

THERMAL PERFORMANCE OF AUSTRALIAN MASONRY HOUSING – HEATING/COOLING DEMANDS UNDER SPRING CONDITIONS

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SUMMARY

The growing world-wide concern regarding the reduction of greenhouse gases and energy conservation in the built environment has been reflected in Australia by the introduction of various software packages to predict the thermal performance of buildings and provide an energy rating. Most local government authorities require all new development applications to meet minimum energy ratings before being approved. Over the last seven years an extensive research program has been underway at the University of Newcastle, in conjunction with Think Brick Australia, aimed at investigating the thermal performance characteristics of masonry. This is being done at a full-scale level with purpose built test modules and has been extended to include the development of building simulation energy models and design strategies for affordable low energy housing under Australian climatic conditions. This report gives a brief overview of the project and outlines the thermal performance of the test modules in terms of the heating/cooling loads for different building envelopes. The difference in behaviour for the four wall types (cavity brick, brick veneer, insulated cavity brick and lightweight) are reported during the spring conditions in October 2007.

INTRODUCTION

Energy efficiency in housing has become a major issue in Australia with a ‘star rating’ scheme being applicable for all new housing. This involves the estimation of the energy required to maintain the interior of the building within a comfortable temperature range, (given the building fabric, design, orientation and locality) using specific software. A star rating is obtained by comparing the energy estimate against set values for individual climate zones. Failure to meet minimum criteria requires changes to the building design or fabric. The primary software used in various parts of Australia is AccuRATE which is a second

generation of the previous rating scheme NatHERS (National House Energy Rating Scheme (McLaren, 2004).

The University of Newcastle, in conjunction with Think Brick Australia (formerly the Clay Brick and Paver Institute) and the Australian Research Council (ARC) has embarked on an extensive research program to study the thermal performance of various forms of masonry construction and roofing systems under Australian climatic conditions (Sugo et. al. 2004, 2005, 2007,). The project is in its seventh year and consists of both experimental and analytical strands.

The project has six distinct phases:

- Phase 1. The construction of a guarded hot box apparatus to determine the thermal resistance of full-scale wall assemblies.
- Phase 2. The construction and instrumentation of four purpose built modules on the University campus to develop a qualitative and quantitative understanding of the thermal performance of typical forms of construction used in Australia.
- Phase 3. The development of energy simulation software derived using zonal and computational fluid dynamics (Luo, 2007) and, fast design tools based on fuzzy-neuro approach (Alashaary, 2008). The experimental data collected from the modules has been used for validation purposes.
- Phase 4. The development of Life Cycle Analysis and Life Cycle Costing models for building envelopes.
- Phase 5. The development of 'hybrid' walling systems and the 'smart' utilization of thermal mass (Gregory, 2008).
- Phase 6. The detailed analysis of numerous climatic regions within Australia to provide effective design strategies for affordable low-energy housing (Upadhyay, 2007).

An overview of the project has been presented as part of the keynote address by Inglis (2008) at this conference. Results from Phase 3, the development of energy simulation software based on the energy balance principal, have been reported separately by Luo et al 2007. This report outlines the thermal performance of the full-scale test modules in terms of the heating/cooling loads during the spring conditions in October 2007. The four modules feature different walling systems, these being: cavity brick, brick veneer, insulated cavity brick and lightweight. The heat gained/lost through radiation via the window is also reported.

Description of Modules

A detailed description of the modules and instrumentation has been described previously and only a brief description follows (Sugo 2004). The purpose of the Thermal Test Modules was to provide qualitative and quantitative data for the thermal performance of masonry/walling systems under typical climatic conditions found on eastern Australian seaboard. The modules are comparable in size to other buildings used in similar studies overseas (Burch et. al. 1982, Dale et. al. 1985). The modules have a square floor plan of 6 m x 6 m and are spaced 7 m apart to avoid shading and minimise wind obstruction. With the exception of the walls and roof, the buildings are of identical construction, being built on a concrete slab-on-ground and aligned in a manner so that the north wall of the building is perpendicular to astronomical north.

