect is a disadvantage in summer, it is an advantage in winter.

5. CONCLUSION

This paper has compared the thermal performance of three types of domestic wall construction: brick veneer, masonry core, and cavity brick. Results for computer simulation of a compact three-bedroom dwelling have been obtained using climatic data from five locations in temperate Australia. Thermal performance has been evaluated in terms of energy requirements for intermittent heating and cooling, and in terms of the occurrences of unacceptably high or low temperatures in summer and winter. The results show that the wall type does not greatly affect intermittent heating requirements, but does significantly reduce cooling requirements. In an unconditioned building, the more massive wall types reduce the occurrences of unacceptably high temperatures in the living zone during the waking hours, but increase the occurrences of warm conditions in the bedroom zone during sleeping hours, requiring provision of effective ventilation. In winter, the more massive wall types reduce the occurrences of unacceptably cool conditions in both living and sleeping zones. Thus we conclude that for the temperate regions of Australia included in this study, the chief benefit of the more massive forms of wall construction is not in reducing heating energy requirements, but in reducing the occurrences of extreme temperatures in summer. This latter effect may however lead to reductions in peak electricity demands by eliminating the need for air-conditioning.

ACKNOWLEDGEMENT

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6. REFERENCES

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