Testing the life cycle performance of thermal mass wall and double glazing in a house design

Lyrian Daniel[1]

[1]University of Adelaide, Australia

ABSTRACT: This paper presents the impact of applying thermal mass and double glazing on a house's energy use, embodied energy and its life cycle costs. The paper will address the question whether or not the use of these materials are viable for the owner in fiscal terms and the whether they do present feasible alternatives to 'standard' materials such as brick veneer and single glazing. Simulation, using AccuRate, as well as monitored inside and outside temperatures and humidity were used to assess the impact of thermal mass and double glazing on the overall energy use of the dwelling and temperatures of the individual spaces.

The preliminary results show that the use of double glazing does reduce the energy loads of the dwelling when simulated in AccuRate, however it could be argued that these energy savings are not significant enough to justify the extra costs incurred or the effect of the increased embodied energy of double glazing on the environment. The thermal mass, in the form of 150mm blue stone lining on a southern wall, greatly improved the performance of the space; therefore is to be considered as a tool for passive thermal design. This study is expected to provide some useful insights in applying certain passive design strategies and their impact on life cycle energy and costs of the building.

Conference theme: Architecture
Keywords: Thermal, Performance, Glazing, Mass

INTRODUCTION

This paper presents the outcomes of research conducted during a University of Adelaide Summer Research Scholarship. It presents the findings of a case study with specific attention to the thermal performance of the use of thermal mass and double glazing and their impact on indoor temperature, potential energy use and life cycle costs. Recorded temperatures and simulations with AccuRate (Version 1.1.4.1) were used to assess the performance of different spaces within the dwelling. The simulation program was then used to explore possible modifications and the effect of these modifications on the thermal performance of the dwelling. Embodied energy estimations and lifecycle cost analysis were also used to assess the benefits of the modifications, both to the owners and the environment.

Double glazing has been suggested as one strategy to improve the thermal performance of a space (Lyons, P. Hockings, B. Government of Australia, 2008). Similarly, in temperate climates thermal mass has been suggested as a tool to store heat gain from solar ingress, heating appliances and waste heat from cooking activities. However, it is important to not only look at the effect of these strategies in terms of indoor space temperature and comfort or reducing energy use, but also whether these strategies are cost effective. The study attempted to address this issue and the performance of these materials to their standard counterparts.

Critical assumptions and limitations of this research are discussed in section 7.0 as they have a significant impact on the results of this study.

1. METHODOLOGY

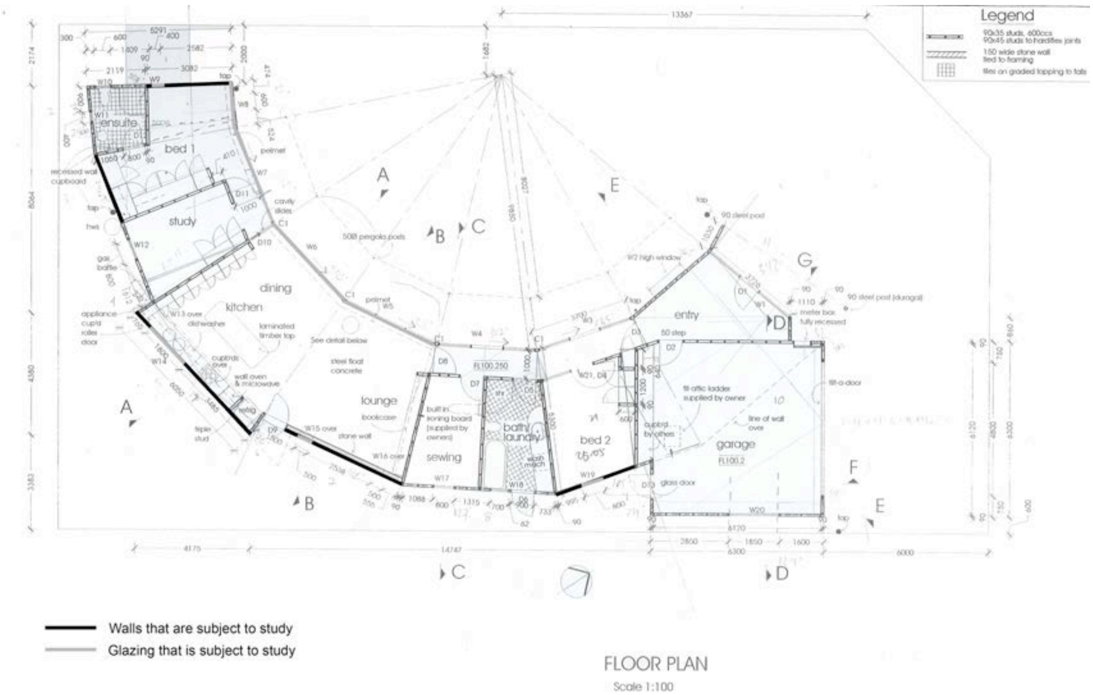
The indoor and outdoor temperature and humidity of the case study house were monitored hourly during 2005 and 2006. Following a general assessment of the dwelling’s performance individual facets of the design were tested using AccuRate to discover the effectiveness of certain elements in passive design. Elements providing the focus for this study were the thermal mass wall in the living area and the double glazing in the same area.