Timber trusses are used to support the roof, consisting of tiles or colorbond material placed over a layer of sarking. The buildings have a ceiling height of 2450 mm. The ceiling consists of 10mm thick plasterboard with glasswool insulation bats ($R\ 3.5\ \text{m}^2\text{K/W}$) placed between the rafters. The R3.5 insulation has been selected to minimise the “through-ceiling” heat flow. Entry to the buildings is via a standard solid timber door located on the southern face of the building. Again, to minimise the flow of heat through the door, a 75 mm thick layer of polystyrene foam was attached to the back of the door. The door is well fitted and normally kept shut. It is only opened to allow necessary access, making the building as air-tight as possible. No carpet or other floor covering has been placed over the concrete slab.

Over the last five years a total of four modules have been commissioned. These are as follows:

- Brick veneer and cavity brick construction (windowless), March 2003.
- Cavity brick construction incorporating a north-facing window April 2004
- Lightweight construction December 2005
- Addition of plasterboard on timber stud internal walls for the LW and Ins.BV modules and single skin brick walls in the CB and Ins.CB modules in May 2007

The modules have undergone a specific observation schedule. As each experimental phase was completed, the building envelope was then modified to investigate alternative configurations. The modules, in their current state, are shown in Figure 1. Each module now contains a north-facing 3-panel sliding door assembly, 2050 mm high x 2840 mm wide, representing $\approx 20\%$ of the floor area which is typical of a living room window/floor area ratio. It consists of clear, 6.38 mm laminated glass, set in a light coloured aluminium frame. The purpose of the window was to allow solar ingress to the modules. The window has not yet been used for ventilation purposes. The modules also contain two L-shaped internal walls as described above. The total internal wall area in each module is $12\ \text{m}^2$.



Figure 1. The Four Thermal Test Modules (a) Insulated Brick Veneer (b) Insulated Cavity Brick (c) Cavity Brick and (d) Lightweight Module.

Currently, the building fabric in the four modules consists of:

Module 1. Insulated brick veneer (Ins.BV), 110mm external brickwork skin, 50mm air cavity with wall-wrap and R1.5 bulk insulation batts incorporated in the pine frame/plasterboard cavity. The thermal resistance of the wall system (R_s) has been determined to be $1.83 \text{ m}^2\text{K/W}$.

Module 2. Insulated cavity brick construction (Ins.CB), 110mm external brickwork skin, 50mm air cavity with R1 rigid polystyrene insulation fixed to the interior masonry skin and finished with 10mm cement render. $R_s = 1.54 \text{ m}^2\text{K/W}$.

Module 3. Conventional cavity brick construction (CB), 110mm external brickwork skin, 50mm air cavity, 110mm internal skin finished with 10mm render. $R_s = 0.47 \text{ m}^2\text{K/W}$.

Module 4. Lightweight construction (LW), polymer render over 7mm fibro-cement sheeting, breathable membrane fixed onto pine stud frame, R1.5 bulk insulation in frame cavity and 10mm plasterboard interior. $R_s = 1.56 \text{ m}^2\text{K/W}$.

The response of the modules can be observed either in the 'passive' or 'free-floating' state, where the response of the module is influenced by the weather conditions and the recent thermal history or they can be 'controlled' where the internal air is heated/cooled to pre-set levels of comfort. The latter allows the heating/cooling energy requirements to be assessed.

Measurement of Heating and Cooling Energy

A commercial 5kW heating/cooling fan unit and control system has been installed in each building module. Heating energy is provided by electric resistive elements whilst cooling is performed via a chilled water heat exchanger system coupled to an external chiller as indicated in Figure 2. The temperature control system has been interfaced to the datalogger. Additional water flow meter and temperature rise sensors for the heat exchanger and 'fan on' sensors have been installed to allow the calculation of the heating/cooling loads.



Figure 2. (a) External water chiller (b) internal fan unit

A hysteresis type control logic is used for the comfort level setpoints. Heating is activated when the internal air temperature falls below 18°C and continues until 20°C is reached at which point the heater is turned 'off'. The building may "free-float" between 20-24°C with cooling being activated above 24°C and continues until 22°C is attained. The buildings may then "free-float" down to 18°C without incurring any energy usage.

