Learning from ‘Earthship’ based on monitoring and thermal simulation

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ABSTRACT: This paper describes research which investigates the thermal performance of Earthship, an autonomous, earth-sheltered housing concept that claims to require no active heating or cooling systems despite extreme climatic conditions. This research aims to test these claims through monitoring and thermal simulations. The study involves monitoring the indoor conditions in an Earthship home in New Mexico USA and uses the measured data to calibrate a computer model used to simulate the thermal performance of the home. A second part of the study compares Earthship thermal performance located in a temperate climate in Australia with that of buildings incorporating different wall construction materials such as strawbale, rammed earth, and brick veneer. Results from both of these studies substantiate the claims. The effect of including a greenhouse, earth-berm, and internal wall material is also explored and quantified. The paper will conclude with a discussion of the scope for reducing home energy use through the use of Earthship design principles and construction methods and the viability for building these houses in the Australian suburbs.

Conference theme: Buildings and Energy
Keywords: Earthship, thermal performance, monitoring, simulation

INTRODUCTION

The Earthship was developed by US architect Michael E Reynolds due to his concerns about the negative effects of conventional housing on the environment and on peoples’ health and wellbeing. He argued that reliance on centralised energy systems “give us acid rain, radioactive waste and powerlines lacing the earth” and that conventional housing is “non-functional” (Reynolds 1990) - and therefore dangerous - when centralised utilities for electricity, water, and sewage treatment are compromised as they often are by natural disasters. He also wanted to put the making of shelter back into the hands of the common person (Reynolds 1990).

His solution was an autonomous home, constructed substantially from consumer waste (such as used car tyres) and natural materials, particularly for the walls which could be built by the owner with common tools (Reynolds 1990). The design extends passive solar principles and uses innovative off-grid systems to provide the occupant with thermal comfort, food, water, shelter and wastewater treatment. Gas is used to backup solar hot water and as a cooking fuel, however the home is principally autonomous, freeing the occupants from ongoing utilities bills (Systems 2012).

Reynolds anticipated that such a home would “reduce and ultimately remove the stress involved with living on this planet, both to humans and the rest of the planet” (Reynolds 1990:19). Earthship dwellers could escape a huge mortgage by using natural and waste materials, building much of their home themselves, and escape the relentless financial stress caused by electricity, water and sewage utilities bill. They could learn to grow their own high quality food – using their wastewater.

The Earthship concept is gaining momentum around the world, appearing on popular television shows such as Grand Designs, and over the last decade Earthship homes have been built in many countries. Three communities of Earthship homes are located in Taos, New Mexico, USA (housing about 200 people) and it is estimated that there are many hundreds built around the world including, USA, New Zealand, Spain, France, UK, Netherlands, Czech Republic, Canada, Mexico, Africa, Guatemala and Haiti (Designs 2012; Hewitt and Telfer 2012). A fully functional Earthship is yet to be built in Australia although planning and preliminary construction work has begun (Lloyd 2012).

It is claimed that these earth-sheltered housing will require no active heating or cooling systems, are almost entirely free of utility bills despite extreme climatic conditions, and can be built in any part of the world (Designs 2012). Very few scientific studies have however tested these claims. This paper presents two related studies that investigate the claims regarding the thermal performance of the Earthship, in its original location and in another climate in Australia. The first study is based on monitoring as well as simulation of the thermal performance of an Earthship home in Taos, while the second analyses the performance of an Earthship home in the Adelaide climate and compares and explores the effects of substituting other wall materials, as well as the effect of the Earthship’s greenhouse, a major feature of the Earthship’s passive solar design, on the thermal performance of the home. The paper concludes with a discussion about the transferability of this design to other climates and built environments.
1. OVERVIEW

With a growing human population on a finite planet solutions are urgently needed to ensure that everyone can be provided with food, water, shelter, sanitation and electricity to meet their basic needs. Other needs such as education, community, recreation and birth control must also be addressed if our civilisation is to continue indefinitely – “sustainably” (Heinberg and Lerch 2010). Population growth seems to be inextricably linked to an increased demand for energy and resources which drives pollution, climate change, and biodiversity loss. According to Heinberg and Holmgren the human population has most probably already overshot a sustainable level and is destined to decline in unison with declining reserves of crude oil (Heinberg 2003; Holmgren 2002). Many cultures have enjoyed the rise in the standard of living and would be reluctant to let it go, for example George H W Bush forcefully responded to a cry for change at the 1992 Earth Summit that “the American way of life is not negotiable” (Pierre-Louis 2012). How then can we all enjoy the perks of our industrial civilisation while maintaining and restoring critical eco system functions essential to our long term survival?