2. CASE STUDY

A residential building was used to be a case study in the research. The house is sited on a corner allotment in a new development at Sellicks Beach. Sellicks beach is located 47 kms south, south-west of Adelaide, South Australia. The open allotment is 612 m2. The site is 15m above sea level. During summer the Sellicks Beach temperature, taken with on-site monitoring data, varies from 12.6 degrees to 26.9 degrees and in winter the temperature varies from 4.3 degrees to 11.8 degrees. The mean annual rainfall recorded at a nearby weather station in Myponga is 762.7mm; the average summer rainfall is 27.2mm per month and the average winter rainfall is 108.2mm per month. The monitoring data was only collected for 8 months.

The dwelling was designed by architect Max Pritchard. The curve of the house is butted up against the south – eastern and south – western boundaries. The design of the curve allows for maximum northern exposure on a site that faces predominantly north – west. The curve is 'faceted' into different living spaces divided by conventional internal walls. The house includes; two bedrooms; ensuite; bathroom/laundry; study; sewing room; open plan kitchen, living and dining area; entry space and a garage. See Figure 1. The garage is the only component of the design that is not part of the faceted curved. It is formed by a square, parallel with the boundaries, that intersects with the curve between the entry space and the second bedroom. The main parts of the house (main bedroom, kitchen, dining and living area) have northern aspects that vary by approximately 30 degrees east and west respectively.

The floor area is 170.41m2 (total floor area of 194.41m2 including garage inclusive), 9.6% larger than the median floor area of a detached dwelling in South Australia (Environmental Protection Agency [EPA] 2008). Additionally, the dwelling has a lower occupancy of 2 (Note: one of the occupants works away from home so is only there 50% of the time, therefore further reducing the occupancy to 1.5) whereas the median occupancy for South Australia is 2.37 (Environmental Protection Agency [EPA] 2008).



Source: (Modified from; Pritchard, 2005)

Figure 1: Plan identifying the glazing and walls that are subject to study.

3. MONITORING RESULTS

The monitoring data was collected from August 2005 to March 2006 using HOBO loggers that were situated 1.6m above floor height where possible. The two bedrooms, the living area and the entry were monitored, as well as the outdoor temperatures for that period.

