An Evaluation of the Nationwide House Energy Rating Scheme (NatHERS)

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Abstract: In January 2003 Amendment 12 to the Building Code of Australia (BCA) included energy-efficiency provisions for Class 1 (detached dwellings) and Class 10 (garages, sheds and the like). In January 2007 the stringency of the BCA provisions were increased and the second generation rating tool AccuRate was introduced. There is however little evidence to support the usefulness of the regulations in meeting the objective "to reduce greenhouse gas emissions by efficiently using energy", or in simple terms, as described on the NatHERS website, "The more stars, the less likely the occupants are to need cooling or heating to stay comfortable."

This paper reports on a recent investigation to assess the effectiveness of the regulations. Energy consumption data were collected from 22 households in and around Adelaide. From this information heating and cooling energy use was estimated and compared with the House Energy Rating derived from the AccuRate software. The results are discussed and conclusions drawn on how a more effective energy-efficiency building regulation may be framed.

Conference theme: Performance
Keywords: Australian Building Code, energy-efficiency, house energy rating.

Introduction

In April 2001, the Australian Building Code Board (ABCB) released a Directions Report (ABCB 2001) that set out the overall path to be followed and issues to be considered during the development of energy-efficiency provisions to be incorporated into the BCA. This report stated that as part of the National Greenhouse Strategy the proposed energy-efficiency regulations were intended to reduce greenhouse gas emissions from the building sector which a recent estimate shows contributes around 21% of Australia's greenhouse gas emissions (AGO 2007).

In January 2003 the BCA introduced Amendment 12 that included energy-efficiency provisions for Class 1 (detached dwellings) and Class 10 (garages, sheds and the like). These BCA energy-efficiency regulations provide deemed-to-satisfy acceptable construction solutions, and verification using computer simulation software approved by the Nationwide House Energy Rating Scheme (NatHERS) administered by the Australian Greenhouse Office. In ACT and Victoria complying with the NatHERS scheme is the sole method of demonstrating compliance.

In 2006 NatHERS introduced a substantially upgraded "second generation software" package AccuRate developed by CSIRO. As of June 2007 AccuRate is the only computer software approved by NatHERS and is referred to as the reference program. *FirstRate5*, developed and marketed by the Victorian Government's Sustainable Energy Authority and *BERS Pro*, developed by SolarLogic in Queensland are in the process of accreditation.

Public Concerns

Since the regulations were introduced public concerns about their value have been raised in several quarters. For example, a recommendation of the Productivity Commission's report into energy-efficiency (October 2005) said that the Australian Building Codes Board should, as a matter of urgency, determine how effective the standards have been in reducing actual (not simulated) energy consumption and whether the financial benefits to individual producers and consumers have outweighed the associated costs. In the event the ABCB without undertaking any review decided as of 2006 that the stringency requirements would be increased. This prompted a press statement by three Federal Ministers (November 2005) that called the proposed 'five-star' energy rating seriously flawed and said "*….the ABCB have made a complete mess of the energy efficiency programme through these pre-emptive and irresponsible measures*". Questioned on this statement in a recent ABC Four Corners program (June 2007) the Federal Minister for the Environment Mr Malcolm Turnbull said "*Well, I don't want to do a running commentary on my predecessor but the five-star code is there and the Government supports it*".

Significant industry bodies such as the House Industry Association (HIA) and the National Association of Forest Industries (NAFI) have also expressed strong concerns about the current BCA regulations. In a letter to the ABCB (November 2005) the HIA said, "*HIA reiterates its strong opposition to the introduction of ill-considered and costly energy regulations……*". Apologists for the regulations characterise such statements as self-interest and lacking responsibility and leadership. However these same champions generally fail to acknowledge two important issues; first, in satisfying Government Greenhouse Policy the BCA regulations place a disproportionate burden on new home owners and those undertaking substantial renovations compared with the general population, and secondly, the possible serious distortion in resource allocation inherent in uncorroborated ineffective energy-efficiency building regulations.

The last point was highlighted in a recent report for the Victorian Department of Sustainability and Environment by George Wilkenfeld et al (2007) who said inter alia "..*the current 5 Star Requirements with regard to thermal performance are uncertain in their impacts, even for their main target (heating and cooling energy)…*" (Wilkenfeld, et al 2007, p23).

