TOWARDS THE EXTREME - HIGH MASS BUILDINGS IN TEMPERATE AUSTRALIA

David Oppenheim and Graham Treloar

School of Architecture and Building, Deakin University, Geelong, 3217, Australia

Abstract - In temperate Australia, traditional solar houses usually aim at 60-80% solar contribution to the heating and cooling of the building. In Northern Europe, however, in order to reduce heating energy requirements further, the approach has generally been to provide high levels of insulation combined with a comparatively air tight construction. Lund [1] has proposed that the thermal inertia of an extremely high mass house is another means of reducing heating and cooling energy requirements by smoothing out the seasonal variation in indoor temperature.

This paper examines these two extremes: the high mass approach and high insulation approach. A number of variations in between are also examined, reducing material volumes down to traditional levels. Glazing levels (single, double and triple), and infiltration rates (medium, 0.5 ac/h and low, 0.1 ac/h) were also varied to allow for the Australian tendancy to interact more with outdoor spaces and regularly 'air out' buildings, even in winter.

Embodied energy levels and reductions in recurrent energy requirements were combined in 60 year life cycle assessments to develop design guidelines for overall energy minimisation. The results of this work suggest that moderately massed, moderately insulated houses with low infiltration rates and double glazing work best in temperate Australian climates.

1 INTRODUCTION

This research was conceived in response to an emerging tendency of some building designers to use increasingly thicker mass walls and insulation in domestic building external envelopes. Lund has stated that for passive solar houses in northern European latitudes up to 1000 cubic metres of concrete or equivalent is needed to provide the thermal mass required to reach zero space heating energy [2]. It was suspected that energy requirements for the manufacture of excessive amounts of thermal mass would be of greater significance than smoothing out the annual heating and cooling loads. To determine whether zero heating and cooling load is a justifiable life-cycle energy objective, this paper includes embodied energy estimates of building materials.

The heating and cooling loads were simulated using the thermal simulation tool 'Cheetah' [3]. Infiltration rates and the window specification were then varied and the thermal performance compared with increasing layers of masonry and insulation in the external walls.

The first objective of the paper is to determine the characteristics of the external walls of a generic passive solar designed dwelling which minimise heating and cooling energy. The second objective is to calculate energy payback periods for the additional materials and estimate 60 year life cycle energy, thereby testing Douglas Balcombe's suggestion that the last 20% or so of heating and cooling energy savings are usually not worth striving for [4].

2 METHOD

2.1 Case Study Description

A simplified building of domestic scale and function was used for the purpose of this energy analysis. The plan was rectangular 16m long x 8m wide x 2.4m high (internal dimensions) facing the equator (north in Australia) with a concrete slab-on-ground floor, insulated metal deck roof, north facing timber framed windows (10% of the net floor area) and south (non-equatorial) facing windows (5% of the net floor area). Initially the reverse brick veneer walls had no internal leaf of masonry but included 100mm of fibreglass insulation, nominally protected externally by 10mm of cement render on an expanded metal lath supported by a timber frame and lined internally with plasterboard (in normal brick veneer construction an external layer of 110mm thick masonry cladding covers a structural timber frame which is clad internally in plasterboard).

The reverse brick veneer walls were varied in two ways. Firstly, the 100mm of insulation was held constant and then an internal leaf of masonry was added. Then further layers of masonry were added to increase the thicknesses to 220, 330, 550 and 880mm, assuming a negligible thickness of mortar between each layer. Secondly, an internal 110mm layer of masonry was held constant and the wall and roof insulation was increased from 100mm to 200, 300, 500 and 800mm. Table 1 list the set of symbols given to these variations (NB: '1m' and '1i' are identical cases, and the mass is always the internal layer).

Table 1 List of Symbols representing External Wall Variations to Case Study

external wall variation	symbol	external wall variation	symbol
0 layer mass, 1 layer insulation	0m	1 layer mass, 1 layer insulation	1i
1 layer mass, 1 layer insulation	1m	1 layer mass, 2 layers insulation	2i
2 layers mass, 1 layer insulation	2m	1 layer mass, 3 layers insulation	3i
3 layers mass, 1 layer insulation	3m	1 layer mass, 5 layers insulation	5i
5 layers mass, 1 layer insulation	5m	1 layer mass, 8 layers insulation	8i
8 layers mass, 1 layer insulation	8m		

The building was divided into two zones: living (including kitchen) and sleeping (including other wet areas). The sleeping zone was given a high solar priority [5] by dividing the plan on a north-south axis rather than an east-west axis. The internal walls designed were indicative only. The window specification was varied between single, double and triple glazing. The infiltration rate was varied between 0.5 and 0.1 air changes per hour (ac/h) to simulate typical and relatively tightly sealed conditions. The building's north and east facades were shaded by 900mm overhangs, while its west facade was shaded by a four metre overhang (ie. a carport) and the south facade was left unshaded.