Other instrumentation records the external weather conditions including wind speed and direction, air temperature, relative humidity and the incident solar radiation on each wall (vertical plane) and on the roof (horizontal plane). For each module, temperature and heat flux profiles through the walls, slab and ceiling are recorded in conjunction with the internal air temperature and relative humidity. Net radiation sensors have been placed at different heights along the glass panel to assess the incoming/outgoing radiation via the window. Internal air space temperatures are monitored at three heights, 600, 1200 and 1800 mm in the centre of the room with the relative humidity and globe temperatures being measured at mid-height. In total, 105 data channels are scanned and logged every 5 minutes for each of the modules all year round.

RESULTS AND DISCUSSION

The results presented here are for the month of October 2007 which represents late spring conditions with cool nights and relatively warm days. Prior to this observation period, the buildings had been run under "controlled conditions" for a period of three weeks, to minimise any influence from the slab-on-ground.

Figure 3 shows the external/internal air temperatures for the first week of October with Figure 4 representing the enlarged mid-week region. It can be observed that there are times when only the LW and Ins.BV modules require additional heat at night or cooling during the day whilst at other times, under more extreme conditions at above 30°C, all modules require cooling. Note that during these warmer days a significant portion of the cooling load is offsetting the radiant heat gained via the window which is a common factor in all the modules.

The total energy demand for this week for each of the modules is presented in Figure 5 showing a greater need for heating and cooling energy for the LW and Ins.BV forms of construction. The mean external air temperature for this week was 19.4°C. The hourly frequency distribution for the external air temperature is given in Figure 6 with temperatures ranging from 9-34°C.

Each subsequent week in the observation period showed a consistent pattern with the LW having a more frequent and higher cooling demand than the Ins.BV with the CB and Ins.CB being the lowest. The LW and Ins.BV also required heating at times. A summary of heating/cooling hours and energy demand and, external air conditions over the 4 week period is presented in Table 1.

For the LW building, there is generally an increase in cooling/heating energy with increasing cooling/heating degree hours however for the other buildings the pattern is not as clear. The CB and Ins.CB do not require any heating and demand less cooling energy as indicated in Table 1. There may be a 'thermal history' carry over effect from week to week making the

interpretation more difficult. The lower energy values for the CB and Ins.CB are expected due to the favourable diurnal swing and a 'comfortable' mean temperature of 20°C. This observation is consistent with those reported by Burch et al (1982).

