Does size matter: a comparison of methods to appraise thermal efficiency of a small house

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ABSTRACT: The Energy Efficiency provisions, within the Building Code of Australia, have created many new challenges for architects and building designers. Prior to these provisions, general environmental design principles and 'rules of thumb' were used to design environmentally conscious dwellings. As the greenhouse agenda has advanced, the architect and building designer are now faced with understanding the effects of their original environmental design training, set parameters in the deemed to satisfy provisions of the BCA and house energy rating simulations. In some situations the logic of the rule of thumb approach seems to be questioned or contradictory to the resultant star rating. This paper will illustrate a recent design experience of a small residence in Launceston, Tasmania. The new dwelling was designed by using 'rules of thumb' for passive solar and environmental design and the philosophy of making a well insulated small box. The design was submitted to a Home Energy Rating assessor for certification. The dwelling initially failed to meet minimum requirement of 4 Stars (AccuRate) to the shock of the designers. This experience caused a self-reflection by the designers of their environmental knowledge and training. This resulted in a questioning of the methods of application of the thermal performance requirements in the BCA. Do the current deemed to satisfy provisions or simulation approaches used by building certifiers encourage or exclude perceived advantageous solutions? Are these approaches being put in place for large housing and unfairly effecting smaller housing? This case study approach will compare the results of each of these three approaches to design of the above mentioned small dwelling and a typical brick veneer project homes. As educators and researchers of environmental design within a school of architecture, this experience has been significant and had an immediate effect on curriculum and research.

Conference theme: Architectural
Keywords: thermal efficiency design, measuring thermal efficiency, rules of thumb

INTRODUCTION

In Australia, over the past two decades, the average house (212.1m2) has increased in floor area by 35.2%, whereas in comparison the average number of household members is declining (ABS, a 2008, ABS, b 2008). Future projections suggest that Tasmania will have the smallest average household size by 2011, with growth only expected in the category of lone person households (ABS, c 2008). Yet, the typical new Tasmanian house in 2006-2007 period was 195m^2 and at least 70% of the existing housing stock has 3 or more bedrooms (ABS, a 2008, ABS, 2009). The greatest projected growth by 2025, across Australia will be in lone person households, it is anticipated to be between 52% and 113% (ABS, c 2008).

A study by Allan *et al* (2003) suggested that the increase in floor areas has been encouraged in Australia by the tax system that favours homeowner and property investment. To maximize returns floor areas are large. Another contributing factor cited was Australia's relatively benign climate, coupled with the low price of electricity. The paper speculated in 2003 whether the new energy efficiency requirements would influence the 'style' of houses to once again include eaves and overhangs (Allan *et al*). One other trend in Australia, which is cause for concern, is the decrease in building longevity (Pears 1998).

Energy efficiency requirements were introduced into the Building Code of Australia (BCA) in 2003. The first white paper concerning this topic was instigated in 1997 after the Kyoto Earth Summit. Research from this time indicates that Australia's existing housing stock was starting from a low base when compared to the EU and parts of the US (Pears 1998). In 2005, Australia was ranked third behind the US and Canada for the greatest level of greenhouse gas emissions (GHG) emissions per capita (WRI, 2005). The primary aim of the BCA energy efficiency requirements and the Housing Energy Rating Scheme (HERS) are to reduce GHG emissions by minimising the amount of heating and cooling required for human comfort derived from the burning of fossil fuels.

There are also health concerns indirectly influencing these requirements but they do not seem to be at the forefront of consciousness or discussed outside interested research communities. The World Health Organisation (WHO) recommends that for well-being, indoor air temperatures should be between 18 to 20°C (WHO 1987:20). Individual studies have shown when indoor room temperature drops to 16°C (Collins 2000:39) respiratory issues can be linked, whilst a further decrease to 12°C (Parsons 2003:295) may result in circulatory issues.

