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A Comparative Study of the Thermal Performance of Cavity and Brick Veneer Construction

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Abstract

Masonry housing in Australia is typically of brick veneer or cavity brick construction. The increased emphasis on energy conservation and reduction of greenhouse gas emissions has resulted in the thermal performance of housing systems coming under increasing scrutiny, with a "star" rating system (based on energy efficiency) being implemented. Little information exists on the thermal performance of masonry under Australian climatic conditions. To address this problem, The University of Newcastle has embarked on a testing program to study the thermal performance of two purpose built modules (one brick veneer and one cavity brick) on the university campus. This paper gives an overview of the instrumentation and data collection and, presents typical results obtained during the first year of monitoring.

1.0 Introduction

In recent years there has been growing world-wide concern on energy conservation, the reduction of greenhouse gases, and sustainability. In Australia, it is estimated that 39% of the end energy usage in domestic buildings is used for space heating and cooling (AGO, 1999). Therefore, achieving better energy efficiency in buildings has become one of the major challenges for architects and builders. These concerns have been reflected at several levels within the Australian scene with the establishment of the Australian Greenhouse Office (AGO) and the Sustainable Development Authority (SEDA) at Federal and State Government levels. Several new measures have been introduced to the building industry including an energy star system rating similar to that used on electrical appliances. In several states it is necessary to obtain a NatHERS certificate (National House Energy Rating Scheme) for all new residential developments prior to building approval. This involves the estimation of the energy required to maintain the interior of the building at 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 the climate zone. Failure to meet minimum criteria requires changes to the building design or fabric. The output of any thermal simulation will therefore have direct implications for the building cost, the embodied energy of materials used in construction and on the thermal performance of the building throughout the life of the structure.

The thermal performance of masonry housing is being investigated at the Faculty of Engineering and Built Environment at the University of Newcastle with several laboratory and full-scale tests being undertaken (Clark et al 2003) in combination with the development of alternative energy simulation models. The experiment described in this report involves the all-year-round monitoring of the thermal response of the first two windowless testing modules, one constructed of cavity brick and the other brick veneer. The modules have been constructed in a manner to reflect the thermal behaviour of the masonry walls and specifically do not contain any windows or openings that allow direct solar access or provide ventilation. In this respect the thermal response of the modules represents an upper bound limit for summer and a lower bound limit for winter. Construction of a third module incorporating a large north orientated window, to allow solar ingress during winter, is currently under way. Each module has been heavily instrumented with temperature, humidity and heat flux sensors which are continuously monitored. The thermal response can be assessed in two ways; a 'free-floating' state, where the temperature in the building is determined by the influence of the external weather conditions or, in a 'driven' state, where the internal temperature is preset using a cooling/heating system and the energy usage in maintaining the set comfort level is measured.

The experimental data is also being used to validate zonal and computational fluid dynamics (CFD) based models with the aim of deriving refined models to estimate the thermal performance of buildings. This report describes the behaviour of the cavity brick and brick veneer modules under "free floating" conditions for the first 12 months of operation.

2.0 Description of modules

The building modules are built on the Callaghan campus at Newcastle in an open location with uninterrupted solar access. The two modules are shown in the background of Figure 1. The module containing the window (under construction) is shown in the foreground and will not be discussed further in this report. The modules are comparable in size to other buildings used in similar studies (Burch, 1982). The modules have a square floor plan of 6 m x 6 m and are spaced 7 m apart from each other to avoid shading and minimise wind obstruction. With the exception of the walls, the buildings are of identical construction, being built on a concrete slab and aligned in a manner so that the north wall of the buildings is perpendicular to astronomical north. Timber trusses are used to support the roof, consisting of clay tiles placed over a layer of foil sarking. The timber trusses are in turn supported by a steel frame to provide the flexibility of removing/replacing walls at a future stage. The buildings have a ceiling height of 2450 mm. The ceiling consists of 10 mm thick plasterboard with glasswool insulation bats (thermal resistance or R-value = $3.5 \text{ m}^2 \cdot \text{K} \cdot \text{W}^{-1}$) placed between the rafters. The R = 3.5 insulation has been used in the ceiling to minimise the "through-ceiling" heat flow. Entry to the building 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 has been attached to the back of the door. The door is well fitting and normally kept shut. It is only opened only 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.