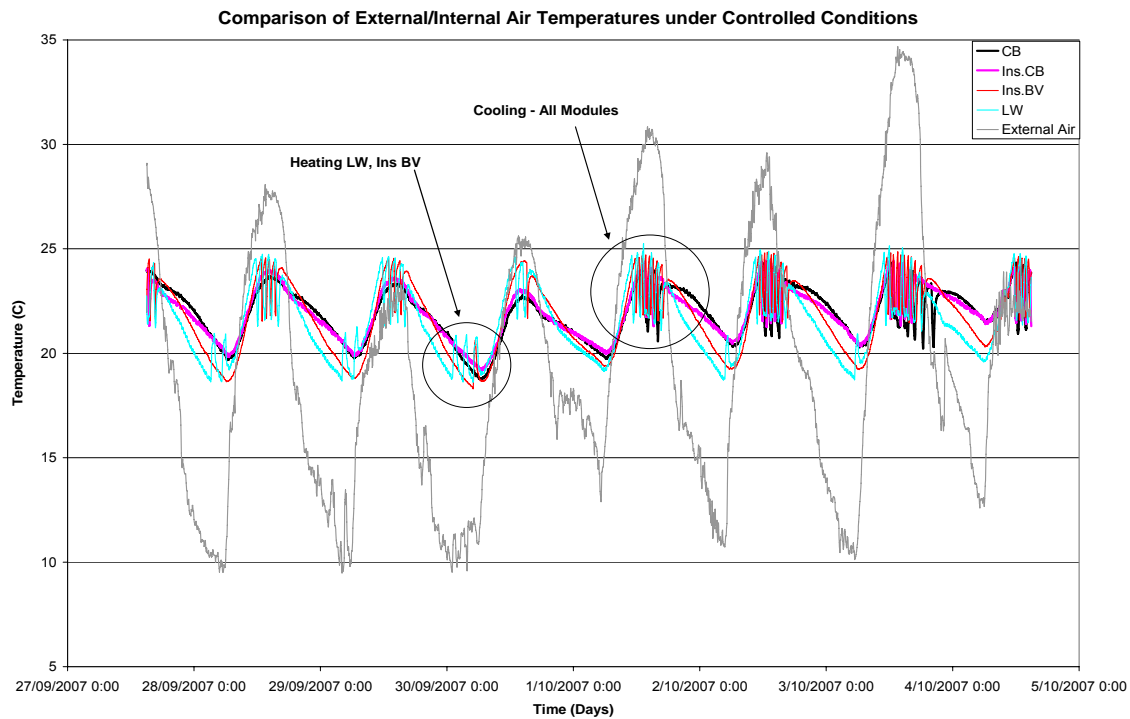


Figure 3. External/Internal/ Temperatures under A/C control, 1st week of Oct 2007.

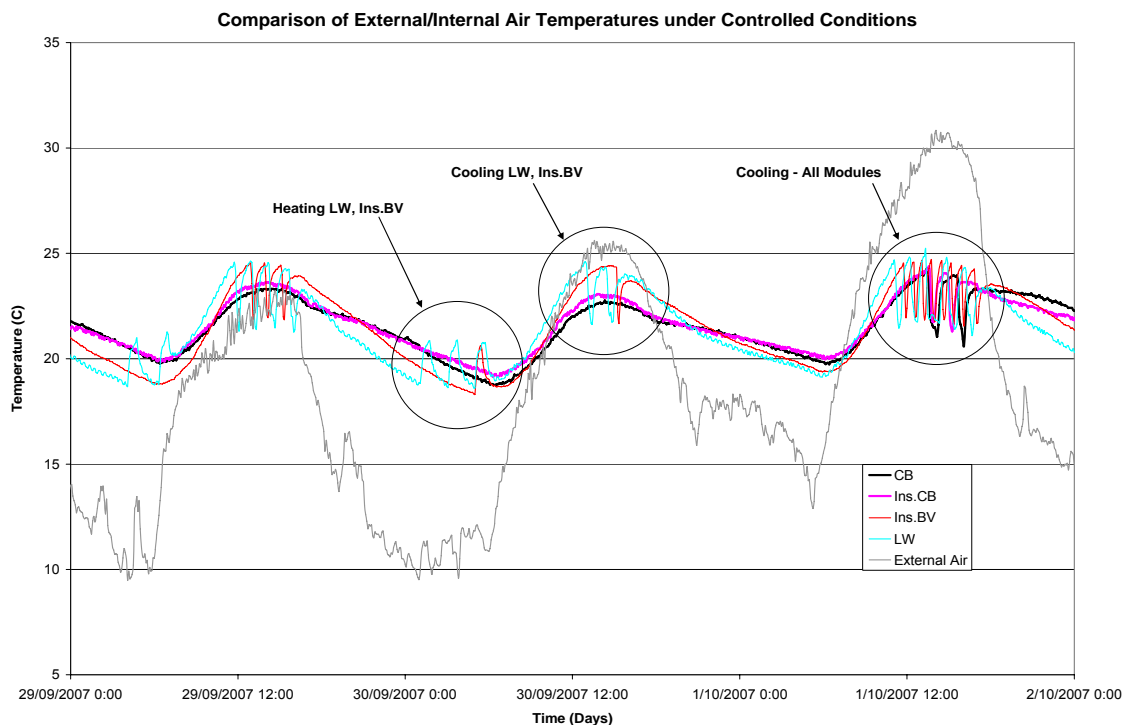


Figure 4. External/Internal/ Temperatures – enlarged mid-week region of Figure 3.