This paper addresses this particular issue: the efficacy of the NatHERS rating scheme (also described as the 5 Star Requirements) in meeting the energy-efficiency objective of the BCA.

Previous Research on NatHERS

While arguments regarding the BCA regulations and NatHERS have raged for a number of years there remains still little or no evidence to demonstrate the effectiveness of the present provisions.

Of the limited research to date most has dealt with the computer software. Prior to 2006 several studies were undertaken to examine the validity of the NatHERS computation engine CHENATH used in the first generation reference program (see for example, Delsante 1995a; 1995b). During the update and re-badging of the software with the name AccuRate the simulation engine was (again) tested using the International Energy Agency BESTEST protocol and found overall to be "very satisfactory" (Delsante 2005). Only one empirical validation exercise has however been reported that compares AccuRate results with a real building. Delsante (2006) showed that with appropriately modified inputs, AccuRate could simulate the monitored temperatures in an unoccupied mud brick house with acceptable results None of this work however addresses the effectiveness of the scheme.

Some studies have questioned the NatHERS scheme in a more general way. For example, in a parametric study Kordjamshidi, et al. (2006) suggested that in operation the NatHERS rating scheme worked to the disadvantage of designers interested in providing a building that operated on passive design principles.

Williamson et al. (2001) compared household energy consumption for heating and cooling of a sample of 31 houses in and around Adelaide with the Star Rating from the then NatHERS scheme software (confusingly called NatHERS). They found no correlation between the actual energy used or greenhouse gas produced and the NatHERS values (MJ/m^2) that determined the Star Rating. To the authors' knowledge no other research has been published that compares actual household energy of a sample of dwellings with the rating scheme.

Present Research Study

The present study expands the work of Williamson et al. (2001). Data from a new sample of 22 households also from in and around Adelaide have been collected and compared with the NatHERS scheme using the AccuRate software.

This sample of houses was derived from a database of some 220 houses that had been rated to demonstrate building code compliance (with the FirstRate program) in the period 2003-05 by the Adelaide company HER Pty Ltd, who provide an accredited rating service for various builders and developers. In each case house plans and other required details were available. Letters were first sent to the home owners describing the project and seeking their involvement. Of those expressing an interest in participating 22 houses were selected, based on continuous occupancy and length of occupancy, for interview and further data collection. Only houses where occupancy was continuous over a two-year period were selected. This provided a limited but consistently stringent sample.

Figure 1: Examples of houses included in research sample

Interviews were conducted during December 2006 with each household to collect background and energy consumption data. This included information about the house, occupants and appliances, and some open ended questions regarding energy-efficiency design intents and performance, thermal comfort perceptions and energy use patterns. Where possible each household provided the researchers with access to gas and electricity accounts which were used to compile a database of household energy consumption. In the cases where billing information was not available or incomplete, the householders gave permission to access this data from their electricity and/or gas retailer. The retailers cooperated in the research by supplying this information.

Each house was (re)-rated with AccuRate V1.1.3.0 using the original house plans and relevant additional information collected during interviews about changes and alternations.

Heating and Cooling Energy Consumption

Heating and cooling-related energy consumption was disaggregated from total consumption data using a least-squares correlation methodology described previously (Williamson et al, 2001). In this present study the results from this method were corroborated using an "energy balance" method. Here household energy consumption during spring and autumn is assumed to be a base load. Variations from the base during winter and summer periods are assumed to be due to heating and cooling appliance use. The scenario facility in MS Excel© was used as a tool to undertake this analysis. The aggregate results of the two methods were found to give good agreement, providing a high degree of confidence that the derived heating and cooling energy figures represent the actual situation. Table 1 gives a summary of the household energy consumption and other information from the sample. Examining these figures we can see that the heating and cooling reticulated energy consumption represents 31% of the total while the GHG emissions attributable to heating and cooling accounts for 33% of the total emissions. The average GHG emissions for the sample 7.5 t/household compares with the average of 7.4 t/household derived for all SA dwellings using 1996 data (AGO 1999).

Household Comfort

The NatHERS website says: "*(t)he more stars, the less likely the occupants need cooling or heating to stay comfortable*" (2007). This would imply that houses with higher star rating should have lower energy consumption for heating and cooling if comfort conditions are being achieved.