During the monitoring period from 06/08/2005 – 31/08/2005 the temperature in the living area ranged between 15.23 – 23.63 degrees, while the main bedroom ranged between 12.16 – 26.34 degrees, and the second bedroom ranged between 12.16 – 22.48 degrees. Using the occupants' thermal comfort range of 18 – 24 degrees, the living area's temperature was acceptable for 83% of the data period. Heater use is evident in the living area, as can be seen in the uncharacteristic peaks in indoor temperature (inconsistent with outdoor temperatures) as shown in Figure 2;

The two bedrooms do not perform very well through winter. The main bedroom maintains an acceptable thermal comfort range for only 37% of the data period, while the second bedroom was only 'comfortable' for 27% of the data period. The architect believed that the living area performed better that the bedrooms due to the presence of the thermal mass of the stone wall and concrete flooring and the use of insulation for the internal walls as well as double glazing in the living. Also the bedrooms did not get a comparable amount of solar heat gain due to their orientation and layout. The next section will test this hypothesis by performing a series of simulations.

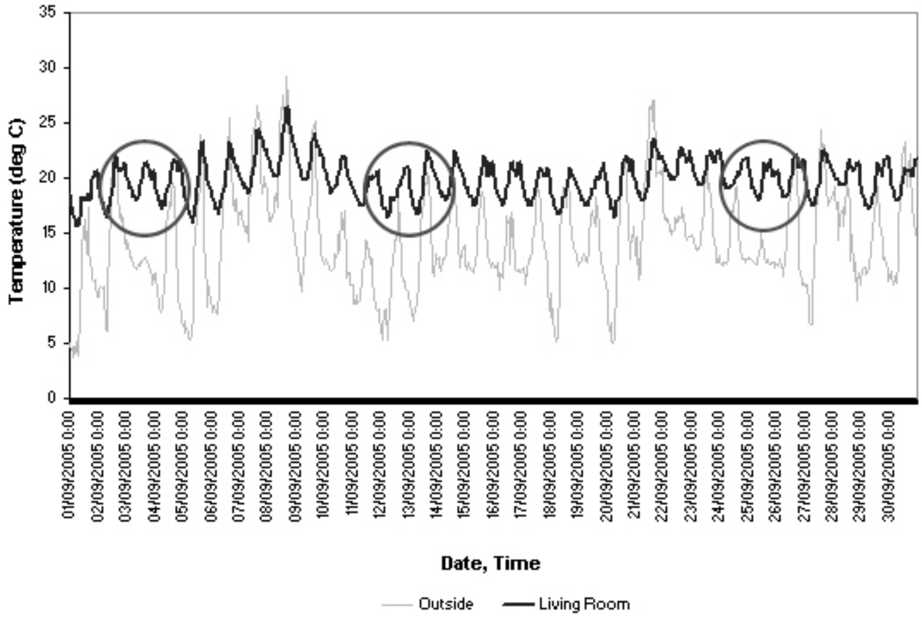


Figure 2: Monitoring graph for August 2005 identifying heater use in the living area.

During the monitoring period from 12/12/2005 – 28/02/2006 (summer months) the living area was between the occupants' acceptable thermal comfort range (20 degrees to 26 degrees in summer) for 91% of the data period. The temperatures in the living area ranged between 19.42 – 32.34 degrees. Venetian blinds and the glory vine on the pergola were used during summer to reduce solar heat gain. The space also employed cross ventilation via windows and doors.

The two bedrooms performed quite well in the summer months. The main bedroom's temperatures were between an acceptable summer thermal comfort range for 83% of the data period, while the second bedroom is 'comfortable' for 89.3% of the data period. Temperatures in the main bedroom ranged between 17.9 – 35.7 degrees, the second bedroom ranged between 18.28 – 35.7 degrees.

Table 1: Percentage of time that the zones are within the acceptable thermal comfort range.

Zone	Summer	Winter
Bedroom 1.	84%	37%
K/L/D Area	91%	83%
Bedroom 2.	89%	27%

*Note: Humidity was not included in the above calculations or assessment; however Sellicks Beach is an area that is not subject to extremes in humidity.
*Note: Data includes temperatures sourced from 24 hour monitoring.
*Note: Limited data.