A review of local and overseas literature indicated a number of papers and reports that highlight concerns with HERS simulation software and deemed-to-satisfy (DTS) provisions, in terms of its:

- **reliability** to forecast conditions comparative to human occupation (Henriksen 2003). In the US a study reported the 'take back effect' phenomena. Some owners of energy efficient homes actually used more energy than expected (EIA DOE, 2007). In New Zealand it was found that there was "…no correlation between the room temperature and the house floor area, number of occupants or household income" by analyzing 100 houses (Isaacs *et al*. 2002). It is important to note that this study was carried out before multi-zone analysis was included in the simulation software;
- **reputation** to generate solutions that ultimately increases energy efficiency and reduce GHG emissions (Wedding, and Crawford-Brown, 2008, The Prince of Wales qtd in Building Science.com)
- **discrimination** against passive design solutions in temperate Australia using AccuRate software (Kordjamshidi and King 2009). Similar criticisms were made of its predecessor, NatHERs (Williamson et al, 2001);
- **accrediated energy assessors** and the **auditing** process of installation. A report in *The Sunday Times* indicated that the Building Energy Rating (BER) awards required by law in Ireland for the resale or renting of homes to be dubious. The paper engaged three accredited energy assessors who achieved three different ratings (Coyle, 2009). A comparable system operates in the Australian Capital Territory, where similar concerns have been raised in the government assembly and as a result a motion to improve the energy efficiency ratings auditing regime was passed (ACT Greens, 2009). Another example cited in Western Australia showed that a design demonstration house in Perth, initially gained 5 stars using NatHERs, 7.2 stars using AccuRate (in its testing phase) and AccuRate 1.1.4.1, 7.3 stars (Karol and McMinn, 2008, p188). One of the authors has also experienced many lengthy discussions at seminars, meetings and forums with Architects, Building Designers, HER Assessors, and Building Certifiers concerning the separation between the building design, the energy efficiency 'bits' and what is actually built. Many HER Assessors comment that not only has this been a cash flow bonus but, it has often put them in a difficult position, as they are being blamed for forcing changes in the 'Architecture'. Some Building Certifiers have found cases where the design practitioner is unaware of the impact of the HER Certificate until construction is well under way. All of these items create a difficult framework for the homeowner who is being bounced between professionals before their home plans can be sent to council. It seems from a number of anecdotal experiences that the final HER certificate differs from the house architectural documentation but the certifier places the condition that the HER certificate is to be adhered to. All of these actions are adverse to the many published examples of best practise design where the building design practitioner either has in house HER skills or works closely with an external HER assessor during the design process (Beranek 1985, Hobbs *et al* 2003);
- **determination of zones in simulation software**. Canadian research (Purdy and Beausoleil-Morrison 2001) observed "significant assumptions and choices made when inputting" data into the simulation software regarding the type and number of zones used to calculate its energy performance;
- **under-estimation of thermal bridging coefficient**. Recent study by *Kosny* and associates (2007) draws attention to the limitation of the software modelling, which is based on 'hot-box' tests, typically containing 14% framing members. In the US, the average framing ratio for housing is documented to be between 24-27%. The actual R-value of the wall is less than the currently simulated wall in software models, due to greater percentages of building framing. Steel frames significantly increased the levels of thermal bridging when compared to timber frames. In Australia, AccuRate does not take into account thermal bridging, like many other software packages around the world (Belusko, 2008);
- **industry influence?** A study in the US reports that research conducted by ASHRAE (American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc.) and the DOE (Department of Energy) "…are often modified based on requests from companies producing different building materials, consulting companies, or trade associations" (Kosny et al, 2007). Many international government and industry bodies reference research by ASHRAE; and
- **comparability of ratings, state variations and software.** Variations exist between the States and Territories regarding energy efficiency requirements, ratings and software. This raises the question, does the 'brand' and understanding of the HERS rating system become diluted due to the levels of variations.

Nearly all these issues raised above have played a part in the principle case study of this paper.

1. CASE STUDY

The small house investigated originated from a desire to design and build a compact residence that fulfilled the: contemporary living requirements of sole occupant but allowed for future expansion; primary use of local materials; reduced amounts of materials, heating costs, cleaning time and its affordability; sufficient external food production areas and proximity to the city centre. In Launceston, there was very limited housing stock that provided such alternatives from the typical 'three bedrooms, two bathrooms and double garage' model or an apartment.

The consideration for energy efficiency was made on the assumptions that a small (44m^2) insulated box, appropriately orientated to the north, including the primary living spaces and windows would more than meet the requirements set out in the BCA. The building designers had a basic awareness of energy efficiency provisions, therefore the completed design was passed to a HER assessor for certification. When the house did not meet the minimum requirement for its climate, the owner started to ask questions of fellow academics, to try and understand why. The house then went through various iterations of HER assessments and an examination of whether it met the DTS requirements of the BCA. This paper will discuss some of these iterations and there respective impact.