During the household interviews the occupants were asked about the perceived comfort conditions in their house with the question; "*Overall, how would you rate the thermal comfort of your living space in summer during the day?*". Similar questions covered the combinations of living/bedroom areas, daytime/night time and summer/winter conditions. The occupants were asked to respond on a 5-point scale extending from too hot to too cold with just right at interval 3. The results are shown in Table 2. The majority of respondents indicated "just right" conditions across all situations with reports of extreme conditions, "too hot" or "too cold", being relative rare. The grey cells in Table 2 indicate situations where some dis-comfort was reported and we can see that the bedroom areas are a particular concern in both winter and summer.

It is instructive to compare these results with previous research (Williamson et al. 1989) into thermal comfort conditions in Adelaide houses. This previous work indicated particular concerns for extreme thermal discomfort in priority order as - hot summer nights in bed room areas, cold winter evenings in living areas, and hot summer evenings & afternoons in living areas. By examining Table 2 it would appear that changes in house construction, or more likely, the increased penetration of fully-ducted air-conditioning systems (92% compared with the previous 16%) has ameliorated severe discomfort, particularly hot conditions in both bedroom and living areas. While some discomfort is still perceived the level seems satisfactory with an emphasis now, at least in this sample, turning to concerns for cold conditions especially in bedroom areas. However, since no statistical correlation could be detected between the level of occupant expressions of discomfort and heating and cooling energy consumption we can assume that, taken as a whole, comfort levels achieved in the houses are acceptable. The base temperatures (average internal temperatures) estimated via the least-squares method for extracting the heating and cooling usage were 16.8^{o}C for heating and 24.7^{o}C for cooling.

Table 1: Aggregated Sample Information

Average Total Floor Area	163 m^2
Average number of occupants	2.4
Average Total Household reticulated energy consumption	38472 MJ
Average heating energy consumption (Electricity, gas & wood)	7910 MJ
Average cooling energy consumption	3951 MJ
Average household GHG emission, all sources	7.5 t CO_2-e
Average household GHG emission, heating & cooling	2.5 t CO_2-e
Main cooling appliances	23% Evaporative 77% RCAC
Main heating appliances	23% Gas 77% RCAC

Note: RCAC denotes reverse-cycle air conditioning

Table 2: Occupant-Perceived Thermal Comfort Conditions

	Living Summer Day	Living Summer Night	Living Winter Day	Living Winter Night	Bed Summer Day	Bed Summer Night	Bed Winter Day	Bed Winter Night
1. Too hot	0%	0%	0%	0%	0%	0%	0%	0%
2.	5%	0%	5%	0%	27%	23%	5%	5%
3. Just right	95%	100%	73%	77%	68%	77%	68%	59%
4.	0%	0%	14%	23%	5%	0%	23%	36%
5. Too cold	0%	0%	9%	0%	0%	0%	5%	0%

Household Energy Consumption and NatHERS

In the FAQs section of the NatHERS website we find the question "*Will a house energy rating tell me how large my energy bills will be?* and the answer
"*A house energy rating is a very good guide to how much heating or cooling might be needed to keep your home comfortable. Your own heating and cooling bills will depend on how you run the house, whether you choose to install air conditioning and/or heating appliances and what types you select …..*" (NatHERS 2007)

So is the NatHERS Star Rating "*a very good guide to how much heating or cooling might be needed?"*

To assess these claims and therefore the effectiveness of the BCA provisions the predicted household energy load (MJ/m^2) using AccuRate V1.1.3.0 was compared with heating and cooling energy consumption (MJ) for the sample of houses. The AccuRate results were also compared with the heating and cooling energy consumption (MJ/m^2) normalized by the Net Conditioned Floor Area (NCFA). In both cases the possible influence of outliers that may distort the outcome of a regression analysis is examined using Cook's distance as a metric (SPSS 2004). Generally a Cook's distance greater than 1 is considered to merit closer examination in a regression analysis. For these analyses the maximum Cook's distance metric is 0.14.

The results as shown in Figures 2 & 3 show no statistically significant correlation. On this evidence the Star Rating (represented by the energy load) provides absolutely *no* guide on how much heating or cooling might be required for a home. So what does this say about the Rating Scheme? Since AccuRate assumes generic occupant preferences and behaviors this result for a particular house is perhaps not surprising. However for a sufficiently coherent sample of houses taken overall we would expect to see a correlation of similar energy indicators: that after all is what the scheme is about.