Manual external shading of windows was simulated to occur when the exterior temperature exceeded 25^{o}C at a shading coefficient of 0.3 (eg. white blinds). Curtain operation was not simulated due to a problem with the Cheetah algorithm, which assumes single glazing with curtains. If double glazing was used with curtain operation, the algorithm significantly overestimated the performance of the curtains. This may improve the performance of particularly single glazed variations when the problem is rectified. Additional ventilation was simulated to operate when the temperature was above 26^{o}C and to cease at below 23^{o}C at 10 ac/h.

END

An internal heat flow of 300 watts was assumed for the period 10pm to 6pm (ie. overnight and through the day). An internal heat flow of 1500 watts was assumed for the period 6pm to 10pm (ie. evening) for the living zone and 300 watts for the sleeping zone. For the purpose of allowing Cheetah to calculate annual heating and cooling loads, constant thermostat settings of 21°C for heating and 28°C for cooling were used for the living zone.

2.1 Climate Description

It is necessary to outline the climatic differences between Melbourne (latitude 37°S) and Wagga (latitude 35°S). Szokolay presents the information for many Australian locations, and some has been summarised below in Table 2. The inland climate of Wagga (approx. 400 kilometres from the coast), while receiving more solar radiation on average, is generally colder than Melbourne's coastal climate.

Table 2 Summarised Climatic Data for Melbourne and Wagga

	heating degree hours	mean temperature °C				solar irrad, kW.h	daily sunshine hours
		max	min	range	daily range		
Melbourne	41 345	19.9	10.5	20.3	9.4	3.97	5.7
Wagga	48 838	21.8	8.9	28.5	12.9	4.91	6.6

source: [6]

2.2 Thermal Simulation Method

The thermal simulation computer program Cheetah calculates "hourly temperatures and heating and cooling energy requirements in up to ten zones of a building, using real climatic data for periods ranging from one day to a full year" [7] based on the response factor method. The efficiency of specific heating or cooling equipment is not considered. The software uses climatic data on an hourly basis, solar radiation inputs, thermal mass, thermal storage, convective heat transfer, internal heat gains and the impacts of user operational devices such as curtains, additional ventilation, thermostats for heating and cooling loads, temporary shading and heat flows associated with the behaviour of the occupants.

The program incorporates a number of simplifying assumptions made necessary by the complexity of building heat flow quantification. These include the assumptions that all heat flow by conduction is one dimensional and that junction details are negligible. The user operated functions of the building such as external shading are not able to be set for seasonal variation.

2.3 Embodied Energy Analysis Method

Energy analysis is not a new field, but it is one of varying terminology and methods [8]. It is therefore necessary to state the method employed for this analysis and define the terms used, though due to complexity it is impossible to be exhaustively descriptive.

Energy will refer specifically to concentrated consumer fossil fuels and derivatives. Other sources of energy such as human labour and 'environmental' energy, including solar and wind power are not included. Annual heating and cooling energy refers to the load, not the energy consumption.