Figure 1. The three building modules for thermal testing



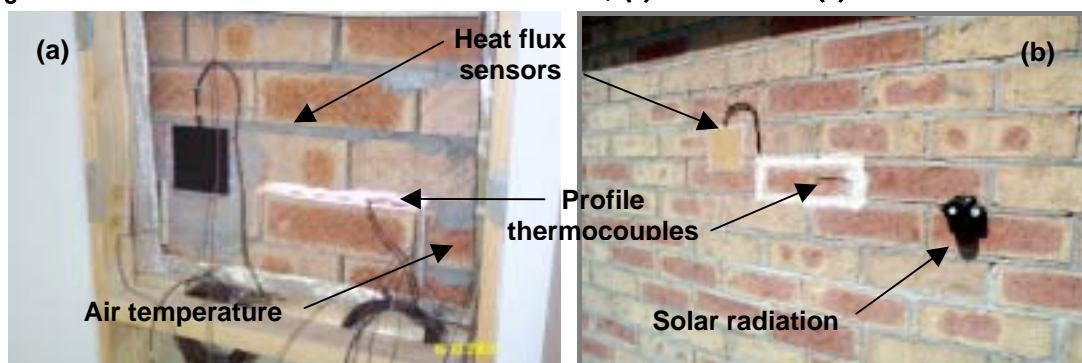
The cavity brick construction consists of two 110 mm thick masonry skins separated by a 50 mm air cavity. The inside wall surfaces are rendered using a cement/sand render with a nominal thickness of 10 mm. The brick veneer construction consists of an outer brick skin, 50 mm air cavity, low glare reflective foil insulation fixed onto a pine timber frame (70 x 35 mm studs at 600 mm centres) and finished with 10 mm thick plasterboard. The interior walls of both building are painted white. Standard steel wall ties, placed at 600 mm centres, are used in both buildings to connect the outer and inner walls. The masonry units used in construction are of extruded type, having two rows of five 25 mm diameter core holes, are light brown to pink in colour with the nominal dimensions being 230 x 110 x 75 mm (L x W x H). The normal 10 mm thick mortar joints were used in construction. Laboratory tests have determined the R-value for the brick veneer wall to be $1.2 \text{ m}^2 \cdot \text{K} \cdot \text{W}^{-1}$ and the wall density to be 210 kg/m^2 . Tests on the cavity wall have not yet been completed but are anticipated to be in the order of $0.7 \text{ m}^2 \cdot \text{K} \cdot \text{W}^{-1}$ and 400 kg/m^2 respectively.

3.0 Instrumentation of modules

The instrumentation records the external weather conditions; wind speed and direction, air temperature, relative humidity and, the incident solar radiation on each wall (vertical direction) and also on a 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. In total 104 data channels are scanned and logged every 10 minutes for each of the modules all year round. The data is recorded using a Datalogger DT600 data logger located in each building. All temperatures are read using Type T thermocouples connected to three 30 channel expansion modules. To minimise any cold junction compensation errors, all the thermocouple inputs are maintained at uniform temperature through the use of a thick wall aluminium box. The temperature recording system (thermocouple wire characteristics, cold junction compensation etc.) has been cross-referenced using a Prema Precision thermometer and the corresponding temperature offsets are adjusted automatically in the logging process.