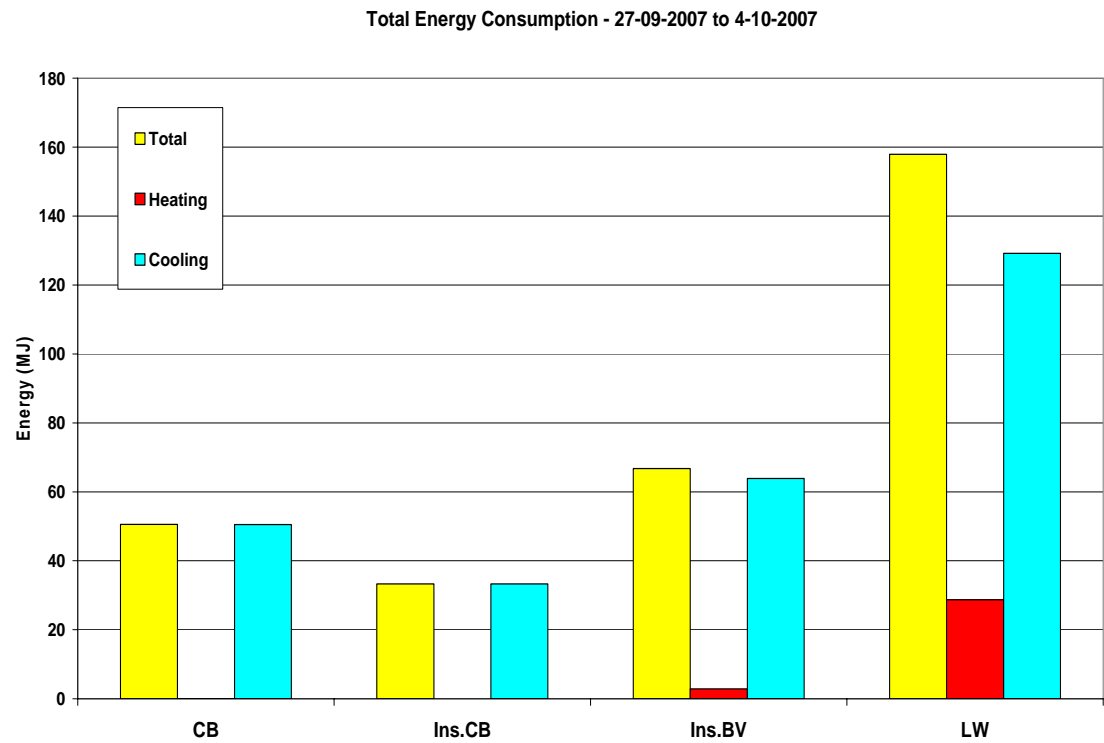


Figure 5. Total Heating/cooling Energy Demand, 1st week of Oct 2007.

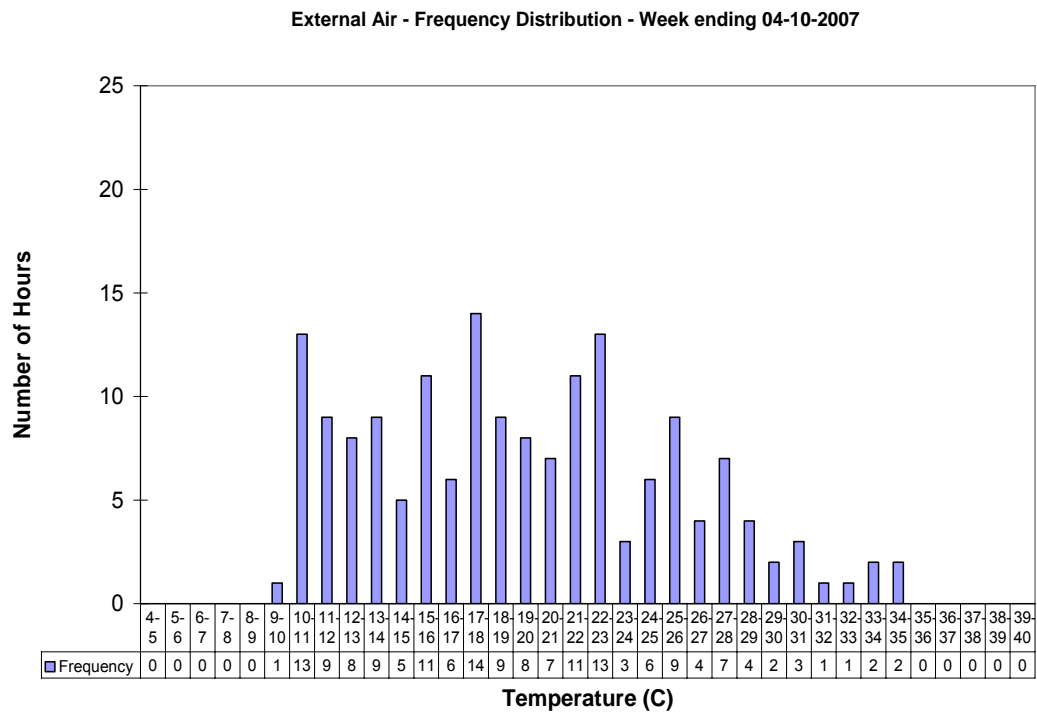


Figure 6. Hourly Frequency Distribution for External Air– First Week of October 2007.