4. SIMULATION RESULTS

Energy Efficiency Provisions were introduced into the Building Code of Australia in 2003 with the intention of reducing the greenhouse gas emissions from Class 2 buildings. Buildings may pass these provisions either by the deemed-to-satisfy method or by using an alternative solution. A common alternative solution is using a thermal simulation program that complies with the requirements of the Nationwide House Energy Rating Scheme (NatHERS) to achieve a specified rating. In 2006 the minimum required rating in South Australia was set at 5 stars. In 2009 the BCA required that "2nd Generation software" must be used to determine a rating. Second generation AccuRate V1.1.4.1 was used for the following simulations.

The initial AccuRate rating of this house was 6.9 Stars. This was modelled using documentation provided by the architect and information from the interview with the occupants. This star rating means the house is able to be built in South Australia and is also potentially energy efficient (6.5 stars and above is thought to be potentially energy efficient). Because at the time of the initial interview the planned glory vine had not fully grown the initial simulation assumed shade cloth on the pergola with a 50% shading factor.

A second rating was conducted to test the impact of the glory vine. Fully grown vine results in significantly higher rating of 7.4 Stars. This is due to the increased amount of shading that the glory vine provided during summer, which reducing the cooling loads. However, because the vine is deciduous it also allows a greater amount of solar heat gain in winter (unlike the shade cloth which shades all year round unless taken down), reducing the heating loads in winter as well. The second model was used as the ‘Base case’ for the next analyses.

4.1. Glazing Modifications
Through discussions with the clients (Young, 2005) it was found that they wanted double glazing on the bedroom windows. The third simulation was therefore run to assess the benefits, if any, that this additional double glazing would accrue. Applying double glazing only improved the rating by 0.1 of a star. The summer temperatures for the bedroom 1 and bedroom 2 spaces were only reduced by 1 degree in most cases and the winter temperatures only increased by 1 – 1.5 degrees. The space that showed the biggest changes from the double glazing was bedroom 2. This is because the only external window is to the south, therefore the double glazing helped to minimize heat loss through that window during winter. The effect of the additional double glazing on the Embodied Energy Estimation for this design is discussed in section 7.0.

This design was also simulated with three other scenarios; single glazed and laminated (only the windows that were already laminated as per the documentation), standard single glazed throughout, and double glazed with laminated (only the windows that were already laminated as per the documentation). Again, none of these modifications significantly affected the temperatures of the living areas and the bedrooms. It was found that the laminated glass only slightly reduced the performance of these spaces. For example with the double glazing simulations; 7.4 stars with laminated as per documentation vs. 7.5 stars with standard double glazing (applied to bedroom 1 and 2 and the living/dining/kitchen).

4.2. Bedroom 1 Study
As discussed above the percentage of time that bedroom 1 was within an acceptable thermal comfort range in winter is very low; 37% (based on monitoring data from August 2005). Using AccuRate efforts were made to investigate whether changes to construction and window size could improve this figure. Thermal mass was increased in bedroom 1 by replacing the plasterboard lining with 150mm bluestone on the southern and western walls. This had the effect of reducing the extremes of temperatures in bedroom 1, being beneficial in both summer and winter; see Figures 3 and 4. In many cases this modification made the most significant improvement to the dwelling’s performance. When thermal mass was only applied to the southern wall of bedroom 1 the star rating was 7.4, however when also applied to the western wall the star rating increased to 7.5 stars. This suggests that a large amount of heat is gained through the western wall during summer months and the application of thermal mass has moderated this heat transfer resulting in a more comfortable space. The temperatures have also increased in the winter months because of the extra thermal mass present to store the small amount of solar heat gain during the day.