An argument often put forward for the BCA energy-efficiency regulations (and NatHERS in particular) can be characterised by the statement **"…***in complying with the energy-efficiency regulation (including achieving a higher star rating) one house will use less energy (and therefore produce less greenhouse gas emissions) than another not complying, <u>all other things being equal</u>….*".

Williamson et al (2006) pointed out the difficulties of corroborating such a statement. However, one way of tackling the problem is to compare the AccuRate energy load for a dwelling with an equivalent energy load. Such an equivalent energy load in a given climate could be considered a function of the heat flow paths through the building fabric, as well as ventilation and casual heat gains due to household usage. Proponents of NatHERS maintain that, since the present scheme is aimed at improving the quality of the building envelope, for an appropriate sample, the energy load normalised by the NCFA would show a small but significant relationship with the NatHERS Star Rating. The equivalent energy load for a household can be calculated from the heating and/or cooling energy consumption by taking into account the efficiency of the installed heating and cooling appliances (Coefficient of Performance (COP) for heating or Energy Efficiency Ratio (EER) for cooling) as shown in Eq (1).

$$EnergyLoad = EnergyConsumption * PlantEff(CoPorEER) \qquad (1)$$

For this analysis general COP/EER values were assigned according to the type of heating and cooling appliances actually installed in each house. For example, for all reverse-cycle ducted air-conditioning systems a heating COP=3.0 and cooling EER=2.8 were used. Figure 4 shows the relationship between household equivalent energy loads and the AccuRate loads. In both cases the load is the sum of the individual household heating and cooling loads. Again there is no significant correlation. Examining the heating and cooling loads separately also shows no correlation. Finally, comparing the NatHERS rating with greenhouse gas emissions attributable to household heating and cooling, as shown in Figure 5, which is the ostensive reason for the BCA regulations, again shows no strong correlation.

An Evidence-Based Scheme Examined

The assumption that dealing with the thermal performance of the building envelope should lead more or less to a reduction in energy consumption and therefore greenhouse gas emissions, all else being equal, is not supported by the evidence presented above. In an effort to improve this situation the basis for an evidence-based HERS scheme with the aim of achieving real overall energy savings or greenhouse gas emission reductions is examined.

To provide an expanded sample of houses for this investigation, the database of 22 houses was combined with 12 houses from the 2001 database making a total of 34 houses. The 12 houses were chosen because they were typical, detached and there was sufficient information to construct the input required for an AccuRate simulation.

A starting point for this investigation is the postulation that with sufficient accuracy, generic input assumptions are acceptable, for example, a single occupancy pattern of preferences and household usage, and suitable TMY climate data, can be used in the scheme. The existing AccuRate user assumptions and climate data were therefore adopted unchanged. Secondly, within the present NatHERS scheme the heating and cooling energy loads calculated by computer simulation are modified by an "Area Correction Factor". This factor is justified on the basis that "*Smaller houses have a greater surface area compared to their floor area than larger houses….. Houses smaller than 200 m^2 benefit from the correction factor and larger houses are corrected to eliminate the mathematical surface to floor area and heat flow anomaly.*" (NatHERS 2007). If actual energy consumption is to be derived then this factor must be removed from the calculation (notwithstanding the political implications). Unadjusted AccuRate load figures are therefore used in the following to derive the energy (and CO_2) estimates.

The AccuRate derived energy consumption was calculated for each house using standard heating and cooling plant COP/EERs. Figure 6 shows the relationship between this AccuRate derived and the actual heating and cooling consumption. Figure 7 shows the same relationship but for the CO_2-e emissions. In both cases we observe a respectable positive statistically correlation that indicates the viability of scheme following this methodology.

These results however when compared with the correlations shown in Figures 2-5 present something of a puzzle and could be claimed by some as justifying the present NatHERS scheme. Examining the correlation matrices in Table 3 (heating and cooling energy) and Table 4 (GHG emissions using factors (AGO 2005b) appropriate to the fuel(s) used in the houses to calculate the actual and AccuRate derived values), we can see the error of such a claim.