Table 1. Summary of Cooling/Heating Energy Demands for the Four Modules in October 2007.

Week Ending	External Air			Lightweight (LW)					Insulated Brick Veneer (Ins.BV)				
	Mean	Heating Deg Hours	Cooling Deg Hours	Heating Hours	Heating Energy (MJ)	Cooling Hours	Cooling Energy (MJ)	Total Energy (MJ)	Heating Hours	Heating Energy (MJ)	Cooling Hours	Cooling Energy (MJ)	Total Energy (MJ)
4/10/2007	19.39°C	272	176	6.1	28.7	18.9	129.2	157.9	0.5	2.9	10.4	63.9	66.8
11/10/2007	18.32°C	262	91	4.4	23.4	10.7	71.8	95.2	0.0	0.0	4.6	28.9	28.9
18/10/2007	18.32°C	303	142	7.0	32.0	9.4	63.4	95.4	1.5	8.7	4.9	33.2	41.8
18/10/2007	20.08°C	129	139	2.2	15.3	13.1	86.5	101.8	0.4	2.4	8.1	49.7	52.1

Week Ending	External Air			Insulated Cavity Brick (Ins.CB)					Cavity Brick (CB)				
	Mean	Heating Deg Hours	Cooling Deg Hours	Heating Hours	Heating Energy (MJ)	Cooling Hours	Cooling Energy (MJ)	Total Energy (MJ)	Heating Hours	Heating Energy (MJ)	Cooling Hours	Cooling Energy (MJ)	Total Energy (MJ)
4/10/2007	19.39°C	272	176	0.0	0.0	5.8	33.3	33.3	0.0	0.0	7.7	50.5	50.6
11/10/2007	18.32°C	262	91	0.0	0.0	1.4	7.1	7.1	0.0	0.0	0.9	6.0	6.0
18/10/2007	18.32°C	303	142	0.0	0.0	3.0	16.6	16.6	0.0	0.0	5.8	39.5	39.5
18/10/2007	20.08°C	129	139	0.0	0.0	4.0	22.3	22.3	0.0	0.0	6.0	40.8	40.8

The favourable energy values for the CB and Ins.CB represent strong evidence for the thermal mass argument under “controlled” conditions since the LW building requires greater amount heating/cooling energy despite its higher R-value. The R-value for the LW walling system is $1.56 \text{ m}^2\text{K/W}$ compared to $1.54 \text{ m}^2\text{K/W}$ for the Ins.CB. The difference in energy for these two walling systems would therefore be due to the presence of internal thermal mass and to a lesser extent on the external mass. Note that under these weather conditions, the uninsulated cavity brick, (R-value $=0.47 \text{ m}^2\text{K/W}$) performed similar to Ins.CB and required less energy than LW construction despite its higher R-value.

In order to further understand the role of thermal mass, modelling of this data is being undertaken using the hybrid energy simulation software developed at the University of Newcastle. The variables being investigated are:-

1. role of internal mass walls
2. role of curtains drawn at night
3. role of diurnal swings by systematically increasing/decreasing the external air temperature by 5°C

Further observations of these modules under both “passive” and “controlled” conditions will continue.

CONCLUSIONS

This report is a brief description of the work being carried out at the University of Newcastle in relation to the thermal performance of masonry. The data collected from actual building modules provides a detailed understanding of the interactions of the various building components under actual weather conditions. The thermal behaviour of the modules is influenced by several factors including the day-to-day and season-to-season weather patterns. The data presented here shows the benefits of thermal mass under ‘controlled’ internal conditions with spring weather patterns of moderate to high diurnal swings and mean temperatures in the order of 20°C . The data from these buildings is also being used for modelling purposes to further understand the role of thermal mass under different weather patterns. Further observations of these modules under both “passive” and “controlled” conditions will continue.

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