The concept of sustainability of the built environment provides principles for ensuring our needs are met now and in the future (Williamson, Radford and Bennetts 2003). Its principles aim to protect the environment which sustains us yet enables development to occur – so that we can maintain our modern way of life. Permaculture (Mollison and Holmgren 1978) developed in Australia in the 1970s offers a similar set of principles and ethics to enable us to design, establish and maintain a permanent culture in the context of energy decline and climate change.

The Earthship is an exemplar of sustainable design principles, however in stark contrast housing design throughout the developed world has done little to respond to the call for sustainable design. In Australia homes have been growing in energy use (Australian Bureau of Statistics 2011) and size (Australian Bureau of Statistics 2005) and are now the largest in the world (Santow 2009). Centralised utilities still prevail around the globe resulting in homes (and occupants) that are condemned to a life of reliance on these systems. Although there are many advantages to being “grid-connected” such as being able to generate income from exporting excess solar electricity generated by the home to the grid, even a well designed passive solar home may not function effectively if centralised infrastructure fails, as it tends to, during natural disasters, peak loads (e.g. electricity blackouts caused by excessive demand), or war.

2. EARTHSHIP DESIGN

In brief the Earthship works like this: the earth-sheltered, passive solar design provides very stable indoor temperatures - the subject of this paper. With little or no need to expend energy on heating or cooling the home’s energy requirements can be met relatively easily (Reynolds 1991) with off-grid renewable energy systems for electricity and solar hot water although bottled gas is often used as a backup for hot water boosting and cooking. Water is collected via gutters on the roof, stored in tanks, and is supplied to appliances and fixtures via filters and a low wattage electric pump. Wastewater is separated into greywater and blackwater and can be routed through a conventional system or routed through the innovative Earthship system: by using greywater for irrigation of an indoor food garden it is treated to a standard suitable (purportedly) for flushing the toilet (Reynolds 2005). Blackwater is sent to a septic tank followed by an outdoor botanical cell, similar to a reed-bed. This is the preferred route for the wastewater, however by use of three-way diversion valves greywater can be diverted directly to the septic tank and blackwater overflowing from the septic tank can be diverted to a conventional drainage field/trench system, providing both a code compliant system and a radically sustainable system within the same design. This two-in-one system helps with gaining approval in risk adverse bureaucracies (Reynolds 2005).

The main load bearing external walls are constructed from end of life passenger vehicle tyres which are rammed with earth excavated from site, or recycled concrete rubble as was the case in Haiti after the catastrophic 2010 earthquake. The rammed earth tyres are arranged in a running bond (like bricks) and do not require the usual steel reinforced concrete footing (resulting in ecological and financial benefits) due to their substantial width (700mm) and flexible and resilient characteristics inherent in the steel belted rubber tyres. Non load bearing internal walls utilise end of life beverage containers – aluminium, glass or plastic – in a mortar of cement or mud. The roof uses conventional construction materials although occasionally sheet metal from white goods has been (re)used.

In summary, Earthship design harnesses the “free services” provided by natural phenomena, coupled with frugal use of modern off-grid technology to provide a home that provides the occupants with the essentials of life without the need to connect to (or pay for) electricity, water or sewage infrastructure.

2.1 Earthship Building Envelope: Design & Theory

The Earthship has evolved and proliferated in the extreme climate of Taos, New Mexico, located at high altitude (2000m) in the south west of the USA (Lat/Long. 36.4, -105.7). It has low rainfall (313mm p.a.) and abundant sunshine year round, with extreme outdoor temperatures ranging from -33 to 38°C and mean temperatures ranging from -13 to 31°C (Western Regional Climate Center 2005).