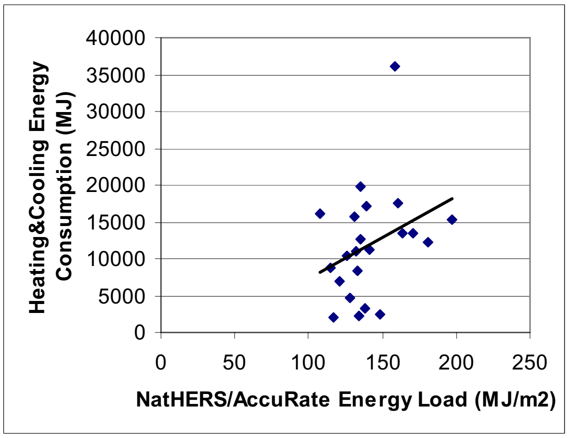

Figure 2: AccuRate (MJ/m^2) vs Total Household Consumption for Heating & Cooling (MJ)

Note: N=22, R^2=0.11, p>0.132, Max. Cook's distance 0.18

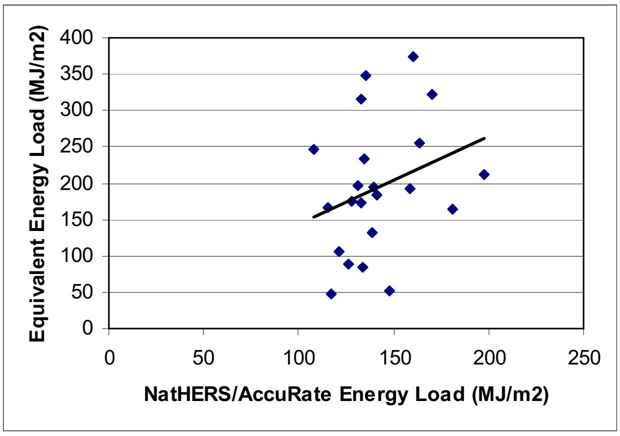

Figure 4: AccuRate (MJ/m2) vs Household Equivalent Energy Load (MJ/m2)

Note: N=22, R^2=0.088, p>0.18, Max. Cook's distance 0.164

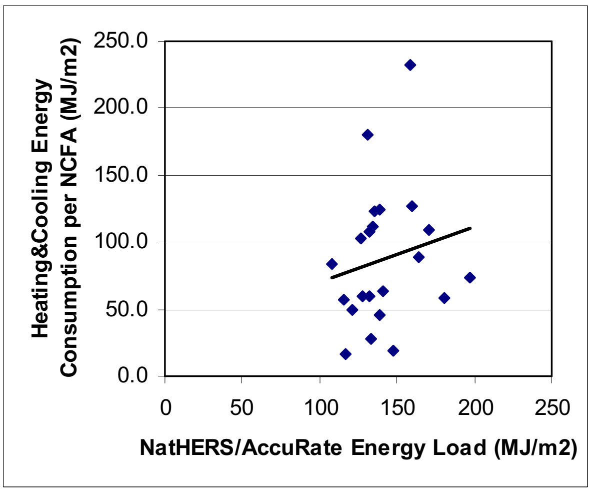

Figure 3: AccuRate (MJ/m2) vs Total Household Heating and Cooling per NCFA (MJ/m2)

Note: N=22, R^2=0.033, p>0.42, Max. Cook's distance 0.175

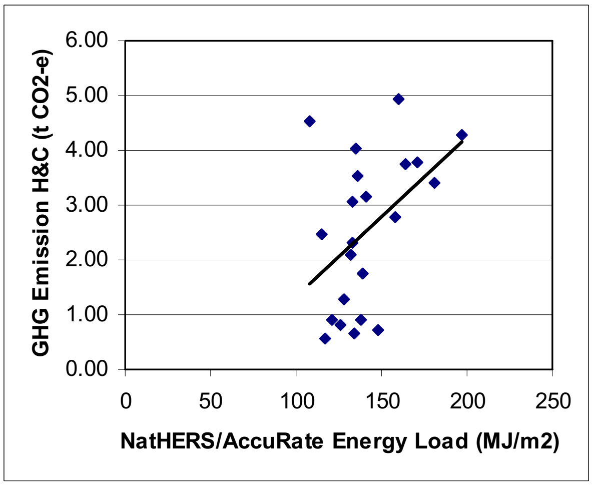

Figure 5: AccuRate (MJ/m^2) vs Total Greenhouse Gas Emission for Heating and Cooling (tonnes CO2-e))

Note: N=22, R^2=0.20, p>0.03, Max. Cook's distance 0.5

These Tables show two measures of correlation, the usual Pearson's R^2, and because rating a sample of houses implies placing them in a relative order, the non-parametric statistic Spearman's rho(ρ), similar to Pearson's correlation, that appraises the significance of the rank order of two measures.