When considering the thermal performance and resultant GHG emissions of a new dwelling, several factors come into play. These include the U value of the building elements, the infiltration of the building elements, the zone planning of the residence and the actual size of the residence. Some of the issues discussed in this paper were raised by the HER assessor and some were not. Many are a mix of new learning by the homeowner after discussion with fellow researchers at the University of Tasmania.

As with the documentation with most new homes, the architectural documentation can be quite descriptive. A copy of the original floor plan, sub floor plan and section can be seen in figures 1 and 2.

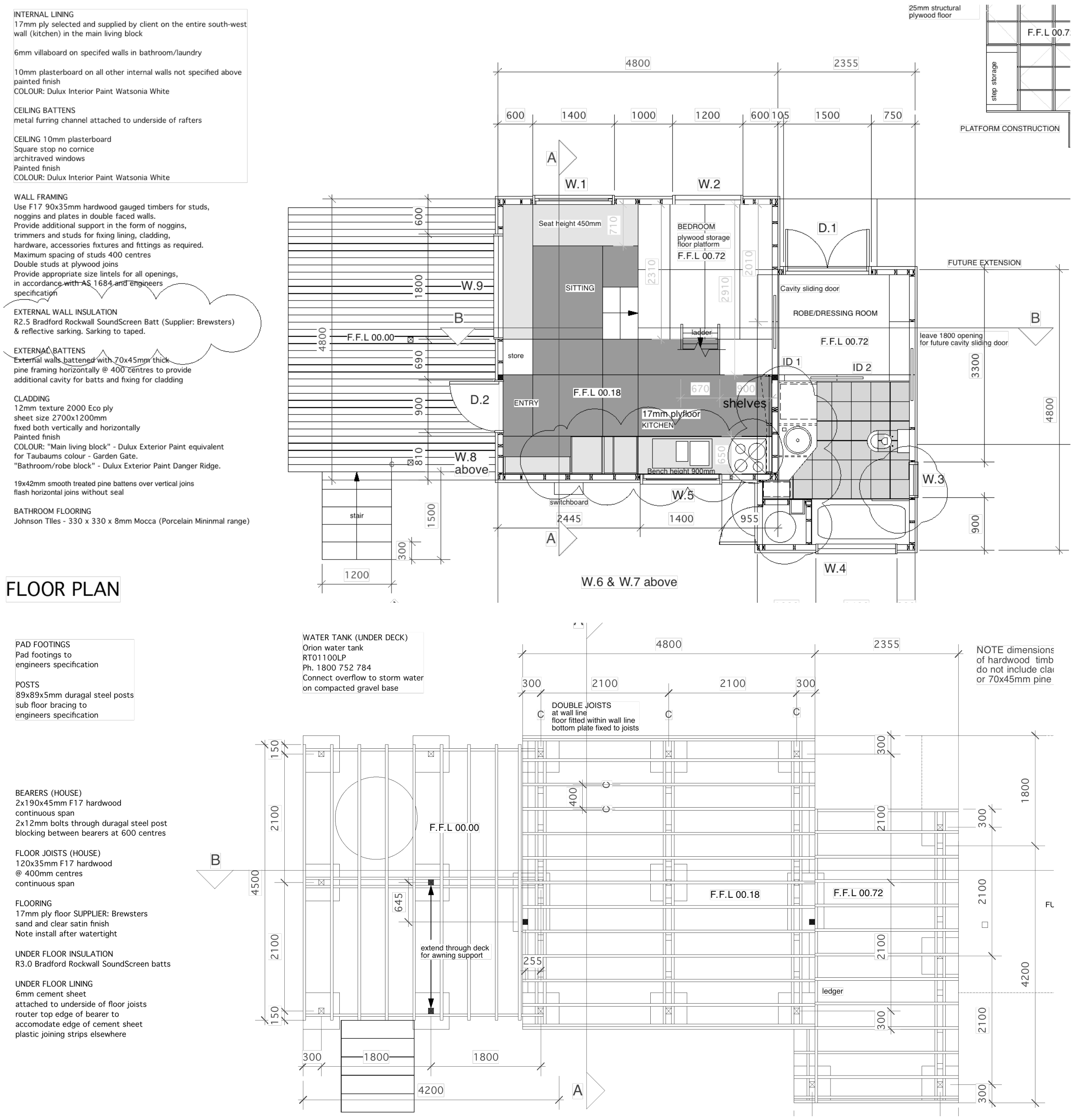


Figure 1: Case Study House: Floor plan and sub floor plan.