The Global Model Earthship, a recent design circa 2008, is conceived as an archetype that, with minor adaptations, will suit a wide variety of climates. It features a long and narrow floor plan typically only one room deep, aligned with the long axis east-west to maximise solar exposure on the south face, surrounded by a full height earth berm (to roof level) to the east, west and north. The equator facing side features an attached greenhouse which acts as a corridor and houses a garden bed “planter” which is a biological cell used for treating greywater and growing food. The
greenhouse is almost one hundred percent glazed with insulated glazed units slanted on a 70 degree angle. In the Global Model design the greenhouse is partitioned from the living space by a double glazed wall with high level windows to allow mixing of air or ventilation, whereas in previous designs (e.g. the Packaged Earthship (Packaged 2012)) the greenhouse was integrated with the living space. The floor is uninsulated thermal mass, typically made of flagstone, brick, concrete or mud, and the roof is highly insulated timber frame, steel clad.

Early designs used operable skylights positioned near the rear of each room to admit light and fresh air however recent designs use earth tubes (air ducts) in the berm to provide cross ventilation and passive heating/cooling. The rate of ventilation through the earth tubes (or operable skylights) can be controlled via a thermosiphon effect generated by exhausting hot air from the greenhouse through large operable vents in the greenhouse roof.

The greenhouse tends to generate excess heat in autumn, winter and spring due to the low angle of the sun and in the summer the greenhouse is cooler due to less solar insolation caused by the high angle of the sun and shade created by plant growth in the indoor greywater planters which tends to be more vigorous in the summer. Excess heat is stored in the thermal mass of the walls and floor, the immense quantity of thermal mass (approximately 630 tonnes in the berm and 85 tonnes in the exterior walls of a floorplan as per Figure 6-7) acting as a thermal regulator, conducting the relatively stable earth temperatures into the interior of the building in the winter and out into the wall/berm in the summer. This dynamic is not restricted to seasonal operation and may also occur for example on a cold summer night. In summary, the walls and berm are “charged” during the warm season thereby removing and storing unwanted indoor heat, and during the cold season, or cold periods, they release wanted indoor heat.

**Figure 1 – Global Model Earthship, Taos, New Mexico, USA, Greater World Community © Martin Freney**

2.2 Thermal Performance

Anecdotal evidence suggests that the thermal performance of Earthships in the Taos climate is excellent although in some European climates backup heating or cooling is necessary (Hewitt and Telfer 2012). In Taos, throughout the extreme outdoor temperature range the occupants of the older style Earthship only require occasional backup heating and the modern Earthship design requires zero backup heating or cooling. However, very few studies have been conducted to scientifically examine Earthship thermal performance. Those that have are summarised below.

Grindley and Hutchinson (1996) monitored an Earthship in Taos and analysed its performance using simulation in the Taos and UK climate. They predicted that the Taos Earthship would overheat in the summer and would require some backup heating during winter nights and the UK Earthship would also overheat in the summer but need only 325kWh pa of heating in the winter months.

Kruis and Heun (2007) monitored an Earthship in New Mexico and used this to calibrate a model which was used to simulate thermal performance in various climates in the USA: humid continental (Grand Rapids), continental sub-arctic (Anchorage), tropical savannah (Honolulu) and semi arid (Albuquerque). They found that heating and cooling energy use would be reduced in all climates although backup heating/cooling would be required at times.

Ip and Miller (2009) monitored an Earthship visitors centre in Brighton, England and found that the indoor temperature was often in the comfort range and relatively stable despite the building being incomplete and still in its initial charging stage (when the soil temperature around the building is stabilising).

In France, Howarth built and monitored his Earthship inspired home called the Groundhouse (Howarth and Nortje 2010) which appeared on TV show Grand Designs with the result that it “proved conclusively that a modified earthship design works well in northern Europe” (personal communication, D. Howarth, 17 August 2012). The home has two wood heaters to “provide extra warmth and ambience when necessary” (Intro Groundhouse 2012).