As we have seen above for the sample of 22 houses (Figures 2-5) there is no significant correlation between the present NatHERS Star Rating (as MJ/m^2) and indices of actual heating and cooling energy consumption or GHG emission. The same is true for the expanded sample. On the other hand (as shown in Figure 6) the correlation between the AccuRate derived energy consumption and the actual heating and cooling energy use is according to both correlation measures significant (R^2=0.405, ρ=0.586). The important point to observe however is that even the correlation between the Star Rating and the AccuRate derived measure of energy use is weak and not significant. Table 4 showing the correlation matrix for GHG emissions indicates the same conclusions.

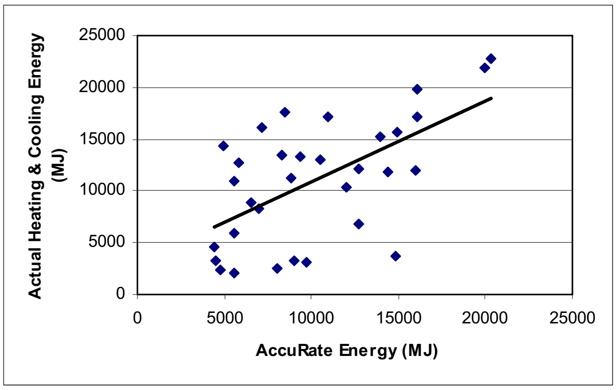

Figure 6: AccuRate derived vs Actual Heating and Cooling Energy Consumption (MJ)

Note: N=33, R^2=0.405, p<0.01

(1 outlier removed)

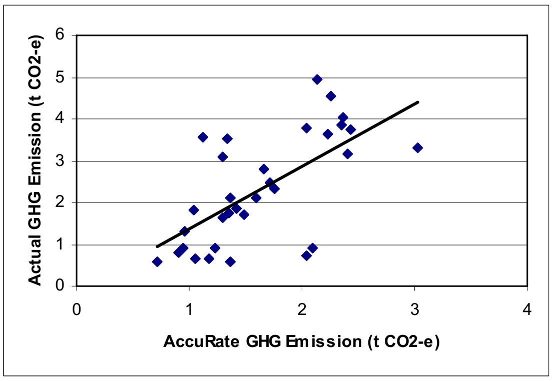

Figure 7: AccuRate derived vs Actual Heating & Cooling GHG Emissions (tonnes CO2-e)

Note: N=34, R^2=0.335, p<0.01

Table 3: Correlation Matrix for Heating & Cooling Energy, Pearson's R^2 & Spearman's ρ N=33

	AccuRate Derived Energy (MJ)	*Star Rating (as MJ/m^2)*	*Actual H&C Energy (MJ)*
AccuRate Derived Energy (MJ)	1.00	R^2 = 0.021* ρ = 0.050 p>0.5	R^2 = 0.405* ρ = 0.586** p<0.01
Star Rating (as MJ/m^2)	R^2 = 0.021* ρ = 0.050 p>0.5	1.00	R^2 = 0.012* ρ = 0.116 p>0.5
Actual H&C Energy (MJ)	R^2 = 0.405* ρ = 0.586** p<0.01	R^2 = 0.012* ρ = 0.116 p>0.5	1.00