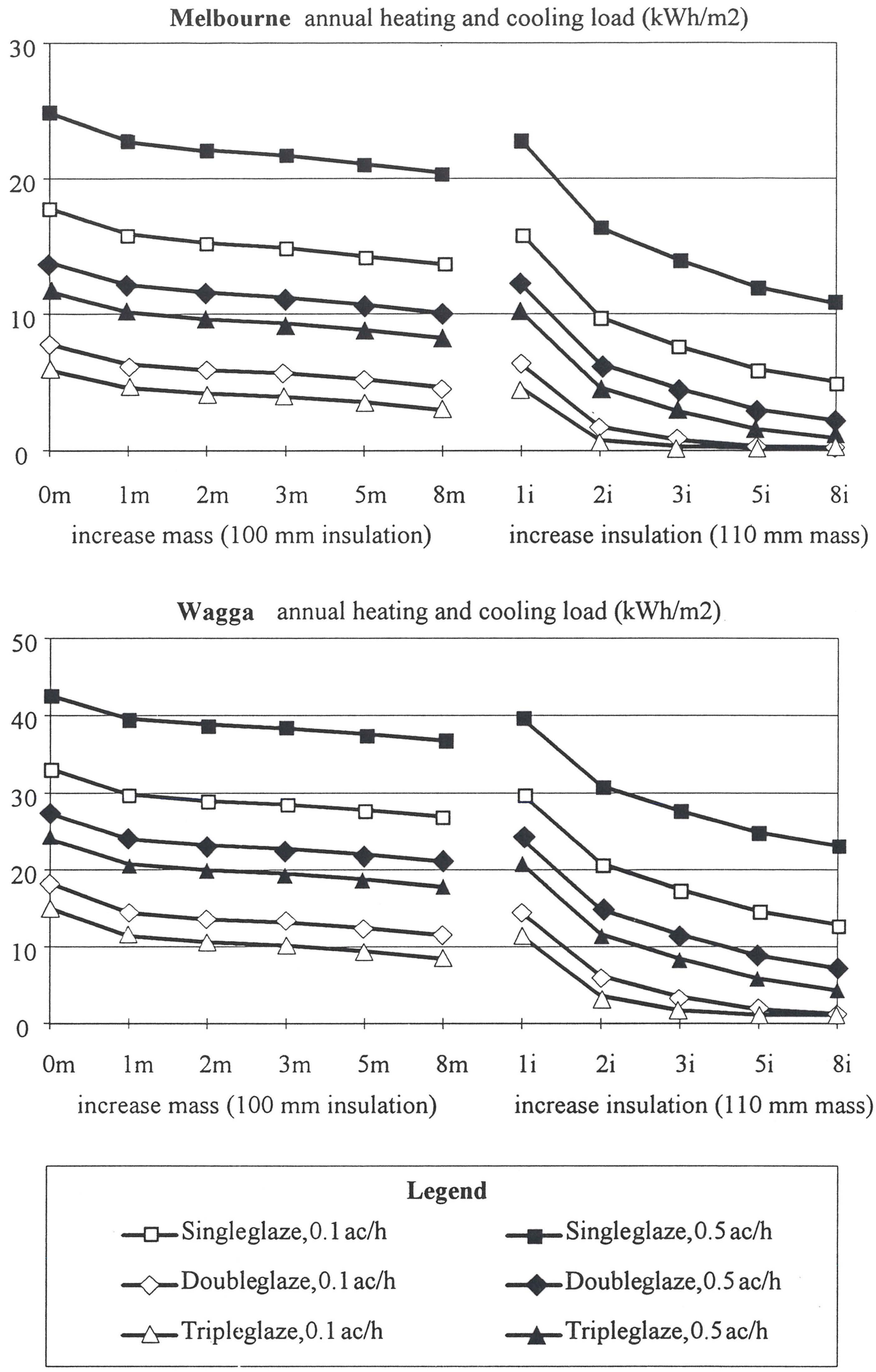

Fig. 1. Heating and Cooling Energy Loads for Melbourne and Wagga
(NB: 1m and 1i are identical cases; mass is always the internal layer)

3.1 Embodied Energy Results and Payback Periods

For the addition of another layer of glass creating double glazing, approximately 8 further GJs of energy were embodied in the building. The saving in heating and cooling energy in each case depended proportionally upon the other building characteristics. In contrast, the inclusion of 8 layers of masonry to the external walls embodied another 670 GJs of energy, and 800mm of roof and wall insulation added another 450 GJs of embodied energy.

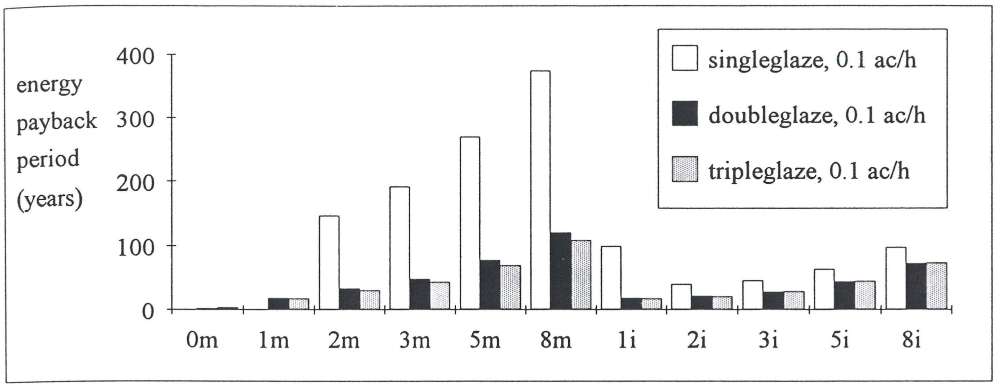

Fig. 2. Energy Payback Periods (years) for additional materials, Melbourne, 0.1 ac/h

The 'energy payback periods' for the 0.1 ac/h set of variations to the case study building for Melbourne are shown in Fig. 2. The high mass options fail in this marginal analysis, while double glazing performs well. Double and triple glazing payback rapidly in the '0m' case, but as Fig. 1. shows, these options are still high in annual heating and cooling load compared to the double and triple glazed highly insulated options.

Energy payback periods, however, do not reveal the energy savings into the future, as estimated by the 60 year energy Life Cycle Analysis (LCA) shown in Fig. 3.