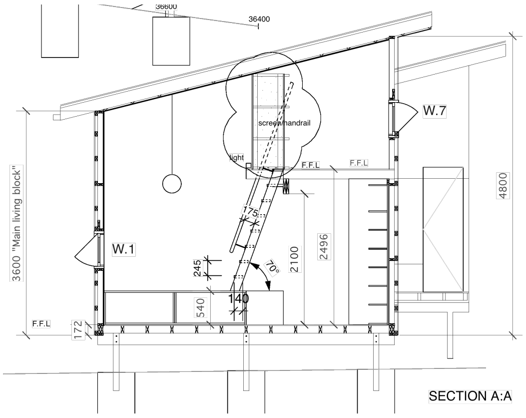


Figure 2: Case study house: section

2. BCA & PERFORMANCE REQUIREMENTS

The BCA allows for two approaches to proving a house design meets the minimum legislated requirements for Energy Efficiency. The first is to show how the design describes or documents acceptable construction practice, which meets the performance requirements of the BCA and is referred to as Deemed to satisfy (DTS). This prescriptive method of compliance is detailed within each part of the BCA. If this approach is not taken, the Alternative Solution route is the other option. An alternative solution method is used to document that the design still meets the minimum performance requirements. For Part 3.12 Energy Efficiency (ABCB 2009) the alternative solution requires the use of a detailed simulation program which operates within and produces a Star rating in Accordance with the House Energy Rating Protocol 2006 (ABCB 2006). For Tasmania the BCA requires a star rating of 4.0 stars. The main detailed simulation packages or HER software used in Tasmania are AccuRate and FirstRate. During the building certification of the case study house the alternative solution path was taken first but as difficulties arose, the DTS path was explored. The final certification was issued based on information provided through a DTS assessment. The use of DTS is becoming less common within the architect and building design profession, as the profession is gradually separating itself from the technical side of energy performance regulation and compliance.

3. HER ASSESSMENT WITH ACCURATE

The case study house is an unenclosed platform dwelling and consists of a bathroom, robe room and an open plan living, kitchen and bedroom room. What one could consider quite a simple plan, with little scope for error or misinterpretation, the series of events below show some distinct variety.

The first AccuRate assessment produced a star rating of 3.6 stars. After an initial investigation it was found that the house had been divided into eight zones and the level of insulation was as per the documentation. A series of iterative simulations (Table 1) were then undertaken to improve the star rating of the house. The fabric profile to account for the insulation that could fit into the proposed cavities was amended at some stage between version 1 and version 5. After querying of the house star rating, the plans were sent to Consultant Auditing Assessor in NSW. Based on this variety of results, one of the authors then undertook blind simulations based on original plans and then an amended version allowing for correct insulation

During this process the case study house thermal performance has varied by 1.4 stars or 31% based on assessors and software users understanding, education and methods of inputting data. If it could be presumed that the margin for error is greater in the Alternative Solution model, then a simple analysis of the DTS process may illuminate some of these variables.

4. BCA & DEEMED TO SATISFY (DTS)

Due to the difficulties being experienced through the HER process the homeowner undertook some personal research with the hope of documenting how the case study house design complied with the DTS provisions of the BCA. A simple spreadsheet approach was undertaken where the total R value of external fabric components and window type and area was listed. As with the HER simulations, one of the authors also examined the fabric profile to ascertain the designs compliance (Table 2).

The first issue to stand out is the difference between the design documentation resistance values for insulation in the walls and floor. These values vary by up to 23%. This error was corrected in the final documentation submitted to council. The bigger and more inconsistent calculation is for windows. The effective area of the windows varies by 25%, the floor area of the house varies by 45% and the resultant window to floor area ratios vary by up to 36%. These variations highlight the different understandings on how to reflect a buildings orientation and floor area in the certification process.