Note: * A case with Cook's distance > 0.50 removed

** - Indicates the Spearman's correlation is significant at the 0.01 level

Table 4: Correlation Matrix for GHG Emissions, Pearson's R^2 & Spearman's ρ N=33

	AccuRate Derived GHG (tonnes CO2-e)	*Star Rating (as MJ/m^2)*	*Actual GHG (tonnes CO2-e)*
AccuRate Derived GHG (tonnes CO2-e)	1.00	R^2 = 0.059 ρ = 0.279 p>0.16	R^2 = 0.335 ρ = 0.604** p<0.01
Star Rating (as MJ/m^2)	R^2 = 0.059 ρ = 0.279 p>0.16	1.00	R^2 = 0.009 ρ = 0.207 p>0.5
Actual GHG (tonnes CO2-e)	R^2 = 0.335 ρ = 0.604** p<0.01	R^2 = 0.009 ρ = 0.207 p>0.5	1.00

Undertaking these comparisons show that there are statistically significant differences in the ranking of houses derived from each of the measures. That is, the rank of individual houses based on the Star Rating would not be the same as the rank based on the AccuRate Derived Energy. Therefore a Rating Scheme based upon AccuRate Derived Energy would be a different scheme to the present Star Rating and rank houses in a significantly different order. In relation to the BCA objective of reducing GHG emissions another important point can be made. Because no significant correlation between AccuRate Derived Energy and AccuRate Derived GHG was observed (R^2=0.024, p>0.3, ρ=0.335), a Scheme based upon energy would rank buildings in a significantly different order (and would therefore in effect be a different Scheme requiring different design decisions) to one based upon GHG emissions.

Conclusions

In a comment to the Productivity Commission's enquiry into energy efficiency the Australian Greenhouse Office said,

> "*NatHERS is not intended to measure actual energy performance of a house. Rather it measures the inherent thermal performance of the building shell* <u>*all other things being equal*</u>*. It is therefore not surprising that there is limited correlation between* NatHERS *ratings and actual heating and cooling energy consumption, although this correlation rises markedly once energy performance of appliances is adjusted for.*" (AGO 2005a)

This statement, meant to justify the present Rating Scheme, just highlights the problem. The analysis presented above using the AccuRate software does not corroborate the statement that there is "*limited correlation between NatHERS ratings and actual heating and cooling energy consumption.."*; in fact it is clear there is no significant correlation. It is not a problem with the AccuRate simulation engine per se, but rather an inherent misconception in the scheme itself. In relation to the present scheme no comfort can be taken from an improved correlation *"once energy performance of appliances is adjusted for"* because such a measure means that the rank order of the houses would be significantly different. In addition if greenhouse gas emission is the true objective of the BCA regulations (and the NatHERS Rating Scheme) then this should be dealt with explicitly and houses ranked accordingly.

In the recent report to the Victorian Department of Sustainability and Environment Wilkenfeld et al. (2007) says,

> "*Under the present 5 Star requirement, the maximum heating and cooling load of the structure is pre-determined, but the actual greenhouse emissions will depend on the outcome of subsequent decisions about energy form, equipment type, efficiency and patterns of use. The policy assumes that improving the thermal performance of the structure should lead to a more or less proportional reduction in greenhouse gas emissions, all else being equal. However, this is not necessarily the case. Setting limits or targets for greenhouse gas emissions directly would give more certain policy outcomes, while allowing applicants the flexibility to lower their compliance costs*." (Wilkenfeld 2007,p4)

Based on the evidence presented in this paper an even stronger statement suggesting that the existing policy will almost *never* result in a reduction in greenhouse gas emissions (or energy consumption or energy costs) seems justified.

However, by examining the evidence a way forward has been tentatively proposed with the present NatHERS scheme being modified to use a different indicator for ranking houses. This new indicator would be based on a non-area adjusted simulated energy load, would deal explicitly with installed heating and/or cooling appliances and be based on an estimate of actual energy consumption or alternatively GHG emissions. (For situations where no heating or cooling appliance is intended to be installed an alternative indicator, perhaps based on comfort considerations, would have to be developed). From the data presented it would seem that a single generic occupancy assumption is sufficient to give a significant result. While this is obviously the most satisfactory situation for a regulatory environment, more careful turning of the assumptions related to a specific social/locality context would most likely provide an even better match between actual and simulated values.

Adopting an explicit energy and/or GHG emission indicator as the basis of NatHERS would give integrity to the scheme and therefore reduce the doubts that the policy goals of improving energy efficiency and reducing greenhouse gas emissions are being achieved. Of course, such a possibility must be based on considerably more evidence than provided by this modest research.

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