3. METHOD

An initial study reported in this paper monitored the indoor air temperature, radiant temperature and relative humidity of an Earthship in Taos and used simulation to calculate the indoor temperature and calibrate the model for future modelling in other climates. Another study looked at the effect of wall construction, the greenhouse and the berm on the thermal performance of a passive solar designed home, based on Earthship, using simulation to estimate the heating/cooling load for each configuration of the building envelope.
4. STUDY ONE: THERMAL PERFORMANCE OF TAOS EARTHSHIP

The indoor comfort conditions in a recent model Earthship in Taos, New Mexico USA were monitored for 7 months spanning winter through summer (January 2012 – July 2012). The data were then used to calibrate a simulation model of the building, conducted with DesignBuilder/EnergyPlus. Particular effort was invested in developing an improved method for estimating the ground temperature, a factor that has great bearing on indoor comfort conditions in an earth sheltered design such as the Earthship. A computer model developed by Williamson (1994) for calculating ground temperatures was further evolved to account for the peculiar slab edge condition in an Earthship arising from the presence of the greenhouse. A relationship between measured temperatures of the greenhouse and outdoor was used to refine the predicted ground temperatures.

Indoor comfort conditions were monitored using sensors connected to a base station located in the Earthship. In the main bedroom, air temperature, radiant temperature, and relative humidity were collected at a point 2000mm above floor level and 150mm from the rear (north) wall. In the greenhouse air temperature and relative humidity were collected at a similar height approximately 600mm from the angled, double glazed fascia. Outdoor temperature and relative humidity were collected outside the Earthship on the berm and solar radiation data was obtained via a third party supplier (Weather Analytics). The greenhouse and outdoor sensors were housed in solar radiation shields.

The DesignBuilder model was created using data from the architectural drawings of the Earthship of a two bedroom Global Model design completed in 2010 with the thermal envelope properties as described in Table 1.

Table 1 - Study One: Construction Layers and Thermal Properties

<table>
<thead>
<tr>
<th>Type</th>
<th>Description (materials listed from outside layer to inside layer)</th>
<th>U value (W/m²-K) (no bridging)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floor</td>
<td>100mm thick concrete, uninsulated</td>
<td>3.355</td>
</tr>
<tr>
<td>Glazing, exterior/interior</td>
<td>Double glazed, 4mm clear, 16mm air, 4mm clear</td>
<td>2.715</td>
</tr>
<tr>
<td>Roof</td>
<td>0.4mm steel, 200mm Polysiocyanurate (PIR), 25mm softwood</td>
<td>0.110</td>
</tr>
<tr>
<td>Exterior Wall</td>
<td>100mm expanded polystyrene (standard), 1200mm earth, 10mm rubber, 630mm earth, 10mm rubber, 25mm lime render</td>
<td>0.235 (not including effect of berm)</td>
</tr>
<tr>
<td>“Can” interior wall</td>
<td>50mm concrete</td>
<td>3.382</td>
</tr>
</tbody>
</table>

4.1 Study One: Occupancy, HVAC and other Assumptions

Very little data was available regarding the operation and occupancy of the home. There were some records of when the building was unoccupied, so these periods were the focus of attempts to calibrate the model. The modelling assumptions were as follows: Occupancy was modelled as zero. Heating and cooling was not used (“free running”). Natural ventilation was scheduled to occur from May to September (all hours) when the outdoor air temperature was less than 21°C and was calculated based on opening and crack sizes, buoyancy and wind pressures. All exterior windows were modelled as closed all the time. Internal windows were modelled as being able to open 30% (of their area) from 11:00 to 16:00hr from May-September. Earth tubes were not modelled. The heavy weight interior wall was modelled as a 50mm thick concrete wall to approximate the amount of thermal mass in the wall (i.e. air filled aluminium cans ignored).

4.2 Study One: Results & Discussion

Figures 2-5 show results for measured bedroom (Meas Br), greenhouse (Meas GH) and outdoor air temperature (Meas Out) compared with the simulated bedroom (Sim Br) and greenhouse (Sim GH) for four selected weeks of the seven month monitoring period which are typical for each season with some noted exceptions. The overall picture is that of extreme outdoor temperatures ranging from -14.4°C to 34°C while a very stable indoor temperature range prevails even without employing any heating or cooling; 17.2°C (Figure 2, day 4) to 24.4°C (Figure 5 day 2). These results substantiate the claim about the thermal performance of Earthship housing. The results also show that the diurnal temperature in the greenhouse fluctuates most in winter (Δ26°C) when the extreme maximums and minimums occur whereas in the summer the diurnal swing is not as great (Δ20°C).