Heat fluxes are measured using 100 mm x 100 mm sensors with typical sensitivities in the order of $25 \mu\text{V/W/m}^2$. The heat flux sensors were placed on the wall in such a manner that the proportion of masonry unit/mortar ratio being measured was representative of that in the masonry wall. An attempt was made to match the absorbance and emissivity of the heat flux sensors to that of the masonry units by painting the exterior sensors a similar colour to that of the bricks. The interior sensors were painted white, to match the walls, whilst the sensors located in the cavity were painted black to allow radiation heat transfer. Figure 2 shows the typical sensor layout used in the brick veneer wall.

Figure 2. Wall sensors used in the brick veneer wall, (a) internal and (b) external



4.0 Results

The buildings have been monitored in the 'free-floating' state since February 2003. Due to the large volume of data available, the behaviour of the buildings will be compared for two different seasons representing periods of cool and hot weather.

4.1 Cool weather conditions

Figure 3 shows the external and internal air temperature for both buildings during the third week of May 2003. The mean external air temperature for this week was 17.5°C and the air temperatures within the cavity brick and brick veneer buildings were 18.5°C and 19.0°C respectively. As expected, the day-night temperature swing in the buildings was much less than that shown by the external air. At the beginning of the week, the swing in the brick veneer building was in the order of 3.5°C and for the cavity brick about 2.5°C whilst the external air swing was in the order of 10–12°C. Also, note the marked reduction in day-night variation and minor decrease in the internal temperatures during the latter part of the week due to the presence of cloud cover. In the absence of strong solar radiation, the temperature of the external wall surfaces followed closely the external air temperature. The temperature of the roofing material cooled down to below ambient during the night, regularly reaching 5–7°C for the time period shown in Figure 3. Under sunny conditions, the maximum roof temperatures were in the range of 50–52°C.

At this time of the year the solar altitude is approaching a minimum and this resulted in the north facing wall receiving a greater quantity of solar radiation than that observed on the horizontal plane, as shown by Figure 4. Note the reduced irradiation levels experienced by the east and west facing walls and, the diffuse radiation received by the south (shaded) wall which is in the order of 80 W/m².

Figure 3. External & internal air temperatures for cavity brick and brick veneer modules, May 2003

