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Abstract

The following research has been undertaken as a response to the recent controversy regarding the suitability of rammed earth wall construction as an effective building envelope. Empirical (in-situ) measurements of temperature and heat flux are taken on the walls of an existing rammed earth building in New South Wales, Australia. An analysis is performed which examines the influence of walls, floor, ceiling and windows on the recorded temperatures within the building. It appears that diffuse sky radiation transmitted by the windows is an important factor in the summer heat load, and that night time cooling coupled with thermal mass has a valuable conditioning effect.

1. BACKGROUND

A two storey university office building constructed from rammed earth is used for this study. These offices do not have a typical HVAC plant. Conditioning is achieved by hydronically heated and cooled floors and exposed ceiling slabs. In the summer the large thermal mass moderates the large daily temperature swings. Night time ventilation helps to keep the building cool. To achieve this ventilation a system of computer controlled vents operates in the offices and in the ventilation stacks as shown in figure 1. Each office has a ceiling fan and a sliding sash window. The building provides for a unique case study of a rammed earth, passively cooled, commercial scale building.

![Figure 1 A Section of the Building Showing its Natural Ventilation Features](image)

The offices are located in the Riverina district in NSW Australia which is characterised by cool wet winters and hot dry summers. The mean temperature for February this year (2001) was 24.4°C with an average high daily temperature of 31.4°C, and an average low daily temperature of 17.6°C, although the lowest minimum recorded was 11.4°C. The summer days often have clear skies. The total global daily radiation is typically 30MJ/m² on a horizontal surface for such a day. These measurements were taken from a portable weather station installed nearby.
2. INSTRUMENTATION

The locations of the monitored rooms are shown in Figure 2, and the installed instrumentation and methodology are given in Table 1. High quality thermistors are connected to Campbell Scientific data loggers. The thermistors and Heat Flux Meters (HFM) are embedded 5mm in the wall surfaces (exterior and interior) and mortared over. The HFM are mounted to ASTM standards (ASTM, 1995). All heat fluxes into the office are taken as positive.

![Figure 2 Floor Plan Indicating the Monitored Rooms (red second storey)](image)

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3. ANALYSIS OF OFFICE - A

The four days chosen for this analysis are from Friday the 23rd to Monday the 26th of February. There were clear skies for most of this period with an overcast sky before the last day. The lowest temperature reached was 14.6°C at 6am on Monday.

The collected data portrays the heat flows associated with the building elements (wall, floors etc.) The two HFM give a direct reading of the heat flowing to and from the inside and outside surfaces of the east wall of the building. Heat is transferred from the walls to the office space by convection and radiation. This may be described by the simplified and combined equation 1.

\[
q_{\text{ext}} = h_{\text{ext}} (T_{\text{surface}} - T_{\text{air}}) 
\]

A value of 6.5 W/m²K was empirically found for \( h_{\text{ext}} \). This was done by matching the measured flux at the internal wall surface with one theoretically calculated using equation 1 (see Figure 3). For this case, the globe temperature was used rather than the air temperature as it is the average of the mean radiant temperature and the air temperature. Having established a value for \( h_{\text{ext}} \), heat fluxes can be determined for walls which only have surface temperature measured.
To establish heat fluxes from floor and ceiling the air temperatures near and on these surfaces were used. The \( h_{ext} \) surface coefficients used were 9.26 W/m²K for upward heat flow, and 6.13 W/m²K for downwards heat flow (ASHRAE, 1997).

\[
q_{wall} = \left( T_{outside\ surface} - T_{inside\ surface} \right) R_{wall}
\]

The \( R \) value empirically established was 0.27 m²K/W based on the rammed earth conductivity of 1.1 W/mK with wall thickness 300mm. The conductivity value was obtained by using a numerical method described by Balcomb (Balcomb & Hedstrom, 1980) and matching simulated and measured heat flux and wall temperatures (Figure 3).