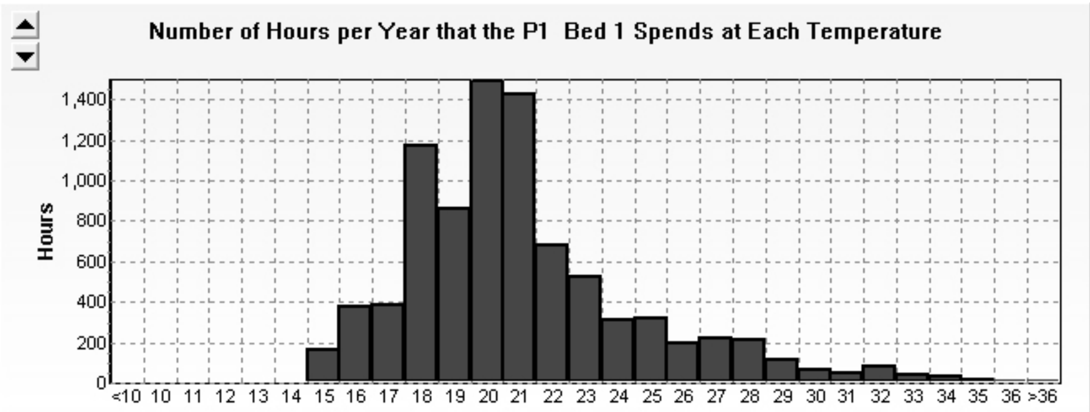


Figure 3: Temperature distribution for Bedroom 1. – Base Design (using AccuRate temperature data).

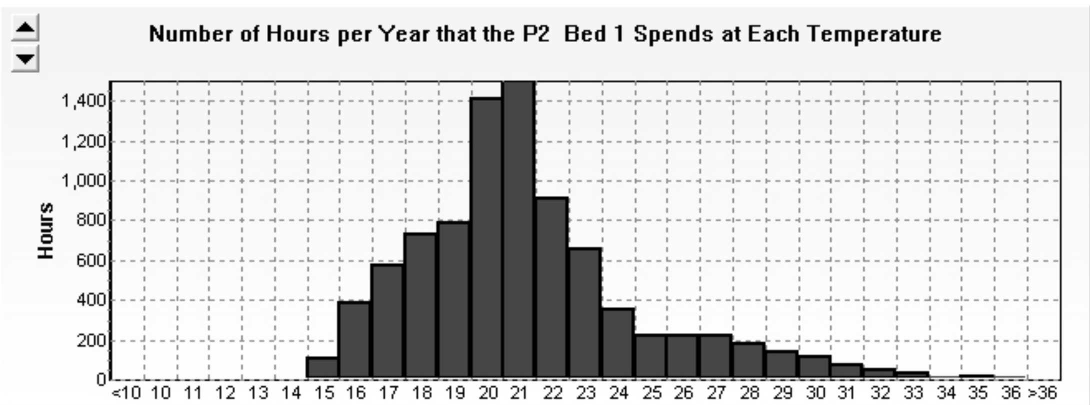


Figure 4: Temperature distribution for Bedroom 1. – Thermal Mass (using AccuRate temperature data).

Adding R2.0 batt insulation to the internal walls had only a very slight effect in raising the winter temperatures. Changes to the glazing were also simulated; (1) larger area of glazing on the northern facing walls (2) changing the glazing type from standard single glazing to standard double glazing (3) decreasing the area of glazing. All of these modifications had a negative effect on the temperature distribution, resulting in colder temperatures and therefore deemed to be unbeneficial to the occupants

4.3 Thermal Mass Modifications

Simulations were also done to test the effects on temperature of removing the stone wall in the living area. The stone wall was replaced with a Colourbond clad/plasterboard lined external wall construction. This simulation resulted in a star rating of 7.1, 0.3 stars less than the rating of the Base Design. The cooling load increases from 26.7MJm2 to 37.2MJm2 while the heating loads decreases from 33.2MJm2 to 27.8MJm2. The temperature distribution became more spread out resulting in more extreme temperatures in the living area. This is largely due to the lightweight construction of the wall which results in quicker heat transfer; therefore the indoor temperatures more closely follow the outdoor temperatures.