Table 1: Comparison of different versions of the case study house modelled in AccuRate

	Version 1	Version 2	Version 3	Version 4	Version 5	Version 6	Version 7
					(NSW Assessor)	UTas 1	UTas 2
External wall	12 Ply, 40 Air gap, R4.0 Batt, 10 PB	12 Ply, 40 Air gap, R4.0 Batt, 10 PB	12 Ply, 40 Air gap, R4.0 Batt, 10 PB	12 Ply, 40 Air gap, R4.0 Batt, 10 PB	12 Ply, 40 Air gap, R2.5 Batt, 10 PB	12 Ply, 40 Air gap, R4.0 Batt, 10 PB	12 Ply, 40 Air gap, R2.5 Batt, 10 PB
Ceiling	1 steel, 50mm Air gap, R4.0 batt, 10 PB	1 steel, 50mm Air gap, R4.0 batt, 10 PB	1 steel, 50mm Air gap, R4.0 batt, 10 PB	1 steel, 50mm Air gap, R4.0 batt, 10 PB	1 steel, 50mm Air gap, R3.8 batt, 10 PB	1 steel, 50mm Air gap, R4.0 batt, 10 PB	1 steel, 50mm Air gap, R3.8 batt, 10 PB
Floor 1	17 Ply, R4.0 Batt, 6 cement sheet	17 Ply, R4.0 Batt, 6 cement sheet	17 Ply, R4.0 Batt, 6 cement sheet	17 Ply, R4.0 Batt, 6 cement sheet	17 Ply, R3.0 Batt, 6 cement sheet	17 Ply, R4.0 Batt, 6 cement sheet	17 Ply, R3.0 Batt, 6 cement sheet
Floor 2	17 Ply, 100 Air gap17 Ply, r4.0 Batt, 6 cement sheet	17 Ply, 100 Air gap17 Ply, r4.0 Batt, 6 cement sheet	17 Ply, 100 Air gap17 Ply, r4.0 Batt, 6 cement sheet	17 Ply, 100 Air gap17 Ply, r4.0 Batt, 6 cement sheet	17 Ply, 100 Air gap17 Ply, r4.0 Batt, 6 cement sheet	17 Ply, 100 Air gap17 Ply, r4.0 Batt, 6 cement sheet	17 Ply, 100 Air gap17 Ply, r4.0 Batt, 6 cement sheet
Windows	All Timber Framed Single Glazed	Low e to W1, W2 & W9	Low e to W1, W2, W6, W7 & W9	Dble Glz W1, W2, W9 & Low e to W6, W7	All Timber Framed Single Glazed	All Timber Framed Single Glazed	All Timber Framed Single Glazed
Zones	8	8	8	8	xx	4	4
Star Rating	3.6	3.8	3.8	4	4.5	3.4	3.1

Table 2: Comparison of the different versions of the case study house using DTS requirements

Climate Zone 7	DTS Requirement (ABCB 2004)	As Per Plans	As Submitted	UTas 1	UTas 2	UTas 3
External wall	R1.9	R3.88	R3.38	R3.38	R3.38	R3.38
Roof	R3.8	R4.91	R4.71	R4.71	R4.71	R4.71
Floor 1	R1.0	R4.33	R3.33	R3.33	R3.33	R3.33
Actual Windows m2		16.20m2	16.20m2	16.20m2	16.20m2	16.20m2
Inc. North reduction		13.22m2	12.40m2	13.22m2	12.95m2	9.96m2
Floor Area		31.74m2	46.00m2	31.74m2	31.74m2	31.74m2
Window Ratio	27% Sgle Timber	42%	27%	42%	41%	31%
Comply		NO	YES	NO	NO	NO

It must be noted that all the analysis to date is on the design documentation and not as built. During the building process, of the case study house, there have been additional modifications, which are not discussed in this paper. These modifications highlight that even after extensive design documentation based analysis, the fabric of the building can be and in this was still modified with a further reduction to the values of the insulation in the walls and floor. There are also some other subtle differences in the two approaches to verification. The process of inputting data in AccuRate requires careful consideration of the buildings orientation and the software models the volume of the house. There is ample anecdotal evidence from discussions with Building Certifiers of the orientation being incorrectly documented to obtain a better star rating or to comply with the DTS provisions. The DTS provision does not consider the volume of a house. Whether the house has 2400mm ceilings or 5000mm ceilings, the same methodology of window area to floor area is adopted, whereas AccuRate will calculate the energy required to heat or cool the entire volume.