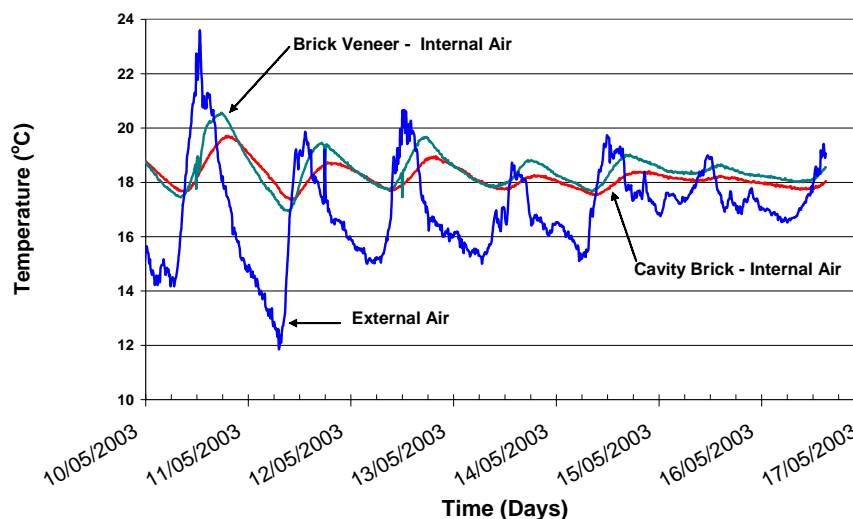
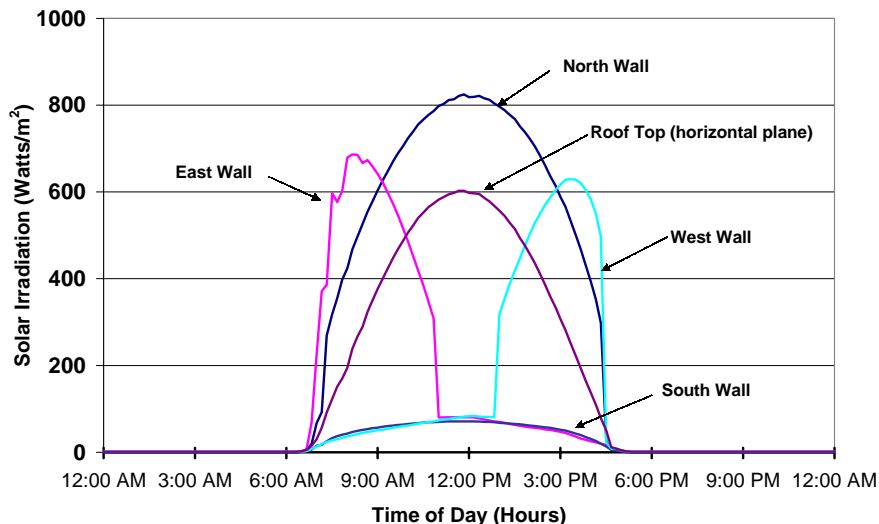
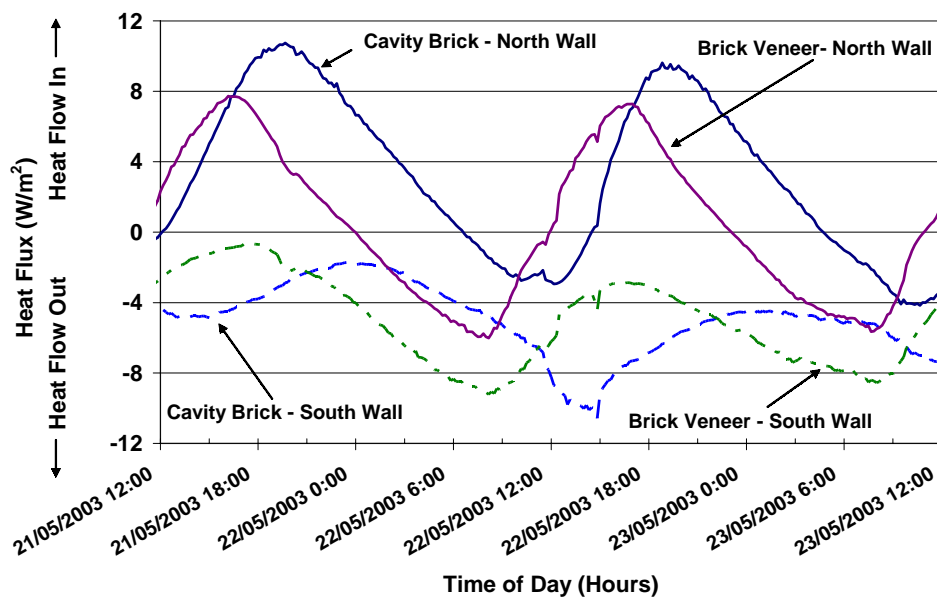


Figure 4. Incident solar irradiation on the exterior building surfaces for 22 May 2003



The effects of solar radiation can be observed by the rise in wall temperatures and the changes in the heat flux entering via the walls. During May, the exterior of the north facing walls regularly reached 35°C during sunny days. For clarity, only the data recorded by the north and south heat flux sensors, mounted on the internal walls, is shown in Figure 5. Note that the polarity of the sensors has been arranged with heat entering the interior space being recorded as positive whilst heat 'flowing out' being seen as negative. The flux entering through the north wall of the cavity brick building is greater than that observed for the brick veneer. Also, the heat flow balance, either in or out, favours a greater proportion of heat 'flowing in' for the cavity brick building. The time when the maximum in-flowing flux occurs is also different, with the brick veneer building showing a shorter lag time, (4.5 hours) compared to the cavity brick module of about eight hours. The heat flux entering via the north wall also influences the south wall behaviour, with maximum and minimums being observed. In these cases, heat is continuously flowing out via the south walls since the values are always negative. Flux variations can also be observed in the east and west walls but are not as pronounced.