A simulation was also conducted to test whether the application of extra thermal mass in the living area would benefit the occupants. The wall orientated towards the south-west, originally of lightweight construction, was given a 150mm stone lining which greatly improved the performance of this space. The modification resulted in the star rating of 7.7, the highest rating of any single improvement. A reason for the high improvement may be due to the way AccuRate simulates the kitchen area; the program assumes that the kitchen (i.e., stove or appliances that produce heat) is used at certain times throughout the day. The heat that is produced by the use of the kitchen would then be stored in the adjacent stone lining to be 'released' when the temperatures drop during the night, resulting in warmer temperatures in winter. The stone would also assist in storing any solar heat gain from throughout the day.

Finally a simulation was conducted to assess the performance of brick veneer walls in this situation. The two south-western walls were changed to brick veneer. An extruded clay brick of typical density was used in this simulation as it performed slightly better than the alternative of pressed clay brick of typical density. The result was a star rating of 7.2; the temperatures were generally higher in summer and lower in winter. When this simulation is compared to that of the extra thermal mass it performs poorly, therefore it appears that when mass in applied internally or 'reversed' it is significantly more effective.

A second brick veneer alternative was simulated with all of the external walls of the dwelling replaced with a brick veneer construction. This resulted in a star rating of 7.3. The performance of the spaces due to this modification differed; bedroom 1 performed worse in summer and remained the same in winter, whereas the performance of the living area was very slightly improved when compared to the simulation of no thermal mass in this space.

These simulations confirmed the hypothesis that the living room performed better due to the presence of thermal mass; however, the impact of double glazing and internal wall insulation was in fact insignificant.

Table 2: Summary of AccuRate simulations; energy loads and temperatures for key study areas.

					MAX TEMPS.			MIN TEMPS.		
Zone	Star Rating	Cooling	Heating	Total	L/K/D S	Bed 1. S	Bed 2. S	L/K/D W	Bed 1.	Bed 2. W
Base Design	6.9	36.5	36.9	75.1	39	41	36.5	15.5	14	15.5
Glory Vine	7.4	26.7	33.2	61.5	38.5	39	36.5	15.5	13.5	15
Single/Laminated	7.1	36	29.3	67	39.5	39	36.5	15.5	14	15.5
Standard Single	7.2	35.4	28.3	65.4	39.5	39	36.5	15.5	14	15.5
Double/Laminated	7.4	24.1	34.5	60.1	37	39	36	15	14.5	15
Standard Double	7.5	29.2	26.2	57.1	38	39	36	16	14	15.5
Mass in Bedroom 1.	7.5	31.6	23.6	56.9	39	38	36	15	15	15
Addition of Mass in Living	7.7	28.3	23.4	53.3	39	39	36	16.5	14	15
No Mass in Living.	7.1	37.2	27.8	66.1	40	39	36	15	14	15
Brick Veneer in Living	7.2	37.4	27	66.1	40	39	36	15	14	15
All Brick Veneer	7.3	35.3	25	62.2	39	41	36.5	15.5	14	15.5

5. LIFECYCLE COSTING ANALYSIS

In order to assess the financial viability the different modifications presented above a lifecycle cost analysis was conducted for five of the alternatives. This was done using Life Cycle Cost Example Spreadsheet. The five different scenarios examined were; (1) Single glazing in the two bedrooms (as built), (2) Double glazing in both bedrooms, (3) Lightweight construction in the living area, (4) Stone lining construction in the living area and (5) Brick veneer wall construction in the living area. Construction cost estimations are based upon figures presented in Rawlinsons Australian Construction Handbook 2009.

5.1. Glazing Scenarios

It was found that the reduction of electricity use incurred through the use of double glazing did not justify the increased first cost of this system. The first costs combined with the present value of 30 years of electricity use of the single glazing systems is $2269, whereas the double glazing system costs $3289. The double glazing system is 45%

more expensive than the single glazing system. Therefore this alternative is not viable from a solely financial perspective.