The simulated results indicate an acceptable level of accuracy despite limitations such as uncertainties about occupancy schedules, use of natural ventilation, and issues affecting ground temperature such as moisture content and soil type. A coefficient of variance of the root mean square error CV (RMSE) between the simulated hourly and measured air temperature was calculated for the 7 month monitoring period. For the bedroom a CV (RMSE) of 9.5% was obtained and for the greenhouse 14.7%. This is considered to be an acceptable result as previous work by Kreider and Haberl (1994) showed that the best hourly empirical models were only capable of producing CV (RMSE) in the 10% to 20% range, thus the accuracy of simulation for the bedroom is better than expected. Prediction of the greenhouse temperature was not as accurate as that of the bedroom which was generally within 2°C of measured. The simulated minimum temperatures of the greenhouse were fairly accurate (although summer week shown in Figure 5 was an exception) however the maximums were often out by up to 12°C. This may be explained by the possibility that the occupants had opened the outside windows and greenhouse roof vents to exhaust excessive hot air (Figure 3, days 2-4). On one of the few cloudy days during the monitoring period (Figure 2, day 2) the greenhouse only heats up to 18.7°C, although it was only 1.3°C outside, and the bedroom temperature was very stable dropping only 1.2°C over the following night, as also predicted by the simulation.

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5. STUDY TWO: EFFECT OF GREENHOUSE AND WALLS IN ADELAIDE CLIMATE

This study was designed to estimate the energy use for a passive solar designed home based on the Earthship model in the Adelaide climate (Temperate/Mediterranean climate) subject to a number of variables, namely the exterior wall construction, interior wall construction, greenhouse, berm and window area. The results will be used in a larger study on life cycle assessment (LCA) comparing the ecological impacts of Earthships with other passive solar homes (not reported here). The effect of window area will also not be discussed in this paper due to editing limitations. Based on the lessons learned in simulating the building in the Taos study, a simulation model also using Design Builder/Energy Plus was created for the current design Global Model two-bedroom Earthship of 121m$^2$ floor area. See Figure 6-7 for details. The roof and floor constructions were constant throughout the study as was the occupancy rate and the various parameters relating to the HVAC settings, and natural ventilation (opening of windows/vents). Although in reality Earthship buildings use no or minimal space heating and cooling, in this study heating and cooling is assumed to be employed because one of the parameters of evaluation is the heating and cooling energy, as heating and cooling is often employed in buildings with common wall constructions.

5.1 Study Two: Occupancy, HVAC and other Assumptions

Occupancy was assumed to be 3.6 people (0.03 people/m$^2$) approximating two adults with two small children. The schedule was 15:00 to 10:00hr every day indicating that they were at home most of the time with the exception of 5hr in the middle of the day. The temperature at which the heater turned on was 18°C and was scheduled for all hours, all days of the week, from May to September. The temperature at which the cooler was turned on was 26°C and was scheduled for all hours, all days, from November to March. Natural ventilation set-point was 21°C, scheduled for all hours, all days, from November to March with 3 air changes per hour, indicating the outdoor temperature at which natural ventilation through openings is allowed to occur. Interior windows opened 30% of their area from 11:00 to 16:00hr, all days, from May to September. The greenhouse blinds were operated automatically by solar insolation, normally open but closing if solar radiation exceeded 200W/m$^2$. Ground temperatures were calculated using a computer model developed by Williamson (1994) based on the berm shown in Figure 6-7.

5.2 Study Two: Building Envelope Configurations

Each exterior wall type was simulated with either heavy weight or light weight internal walls and each of these combinations were simulated with and without the greenhouse. Their construction layers and thermal properties are given in Table 2 and Figure 6-7 which shows the “with greenhouse” configuration. The “without greenhouse” configuration is identical with the exception that the greenhouse is replaced by a 900mm fixed overhang (shade device) and the 275mm adobe (mud brick) partition wall is replaced by the exterior wall material, with the exception of Earthship exterior wall types for which the partition wall is insulated Timber Frame. Exterior walls that were structurally capable of being bermed were simulated with and without the berm and likewise exterior wall constructions that might benefit from additional insulation were simulated with and without an additional external insulation layer. Finally each of these combinations were simulated multiple times with varying amounts of glazing to
establish the optimum amount of glazing. As the optimal glazed area for some of the building envelopes was deemed to be too low for adequate daylighting and views (e.g. 10-20%), a value of 50% glazed area (of the north wall – not floor area) was established as a minimum thereby ensuring all configurations had adequate daylighting and therefore would not need to factor in additional energy for artificial lighting.