Figure 5. Heat flux measurements on the interior north and south walls of the cavity and brick veneer buildings for 22 May 2003

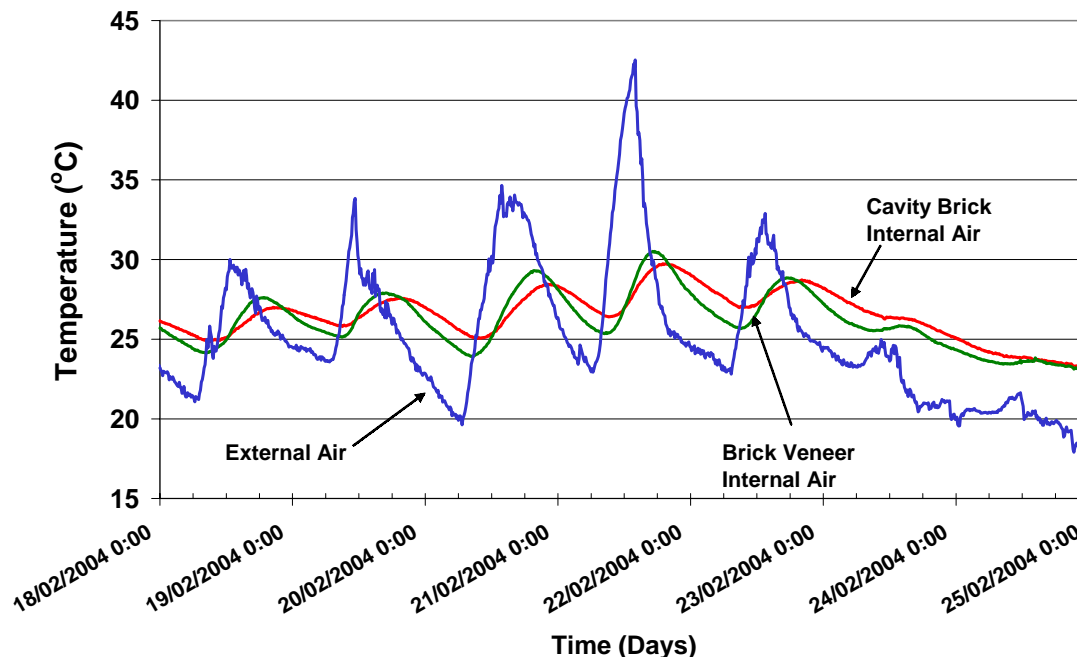


4.2 Hot weather conditions

During February 2004 Newcastle experienced heat wave conditions with a maximum air temperature of 43°C being recorded. Figure 6 is similar to Figure 3 and shows the external and internal air temperature for both buildings during the third week of February 2004. The mean external air temperature for this week was 24.7°C and the mean air temperatures within the cavity brick and brick veneer buildings were 26.2°C and 25.9°C respectively. The maximum external air temperature recorded adjacent to the test buildings was 42.5°C at 2 pm. At this time, the internal air temperature in the cavity brick module was 28.5°C and 28.7°C in the brick veneer building. The maximum internal air temperature for the cavity brick occurred at 8:30 pm and was 29.7°C. For the brick veneer building a maximum of 30.5°C occurred at 6:00 pm. The maximum external surface temperature recorded on this day was 72°C on the tiled roofs at 2 pm. The hottest external wall temperature was 46°C recorded on the west facing walls at 4:30 pm.