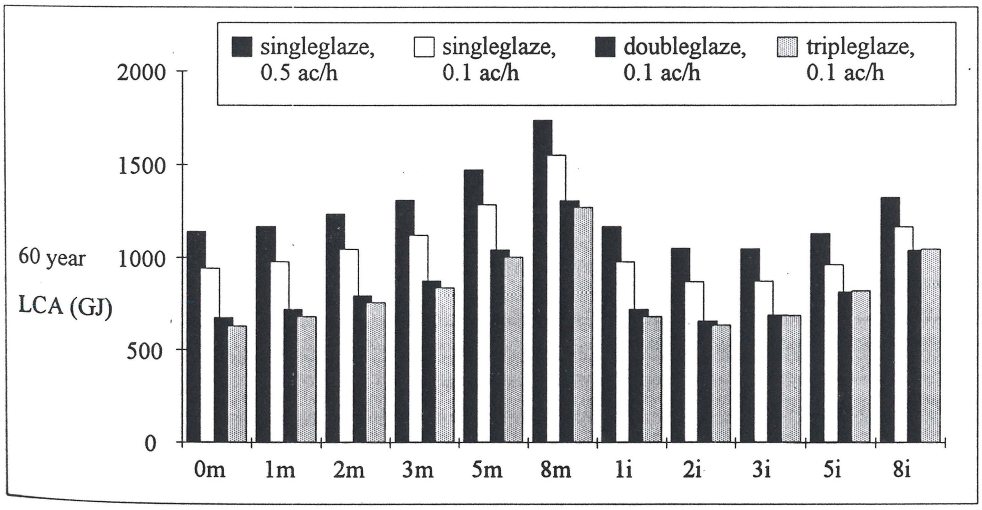

Fig.3. 60 year Energy Life Cycle Analysis (LCA) for Melbourne (GJ)

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Again the high mass options fail and triple glazing appears not to be viable. Low mass double glazed options ('0m' and '1m') seem to perform as well here as '2i' and '3i'. Future uncertainty as to the supply and quality of energy mean that the double glazed '0m' option, with an annual heating and cooling requirement over 10 times that of the double glazed '3i' option, is less favoured. The '2i' and '3i' double glazed options pay back in around 20 - 30 years.

3.3 Design Guidelines

For both Melbourne and Wagga, it appears necessary to have double glazing and 200 to 300mm of wall and roof insulation (with emphasis on the roof: this paper has concentrated on external walls in an effort to assess thermal mass, somewhat side-stepping the importance of heat loss through the roof). Reducing infiltration rates by tightening up the building fabric to of the order of 0.1 air changes per hour is seen as desirable.

There are local design issues such as catching cooling breezes and responding to the client's site brief which are not covered here due to the generalised nature of the paper. These design guidelines are intended as a starting point, to be tested in each case against many performance parameters, such as cost, comfort, appearance, carbon dioxide emissions etc, as well as energy.

4 CONCLUSIONS

There are inherent assumptions in the thermal simulation method (eg. no curtain operation) and embodied energy method (eg. 'onsite' construction energy excluded) which result in a degree of uncertainty in the data. This means that making close distinctions between building techniques is risky, especially where projections far into the future are critical.

The opinion of Douglas Balcombe mentioned earlier is again emphasised here: that the last 20% or so of domestic heating and cooling energy savings are often not worth striving for. The results of both the thermal simulations and the embodied energy analysis seem to support this statement, but the percentage is probably less when energy is the only objective. The thermal simulation results for both Melbourne and Wagga suggest that larger quantities of thermal mass (ie. 5 to 8 layers) do not perform as well as moderate levels of insulation, ie. the annual energy heating and cooling energy requirement is higher and the energy payback period is too long.

The higher infiltration rate simulated (0.5 ac/h) addressed the indoor/outdoor activity patterns of the Australian 'lifestyle', while the lower infiltration rate (0.1 ac/h) was included to demonstrate a 'zipped-up' construction method. The results for external wall and glazing variations were generally not dependant upon the lower infiltration rates, though the lower rates improved performance considerably.

Compared to Europe all of these options are low energy consumers, as one would expect in Melbourne and Wagga's mild climates. However, to move towards the zero heating and cooling energy house, the designer does need to take the European approach of "zipping up" the house into consideration. These results are further reinforced by the embodied energy analysis that shows that insulation has a far quicker energy payback than high levels of mass, assuming the masonry is not recycled ie. in its first use.

Extrapolating these results to encompass Lund's extremely high mass house with 1000 cubic metres of concrete or equivalent [12] it is clear that 'above ground caves' are less energy conserving for temperate Australian climates than the zipped-up, moderately insulated, moderately massed house described in section 3.3 Design Guidelines.

5 ACKNOWLEDGEMENTS

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End notes

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