Table 2 – Study Two: Construction Layers and Thermal Properties

<table>
<thead>
<tr>
<th>Type</th>
<th>Description (outside to inside)</th>
<th>U value (W/m²-K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floor</td>
<td>100mm thick concrete, uninsulated</td>
<td>3.355</td>
</tr>
<tr>
<td>Glazing, exterior</td>
<td>Double glazed, 4mm clear, 6mm air, 4mm clear</td>
<td>3.146</td>
</tr>
<tr>
<td>Glazing, interior</td>
<td>Single glazed, 6mm clear</td>
<td>5.801</td>
</tr>
<tr>
<td>Roof</td>
<td>0.4mm steel, 196mm cellulose, 13mm plasterboard</td>
<td>0.196</td>
</tr>
<tr>
<td>Brick Veneer</td>
<td>110mm brick, 40mm air gap with reflective foil, 70mm glass fibre, 10mm plasterboard</td>
<td>0.337</td>
</tr>
<tr>
<td>Concrete Block Insulated</td>
<td>100mm EPS, 300mm concrete blocks (hollow, heavyweight)</td>
<td>0.346</td>
</tr>
<tr>
<td>Double Brick</td>
<td>110mm brick, 50mm glass fibre, 110mm brick, 10mm plasterboard</td>
<td>0.512</td>
</tr>
<tr>
<td>Earthship, bermed, insulated</td>
<td>100mm EPS, 1000mm earth, 10mm rubber, 630mm earth, 10mm rubber, 25mm lime render</td>
<td>0.235 (not including effect of berm)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type</th>
<th>Description (outside to inside)</th>
<th>U value (W/m²-K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earthship, no berm, insulated</td>
<td>25mm lime render, 100mm EPS, 10mm rubber, 630mm earth, 10mm rubber, 25mm lime render</td>
<td>0.299</td>
</tr>
<tr>
<td>Lightweight interior wall</td>
<td>10mm plasterboard, 90mm air gap, 10mm plasterboard</td>
<td>2.246</td>
</tr>
<tr>
<td>Rammed Earth (RE)</td>
<td>300mm rammed earth</td>
<td>2.128</td>
</tr>
<tr>
<td>RE Insulated</td>
<td>25mm lime render, 100mm EPS, 300mm rammed earth</td>
<td>0.333</td>
</tr>
<tr>
<td>Reverse Brick Veneer</td>
<td>8mm Cement fibreboard, 70mm glass fibre, 40mm air gap with reflective foil, 110mm brick, 10mm plasterboard</td>
<td>0.322</td>
</tr>
<tr>
<td>Straw bale</td>
<td>50mm lime render, 450mm straw bale, 50mm lime render</td>
<td>0.108</td>
</tr>
<tr>
<td>Heavyweight interior wall</td>
<td>150mm mud brick (adobe). Note this wall type also used for Partition Wall.</td>
<td>2.703</td>
</tr>
<tr>
<td>Timber Frame</td>
<td>10mm cement fibreboard, air gap with reflective foil, 90mm glass fibre batt, 10mm plasterboard</td>
<td>0.424</td>
</tr>
</tbody>
</table>

Figure 6 – Section of Earthship model with greenhouse and berm

Figure 7 – Plan of Earthship model with greenhouse and berm

Table 2 – Study Two: Construction Layers and Thermal Properties
5.3 Study Two: Results

It was found that for all exterior wall types, the heating and cooling load was less when heavy weight interior walls (mud brick) were employed rather than light weight (plaster board on timber stud). For brevity Figure 8 only shows the results (in kWh pa) for heavy weight interior wall building envelope configurations. Results are shown for the optimal or minimum window size (of 50% of north wall area) whichever was greatest. Star Bands using the Australian NatHERS rating (Department of Climate Change and Energy Efficiency 2012) have been calculated based on 121m² floor area for Adelaide climate. The results are paired to show the effect of the greenhouse on each exterior wall type and are listed in order of energy use for the "with greenhouse" configuration.