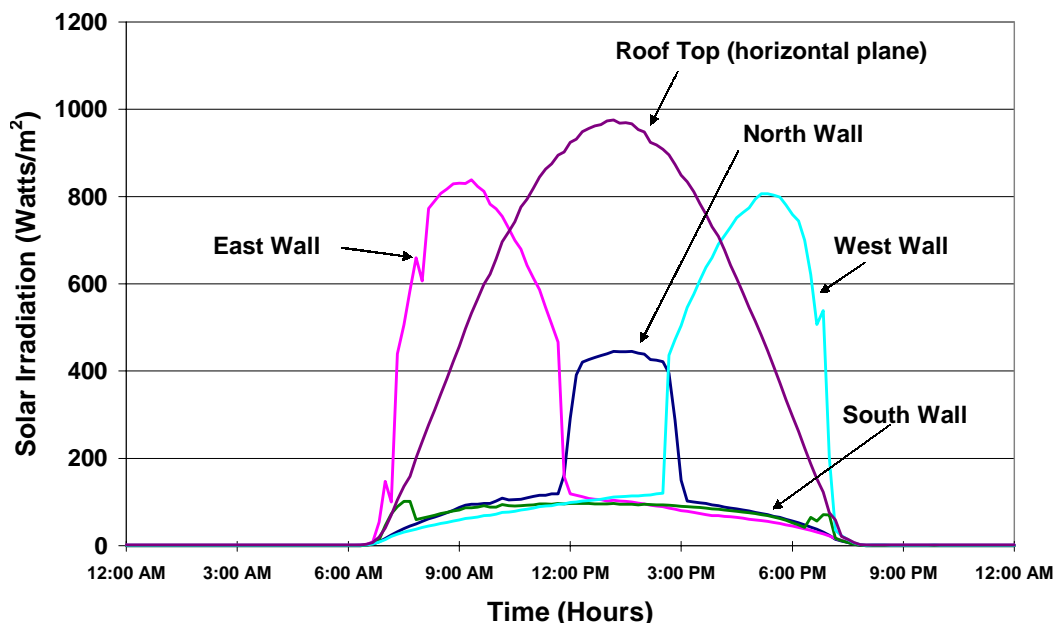
The external air day-night temperature swing was much greater at this time of the year than that in May, being in the order of 15–20°C. However, the temperature swing within the buildings shows only a minor increase, being 3–3.5°C for the cavity brick and about 5°C for the brick veneer building as indicated in Figure 6. Note the cooler weather conditions at the end of the week and the steady decline in internal temperatures of the buildings. Both buildings remained warmer than the external air conditions for several days.

Figure 6. External & internal air temperatures for cavity brick and brick veneer modules, February 2004



The incident solar radiation on the exterior surfaces of the buildings has also changed, with the east and west orientated walls receiving higher radiation levels for longer periods of time. The radiation falling on the north wall has decreased significantly ($\approx 450 \text{ W/m}^2$) due to the higher solar altitude and is further attenuated by the eave providing shade on the wall. The level of radiation observed on the horizontal plane has increased, reaching a maximum of just under 1000 W/m^2 . The diffuse radiation being received by the south wall has increased marginally up to a maximum of 100 W/m^2 . These trends are shown below in Figure 7.

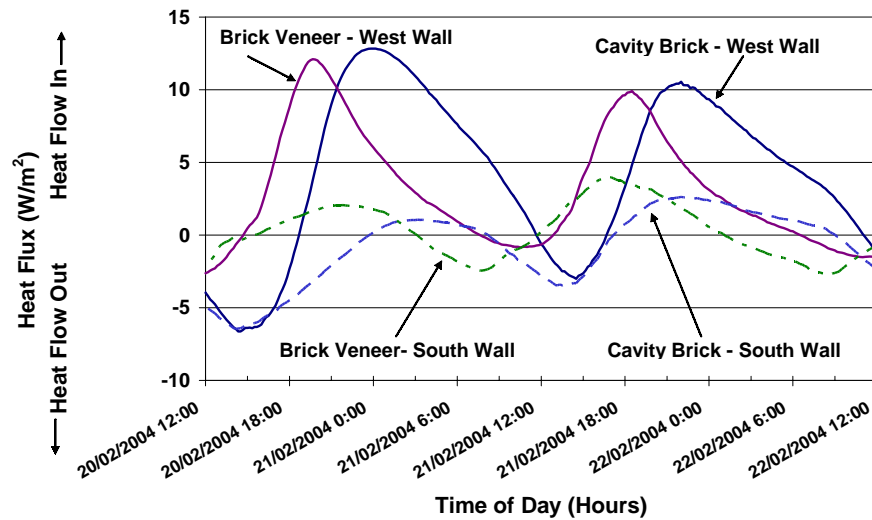
Figure 7. Incident solar irradiation on the exterior building surfaces, 20 February 2004