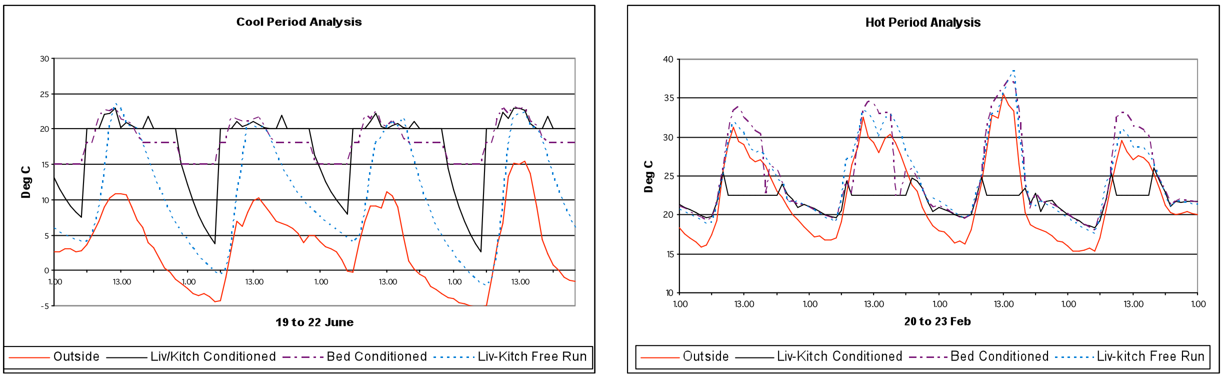
5. SOME INTERESTING ANOMALIES

The use of AccuRate as an analysis tool has many benefits. The software produces a range of reports, which include energy consumption and hour-by-hour temperature files. These files can be interrogated to examine where problems may exist in the design and what subtle informed improvements could be made to improve a buildings fabric thermal performance (Holst 2003). During this process some interesting anomalies were noticed which apply specifically to the case study house. Designed primarily as a one to two person household, it has a single volume for living and sleeping. At a design level this approach makes a lot of sense but at a thermal analysis level, there are a few problems. The problems relate to the thermostat setting for each of the zones. The protocol for house energy rating software (ABCB 2006) defines thermostat setting as per Table 3 for the Launceston climate. In this model there are differing and at times competing thermostat settings for the simulation of a single zone small house. The Figures (3 and 4) below show this conflict during a 4-day hot and cool period. During the cool period the living and bedroom are being heated to 20.0 & 18.0 deg C respectively, whilst they are in the one volume. This conflict must make for some interesting internal calculations, within the software, of heat flows between different zones co-located in a single volume. It can also be seen that the bedroom is heated overnight and that the living room receives some of this heat. As both rooms are part of the one volume, they should have a similar temperature, which would add considerably more energy consumption to the simulation. During the hot period the living zone is being cooled dramatically but a close examination of the free running and conditioned bed zones shows that there is very little coolth being transferred to the bedroom zone during its non conditioned times. In both these scenarios, the software may be giving undue advantage to the single volume building due to method used for calculating heat flows between rooms in a single volume. It also raises the issue that the software may be unsuitable for this type of house design.

Table 3: Protocol for house energy rating software thermostat setting

Zone Type	Time Period	Heating	Cooling
Living	07:00 to 24:00	20 deg C	22.5 deg C
Bedroom	08:00 to 09:00 16:00 to 24:00	18 deg C	22.5 deg C
Bedroom	24:00 to 07:00	15 deg C	22.5 deg C

Source: ABCB (2006)



Figures 3 and 4: Comparison of AccuRate Analysis of Case Study House: Cool and Hot Periods

6. BUT DOES SIZE STILL MATTER

A survey of several national and Tasmanian project house builders was undertaken to establish if there were any one bedroom houses which could be compared to the case study house. This became quite difficult as most the developers had a minimum house size of three bedrooms. After extensive searching a single developer was found that provided smaller houses up to 120m2. A summary of some of the findings are listed below:

- Developer A: of the 48 pattern book designs, no two-bedroom homes were available. Only five plans were 190m2 or less. The smallest house plan was a three-bedroom house of 153m2;
- Developer B: of the 55 pattern book designs, no two-bedroom homes were available. Only four plans were 190m2 or less. The smallest house plan was a three-bedroom house of 166m2; and
- Developer C: of the 43 pattern book designs, no two-bedroom homes were available. Only 10 plans were 190m2 or less. The smallest house plan was a three-bedroom house of 129.6m2.