5.2. Living Area Thermal Mass Scenarios
The lifecycle costing for the living room scenarios showed that despite significant savings in energy use the first costs of the stone lining were too great for this alternative to be feasible. The overall costs for the stone lining was $21916, 550% more expensive than the lightweight construction and 221% more expensive than the brick veneer construction. Despite this, it could be argued that the stone construction may have a longer lifespan and increased aesthetic qualities that could off-set the increased expenses. The overall costs for the lightweight construction were estimated at $3480and $6826 for the brick veneer construction.

While the two key materials studied; stone and double glazing, have not proved to be financially practical, significant increases in energy prices over the lifespan of the construction would potentially increase their feasibility in domestic construction.

This study has not considered the effect on the environment from the increased energy use of the cheaper options. However, often owners chose these more expensive options because of their perceived benefit, through a reduction of energy use and subsequent reduction in pollution to the environment, and the owners are comfortable with the extra expense incurred.

However if these materials are increasingly used in domestic construction the costs have the propensity to be reduced significantly over time. This would mean that the energy savings of more thermally efficient dwellings would have a positive impact on the environment and decrease dependency on un-renewable sources of energy.

6. EMBODIED ENERGY ANALYSIS

Using Spreadsheet for the calculation of embodied energy and CO2-e emissions of the materials in a house including replacement materials (Pullen 1995), the Embodied Energy of the design (including outdoor paving and pergola) was estimated to be 7.03MJ per m2. When comparing the EE of this design to the EE of a standard brick veneer house in South Australia it is possible to see that the EE of this design is significantly higher than that of the standard house (7.03MJ per m2 vs. 5.5MJ per m2). This higher EE estimation may be attributed to the elongated plan employed to maximise the potential of the allotment's northerly aspect. While the EE estimation is higher, the energy use for 30years (estimated life time of dwelling) of this design is significantly lower than that of a standard South Australian house standard energy use figures based upon energy load calculated by AccuRate when 5 stars are achieved (necessary rating to build in South Australia). The estimated energy use over 30 years for this design is 18.45GJ per m2, while the estimated energy use over 30 years for the standard house is 37.5GJ per m2. While the lower EE may not account for all of the energy savings (factors such as orientation and design have a significant affect) it shows that the materials used in construction can have a significant effect on the energy use over a long period of time, this is especially pertinent if the cost of energy significantly rises in the life time of the house.

While the estimated energy use from AccuRate is 18.45GJ per m2 over a 30 year period, the actual energy use would be considerably lower because the occupants do not actually use whole house heating or cooling (excluding the portable electric heater) assumed by AccuRate to provide the user with a rating. The majority of the energy used is offset by the 1500Watt Photovoltaic cells, making the house less reliant on the electricity from the grid and resulting in a more environmentally conscious and potentially sustainable home.

*Note: AccuRate does not estimate the energy use of appliances.

Table 3: Summary of total embodied energy results for the base design.

Element	MJ	%
Footings/Floor	374924.94	27.42
Roof	375678.80	27.47
External Walls	232485.91	17.00
Windows	179720.11	13.14
Internal Walls	46611.58	3.41
Doors	13367.40	0.98
Finishes	19012.78	1.39
Fitments	35216.48	2.58
Plumbing	31590.74	2.31
Wiring	3575.69	0.26
External	55168.14	4.03
Total	1367353	100.00

The method to estimate the embodied energy was based on work by Pullen (1995) using the input-output method of calculation and the Australian and New Zealand Standard Industrial Classification material figures.

The addition of double glazing to the two bedrooms (as per the AccuRate Simulation above; Standard Double) does not have a large effect on the Embodied Energy Estimation; it is only 0.02MJ per m2 higher than the base design.