The results shown in Figure 8 indicate that when a greenhouse (with solar controlled blinds) is attached to the north face of the home, there are energy savings for all exterior wall types. Those that benefit the most are Timber Frame, Rammed Earth, Brick Veneer benefiting by 1075, 907, 1008, kWh pa respectively. Earthship (Insulated & Bermed) has the least to gain from the greenhouse with an energy saving of only 505 kWh pa.

As the results for the light weight internal wall configurations are not displayed in Figure 8 selected results will be discussed briefly here. The following results are the amounts of additional energy needed to maintain comfort conditions if a lightweight construction is used for interior walls instead of heavy weight. Timber Frame, Timber Frame with Greenhouse, and Brick Veneer required the most additional energy: 666, 649, 604 kWh pa respectively. Concrete Block Insulated Bermed with Greenhouse and Earthship Insulated Bermed with Greenhouse required the least additional energy: 190, 198 kWh pa respectively. Thus homes that have sufficient thermal mass in the exterior walls don't benefit as much from heavy weight internal walls.

The insulated and bermed Earthship have the least heating and cooling load of all the building envelopes that were simulated. It achieves 9 stars NatHERS rating for the design with a greenhouse (i.e. Global Model design) and an 8.5 star rating without a greenhouse (i.e. Packaged design). Similar performance was achieved by the insulated and bermed Concrete Block wall indicating that this wall construction method offers an alternative to a tyre wall. Without the berm the insulated Earthship and insulated concrete block exterior walls perform similarly to straw bale and insulated rammed earth, all of which would receive a 8 star NatHERS rating if a greenhouse were included in the building envelope or a 7.5 star rating without the greenhouse. Double Brick and Brick Veneer constructions have the capacity to achieve 8 stars when the design incorporates a greenhouse, however without the greenhouse Double Brick drops to 7 stars and Brick Veneer to 6.5 stars — still a good result indicating that traditional materials coupled with passive solar design principles could lead to significant energy savings. Timber Frame, a common construction method in Australia, also performed similarly to Double Brick and Brick Veneer although it just falls into the 7.5 star band when a greenhouse is included and receives 6.5 star rating without greenhouse as does Brick Veneer. Rammed Earth, built without insulation (as is common in Australia), receives a rating of 7 stars with greenhouse and 5.5 without greenhouse whereas when insulation is included as an external layer (and hidden by render) the star ratings jump to 8 and 7.5 indicating that insulation may help the earth building industry regain their environmental credentials (Thomas 2011) in relation to heating and cooling energy use.

6. CONCLUSIONS

The monitoring study demonstrates that the Global Model Earthship works extremely well in the extreme Taos climate confirming anecdotal evidence. The simulations give confidence that homes built according to the Earthship...
principles, in a Mediterranean climate such as Adelaide’s, would provide thermal comfort conditions with a minimal amount of energy, or in free running designs, periods of uncomfortable indoor conditions would be minimal and easily tolerated. Although the Global Model Earthship, (bermed, insulated, tyre wall with attached greenhouse) provides the greatest energy efficiency in the Adelaide climate, various design options are available to accommodate constraints that may be imposed by the site or regulatory agencies. On small suburban blocks where a berm may not be suitable due to its size and appearance, innovative design could overcome these problems, for example retaining walls could be used to wall-in the berm so that it would appear more like a fence, and terracing of the berm could enable gardening thereby utilising the "wasted" space the berm occupies. Features that enable shading of the greenhouse in the summer, yet admit full winter insolation, and passive cooling features such as earth tubes (which were not modelled in this study) may help to reduce heating and cooling energy even further.

In terms of the autonomous house concept, especially one built with large amounts of consumer waste, Earthship offers possibilities for adaption and mitigation of the effects of climate change, energy decline, resource scarcity and pollution, and improves preparedness for natural disasters. It provides the means by which households can curb excessive resource consumption while maintaining a high standard of living, and enjoying less financial strain. Indeed if Australians want to build the world’s largest homes... they should be built following Earthship principles.

7. REFERENCES