An average of only 13% of homes on offer are the same size or smaller than the ABS statistics for median new house in Tasmania. The lack of one or two bedroom home plans shows that even though the number of household occupants is shrinking, the size of new homes on offer is not.

But does size matter? If the sole purpose of the energy efficiency provisions is to reduce GHG emissions, is there any relationship between the 3.1 star case study house and typical developer houses. To examine this, the mega-joules per square metre, house conditioned floor area, number of bedrooms and possible occupancy patterns need to be explored. Table 4 provides a summary of these calculations for Tasmania and New South Wales. The dramatic difference in the CO2 emissions between the two states is due to the differing proportions of renewable energy.

It can be seen that the 3.1 star version of the case study house would produce marginally more GHG emissions than the 'typical' project home. However, if the occupancy of these two homes were both for two people, the 3.1 star case study house produces as low as 34% of the GHG as the 4 star typical home and 48% of the GHG as the 5 star typical home.

Table 4: Summary of Case Study House versus Project Homes: GHG emissions

House type	Stars	mJ/m2	M21	Cond. Area	Total GJ	No. Beds	No.O cc.	GHG per person kg CO2	
								Tas #1	NSW #2
Case study V7	3.1	486.6	31.7	21.16	10.3	1	1-2	337-675	1409-2817
Case study V5	4.5	240.0	46.0	21.16	5.1	1	1-2	166-332	697-1395
Case Study #3	4.0	272	31.7	21.16	5.8	1	1-2	189-377	793-1586
Project Home A	4.0	272	153.0	95.53	26	3	2-6	282-845	1185-3556
Project Home B	4.0	272	166.0	79.8	21.7	3	2-6	235-705	989-2967
Project Home C	4.0	272	130	82.7	22.5	3	2-6	244-731	1026-3077
Project Home D	4.0	272	120	80.0	21.8	2	2-4	354-708	1491-2981
Typical Home #4	4.0	272	195	111.2	30.2	3	2-6	327-982	1377-4130
Typical Home #4	5.0	208	195	111.2	21.7	3	2-6	235-705	989-2967

#1: 63-68 kg of CO2 per GJ of electricity for Tasmania (Department of Climate Change 2009), #2: 249-298 kg of CO2 per GJ of electricity for NSW (Department of Climate Change 2009), #3: A simple analysis if the Case Study House was 4.0 Stars, #4: A typical sized new home as per ABS, a 2008

7. CONCLUSIONS

As noted "…all models are wrong, but some models are less wrong than others" Clark & Mangel 2000 qtd in Henriksen 2003:326). The authors are in support of AccuRate software despite the number of issues raised by this paper. AccuRate permits a more detailed evaluation of the volume, interaction between spaces and building fabrics and its orientation, which can be, misrepresented in the DTS provisions. Most of the problems identified in this study are related to the users more so than the actual software. The users being the: HER Assessors, Builders, Building users, Building Designers, Architects and Building Certifiers. This raises the matter of adequate education of all users of HER software, the level of appropriate documentation to adequately simulate a design and published rules on the method of converting drawings into a data set (text or graphical) for input into HER software. Another paper presented at this conference by Dewsbury and Wallis will discuss research findings regarding the HER process and residential framing practises. This study also highlights the need for 'warehouse' style and/or single volumes with multiple functions to be reappraised in the software modelling.

The objective of the energy efficiency provisions within the BCA is to reduce GHG emissions. This simple study shows that the floor area of typical new homes have not been reduced, as house sizes are increasing and occupancy rates are decreasing. The 3.1 star case study house and the typical 4 Star house use considerable differing quantities of resources during construction and operation.

A projection of future housing needs indicates significant growth in single person households, which is not reflected in the current house building trends. This research showed that the small 3.1 Star case study house may achieve significant long term reductions of GHG emissions due to the lower occupant to floor area ratio. So to revisit the question posed at the start of this paper, size does matter and it does not appear to be appropriately considered or recognized in the energy efficient provisions in the BCA.

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