These changes in solar radiation influenced the thermal behaviour of the walls. The exterior surface temperature of the south and north walls followed closely the external air temperature. The east and west walls reached higher temperatures, with the west wall recording the hottest temperatures in the range of $40\text{--}52^\circ\text{C}$ in the afternoon. When the walls were out of direct sunlight, in shade or at night, the exterior surface of the walls cooled down to the external air temperature. Examination of the heat flux readings on the interior surfaces shows that heat enters via the east and west walls and leaves via the south wall. Figure 8 shows this behaviour although for clarity only the west and south wall interior flux are shown. The peak flux entering through the west walls is in the order of $12\text{--}13 \text{ W/m}^2$ for both buildings (also note

that some heat flows out as well). Figure 8 also shows that heat generally flows out via the south wall with maximum and minimums being observed. Again, note the different lag time for the buildings, the peak solar radiation on the west wall was at 5:30 pm however, the peak heat flux occurred around 8 pm for the brick veneer and 10 pm for the cavity brick building.

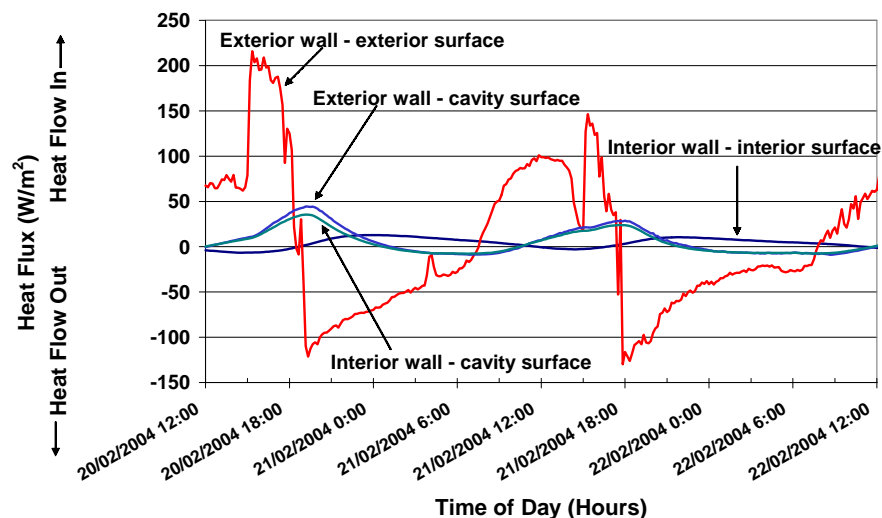
Figure 8. Heat flux measurements on the interior west and south walls of the cavity and brick veneer buildings for 21 February 2004



Comparison of Figures 7 and 8 shows that there is a substantial attenuation of the solar radiation flux, the peak value is in the order of 800 W/m^2 , yet only a small proportion of that enters the building. This behaviour is explained more clearly by observing the through-wall flux profile presented in Figure 9. Again, for clarity only the profile through the west wall of the cavity brick building is shown. The flux attenuation through the west wall of the brick veneer building has very similar characteristics.