Other means of heat transfer are through air infiltration and transmitted solar radiation through the windows. A pressure due to hot air collecting in the ventilation stacks during the day may lead to some unwanted infiltration due to leaks in the louvers located under the windows and the ventilation stacks. This was not assessed. The windows are shaded to stop direct solar radiation. However the diffuse component of sky radiation which enters the building has been estimated from figures taken from the Australian Solar Radiation Data Handbook (Lee et al., 1995) for Mildura which has a similar climate. Equation 3 gives the radiation on a vertical surface (Szokolay, 1987).

\[
G_{vertical} = G_b \cos(INC) + 0.5G_d + 0.5 p(G_b + G_d)
\]

\( G_b \) is direct beam radiation, \( G_d \) is diffuse radiation and \( p \) is ground reflectance taken as 0.2. The heat flux getting through the window, \( q_{window} \), is then calculated from equation 4 (ASHRAE, 1997). SHGC is the solar heat gain coefficient estimated for the effect of a venetian blind and 3.2mm glass. \( U \) was calculated as 3.0 W/m²K for the heat conduction part of the equation.

\[
q_{window} = G_{vertical} (SHGC) + U_{window} \left( T_{outside} - T_{inside} \right)
\]

The net energy transferred to, or from, the room for each surface from 9am – 5 pm is calculated by multiplying the flux by the area of the surface in question and integrating over the time period.

### 3.1. Stratification

Stratification is seen to occur all the time in this space, although the height of the office is only 2.7m (Figure 4). The effect of the night cooling is indicated by an overall decrease in the inside temperatures, yet an increase in stratification. There is also quite a sharp rise in interior temperatures at the start of day light, followed by a reduced increase in temperature towards dusk. The benefit of night cooling can be seen on Monday, which had the lowest indoor temperature and yet a reasonably high outside day temperature.
3.2. External Walls, The Decrement Factor and Thermal Lag

The east facing external wall in office A is entirely exposed to the sun. Figure 5 shows the measured heat fluxes at the outside and at the inside together with a fictitious flux (a wall assuming no thermal mass). A large peak in the external flux is a result of the early morning sun (23rd and 26th).

When the fictitious flux is compared to the measured inner surface flux there is a decrease in amplitude of about 25% and a phase shift of about 10 hours (Figure 5). This is an indication of the benefit of a high mass wall. Never-the-less the wall does continuously transfer heat into the office. However, there is an early morning rise in air temperature of the office which appears not to be accountable from the wall. This air temperature increase brings the wall heat transfer down to zero, or even slightly negative, suggesting that there is something other than the wall affecting the room temperature.

Figure 3, (previously), shows the match obtained between the measured wall flux, and a theoretical flux using equation 3 with globe temperature rather than air temperature. A calculated flux for the south wall is also shown on this figure. The effect of the night cooling is apparent, but during the day light hours this south wall is removing heat from the office. Therefore, the south wall is not responsible for the increase in office temperature during the day time.
3.3. **Energy in office A from 9am to 5pm**

Having established heat fluxes for each surface it is possible to find the energy (heat transfer) to the office. An assumption has to be made that the flux calculated is an average over its entire surface. This is probably more realistic for the floor and ceiling (horizontal) surfaces than for the walls. A more uniform horizontally temperature (due to stratification) exists. A summary of the calculated energy to or from the space by each element is shown in figure 6. It can be seen from these rather simple calculations that diffuse radiation through the window is very likely to be the most significant factor in heat gain.

![Figure 6](image_url)  
Figure 6  A Combined Graph of Net Energy Transfer and Interior Air Temperature from 9am to 5pm.

4. **CONCLUSION**

Use of simple techniques has given a partial insight into the performance of a passively conditioned rammed earth building. The high mass walls delay and moderate heat transfer from the outside, yet there are other significant factors such as windows and ventilation which may counteract this performance. A closer look at isolating these parameters requires further investigation. The air flow through the building during the night cooling phase should be closely examined as it is crucial to day time comfort conditions.

**REFERENCES**