The addition of the stone walls in bedroom 1 (as per AccuRate simulations above relating to improving the performance of bedroom 1) also has a very small affect on the Embodied Energy Estimations; only 0.001MJ per m2 higher than the base design. However the costs involved with the installation and materials of the stone wall would be significantly more than that of the standard plasterboard lining.

When the Embodied Energy was estimated for the Brick Veneer modifications (only applied to the south-western walls of the living area) the result was 7.2MJ per m2. This result is 0.17MJ per m2 higher than the base design, probably due to the increased production process of bricks.

7. CRITICAL ASSUMPTIONS AND LIMITATIONS

Throughout this study a series of positions have been assumed by the author and by the programs used. There are also limitations to this study that need to be brought to attention.

One of the key limitations to this study is the small sample of monitoring data taken from the subject dwelling which may reflect the results in section 4.0. The humidity was not considered when assessing the percentage of time, that key areas of study, were within a comfortable temperature range. This however was not deemed to be too detrimental to the study as Sellicks Beach is not an area that is subject to extremes of humidity. Human thermal comfort preference, tolerance and user habits were not explored in detail as information was lacking in that area, however often these factors can significantly determine the perceived thermal performance of the dwelling.

Energy use records were not available for this dwelling restricting the study of energy use to the heating and cooling loads provided by AccuRate.

The simulation program AccuRate contains within its programming assumptions such as; user profiles, kitchen use profiles, occupancy profiles and user preferences. It also fails to simulate appliance usage, i.e. lighting, water heating and entrainment systems.

It was assumed that a reverse cycle split-system air conditioning unit was to heat and cool the spaces. The predicted energy loads (from AccuRate) were the basis of calculations to assess the energy use of the different scenarios. The price of electricity, $0.17kWh, was sourced from a domestic AGL account for the period of January to March 2009. For the purpose of this exercise it has been assumed that the dwelling has a lifespan of 30 years.

CONCLUSION

In conclusion this research has found that the use of thermal mass walls and double glazing in passive house design is beneficial to the occupants in terms of thermal comfort. While stone is also favourable due to low embodied energy estimates neither it nor double glazing proved to be financially feasible alternatives over a lifespan of 30 years at current energy prices.

It was found that thermal mass in the form of stone lining in wall construction significantly improved the temperatures in the spaces where it was applied. This coupled with low embodied energy estimates shows it to be a material to consider in relation to energy efficient building envelope, however high labour costs reduce its financial feasibility.

The application of double glazing in specific areas also had a notable improvement on the temperatures; however the higher embodied energy estimations and lifecycle costs reduce the feasibility of this material in domestic construction when compared to the benefits it provided.

So while these alternatives are not currently financially feasible, the improvement to the building envelope performance that can be attributed to them will become more cost effective as energy prices increase.

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REFERENCES

Environmental Protection Agency (2008). State of the Environment Report for South Australia 08 - Human Settlement Population and Urban Form, Available from http://www.epa.sa.gov.au/soe/soe2008.html, accessed 4 February 2009.

Environmental Protection Agency [EPA]. (2008), 'The State of Our Environment: The State of the Environment Report for South Australia 2008', Environmental Protection Agency [EPA], Adelaide. pp. 204.

Lyons, P. Hockings, B. Government of Australia, (2008). Your Home - Technical Manual 4.10 Glazing. Available from http://www.yourhome.gov.au/technical/fs410.html#glazing, accessed 4 February 2009.

Pritchard, M (2005). Documentation for 'Young Residence' Sellicks Beach, October 2003.

Young (2005). Interviewed by Veronica Soebarto, tape recording. School of Architecture, Landscape Architecture and Urban Design, University of Adelaide, South Australia.

Pullen, S. (1995) Embodied Energy of Building Materials, School of Architecture, University of Adelaide, Adelaide (unpublished Thesis).

Rawlinsons Construction Cost Consultants and Quantity Surveyors Australia (2009). Rawlinsons Australian Construction Handbook 2009. Rawlinsons Publishing, Perth, Australia.