The data in Figure 9 shows that the maximum heat flux entering the external brickwork on west wall is about 200 W/m^2 compared to the incident flux of 800 W/m^2 falling on the wall over the same time period shown in Figure 7. This would indicate that a large portion of the heat is reflected or radiated back to the external environment by the exterior surface of the brick. Figure 9 also shows that significant amounts of the heat stored in the wall is released back to the exterior environment, indicated by the large negative flux regions occurring during the night. Also, note the significant difference between the observed heat flux on the external and cavity surfaces of the exterior masonry skin. This attenuation reduces the peak heat flux from about 200 W/m^2 to 50 W/m^2 . This behaviour is again repeated by the interior masonry skin and further attenuates the flux down to peak values of $12\text{--}13 \text{ W/m}^2$ as shown in Figure 8. The flux reversal occurs through both masonry skins and reduces the net flux entering the building. This reversal is driven by day-night temperature swing with cooler night time temperatures increasing the radiation and convective heat transfer rate from the masonry wall to the outside environment.

Figure 9. Through-wall heat flux profile of the west walls of the cavity brick building, 21 February 2004



5.0 Discussion

The data presented here represents only a small portion of the overall volume of data collected to date. The thermal behaviour of the buildings is influenced by the day-to-day and seasonal variations. The thermal behaviour of the modules also represents upper and lower extremes as there is no direct entry of solar radiation, to provide solar passive heating in winter, or night-time ventilation during summer to cool the building's interior. The response of the modules is also affected by several other parameters related to the geometry of the building including wall/floor area ratio and the lack of internal partitions. Whilst these factors may not allow the internal air temperature data to be directly compared to domestic housing, the data provides a useful understanding of the thermal performance of masonry walls under Australian climatic conditions. As mentioned previously, the data is also being used to calibrate CFD and zonal models for describing the thermal performance of buildings.

It also important to note, that under 'free-floating' conditions, the internal temperature of the buildings will rise/fall in an attempt to reach equilibrium with the external conditions. This can be observed by comparing the internal/external mean temperatures. These temperatures are similar, with the internal temperatures generally being slightly higher. The higher mean internal air temperature in the buildings is likely to be due to the absorption and conduction of solar radiation by the masonry walls. The presence of cloud cover significantly reduces the maximum temperatures observed on the surface of the external masonry walls. Both buildings show the ability of masonry walls to attenuate the day-night temperature variation. The internal air variations were in the order of 2.5–3.5°C for the cavity brick module and 3–5°C for the brick veneer for external air variations up to 20°C. The cavity brick module showed a smaller variation despite this walling system having only approximately half the R-value of brick veneer construction.

The data also demonstrates the ability of masonry walling systems to attenuate incident solar radiation. For summer conditions, Figures 7 to 9 show that the peak solar radiation levels falling on the West wall are in the order of 800 W/m² with only about 200 W/m² being absorbed by the exterior masonry surface. However, the peak flux values entering the buildings are very low, 12–13 W/m². The reduction of flux values is a result of the thermal properties of the masonry walls and the cooler night time temperatures allowing much of the stored heat in the masonry wall to be re-radiated to the outside environment. The results also emphasise the need for appropriate roof insulation due to the extreme temperature range experienced by roofing materials (-4 to 70°C). The roof cools down below ambient temperature during the night and receives high levels of solar radiation for prolonged periods of time during summer.

6.0 Conclusions

The data presented here gives a brief insight into the actual thermal performance of cavity brick and brick veneer walls. As mentioned previously, the behaviour is influenced by several factors including the day-to-day and season-to-season weather patterns. Given the available data, both cavity brickwork and brick veneer construction show the ability to attenuate the effects of direct solar radiation. From a building point of view both modules respond slowly to extreme hot/cold weather conditions, moderating the internal temperature. The greater thermal mass of cavity brickwork construction reduces the internal day-night temperature swing when compared to the brick veneer despite the latter form of construction having a higher thermal resistance value. This work is continuing with the next stages of the project involving controlled internal conditions.

7.0 Acknowledgements

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