House/Home Energy Rating Schemes/Systems (HERS)

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ABSTRACT: HERS are methods of rating the energy performance or energy-efficiency of a house by calculating (usually incorporating a computer simulation) the energy load and/or energy consumption of a dwelling for several end-uses such as heating, cooling and water heating. Inherent in all the methodologies is the assumption of 'typical' occupant-related factors such as number of people, number and use of appliances, and thermostat settings. The climate used in the calculations is also standardised for a given location. Typically a HERS rating is expressed as a number of points or a number of Stars. A house rating however, has many potential sources of error such as inaccurate calculation algorithms, incorrect assumptions about the physical properties of the building, wrong assumptions concerning the operation of the building and finally mistakes in data entry to the computer program.
Given the apparent importance placed on HERS in national greenhouse reduction policies it is surprising to find so little written about them and almost no work that investigates the claims that HERS save energy and costs and reduce greenhouse gas emissions.
This paper describes research in Australia that has attempted to correlate the rhetoric of HERS with reality. The results have possible implications for all HERS.

Keywords: energy rating, energy use, greenhouse gas reduction

1. INTRODUCTION

HERS are methods of rating the energy performance or energy-efficiency of a house by calculating (usually incorporating a computer simulation) the energy use of a dwelling for several end-uses such as heating, cooling and water heating. Typically a HERS rating is expressed as a number of points or a number of Stars. A house (or home) with a greater number of points or Stars is thought to be a 'better' house. Worldwide HERS show several variations in objectives, assessment methodologies and measurement criteria.

In the US HERS (Home Energy Rating System) are said to provide a standardized evaluation of a home's energy efficiency and expected energy costs. A home energy rating can qualify a home owner or home buyer for an energy efficient mortgage (EEM) or an energy improvement mortgage (EIM). Since the 1992 Energy Policy Act HERS are required to '… take into account local climate conditions and construction practices, solar energy collected on-site, and the benefits of peak load shifting construction practices, and not discriminate among fuel types." One such HERS is EnergyGauge® operated by the Florida Solar Energy Centre who explain,

"*HERS (Home Energy Rating Systems) provide a standardized evaluation of a home's energy efficiency and expected energy costs. A home energy rating can qualify a home owner or home buyer for an energy efficient mortgage (EEM) or an energy improvement mortgage (EIM).*" [1]

In the UK the National Energy Foundation operates the National Home Energy Rating (NHER) about which they explain,

"*Energy Rating for Homes is quite simply a way of comparing the amount of fuel that would be used by different homes assuming that the occupants live in them in the same way. A computer program can be used to give each home a score, where higher numbers indicate more energy efficient homes that should be cheaper to run and easier to keep warm.*" [2]

For European Union countries Directive 93/76 (SAVE) sought to rate energy use in buildings with the aim of stabilising or reducing CO2 emissions. The precise energy rating methodology was left to individual member states to implement. However, in January 2003 this was superseded by Directive 2002/91 with the objective of promoting the improvement of energy performance of buildings within the EU through cost-effective measures, with no compromise to comfort and Indoor air quality. This Directive makes it compulsory for energy performance certificates for new and existing buildings to be available when they are constructed, sold or rented out. Here the 'energy performance of a building' is defined as "*the amount of energy actually consumed or estimated to meet the different needs associated with a standardised use of the building, which may include, inter alia, heating, hot water heating, cooling, ventilation and lighting*." [3] [4]

Article 4 of Directive 2002/91 says, “This methodology shall be set at national or regional level. The energy performance of a building shall be expressed in a transparent manner and may include a CO2 emission indicator.” To achieve the aims of Directive 2002/91 the energy performance of a building must be expressed in criteria such as carbon emissions, energy cost and/or primary energy. The Directive requires member states to notify implementation by January 2006, but as of March 2006 only three States (Denmark, Ireland & Italy) have transposed. It is now likely that full operation of the Directive will not take place until 2009. A recent review of HERS in European countries shows that only six member States have relatively detailed HERS in operation that would comply with the Directive [5]. Of these Denmark’s energy rating system is considered to be the most complete.

In Australia a component of the National Greenhouse Strategy commits to, “develop a minimum energy performance requirement for new houses and major extensions taking into account, as appropriate, opportunities offered by existing performance measures, or ratings, such as the Nationwide House Energy Rating Scheme (NatHERS).” [6]

This scheme began operation in 1998 on a voluntary basis and in 2002 was included in the mandatory energy-efficiency requirements of the Building Code of Australia (BCA). The scheme and its software have recently undergone a major revision. The NatHERS Star rating is derived from the sum of the heating and cooling energy loads expressed in MJ/m^2 of conditioned floor area. As such the rating is intended as a measure of the energy-efficiency of the building envelope. With the desire to keep the method ‘fuel neutral’, it does not include consideration of the devices that actually use energy – heaters, coolers, water heaters and so on.

Inherent in all HERS methodologies is the assumption of ‘typical’ householders expressed by occupant-related factors in the calculation such as number of people, number and use of appliances, and thermostat settings. The climate used in the calculations is also standardised for a given location. A house rating however, has many potential sources of error such as inaccurate calculation algorithms, incorrect assumptions about the physical properties of the building, wrong assumptions concerning the operation of the building and finally mistakes in data entry to the computer program.

Given the apparent importance placed on HERS in many countries to limit greenhouse gas emissions it is perhaps surprising to find so little written about them and almost no work that investigates the claims that HERS actually save energy and costs and reduce greenhouse gas emissions. A search of journals shows only one article that investigates the accuracy of HERS [7]. In the US Stein investigated the operation of HERS, and compared the house rating against actual energy consumption. He came to the conclusion that, “… *none of the HERS we examined showed any clear relationship between overall rating score and actual energy use or cost*.” [7, p61] and noted that of the HERS examined some overestimated the gas and electricity use by as much as 100 per cent.

The following presents research in Australia that has attempted to correlate the rhetoric of the NatHERS with reality.

2. AUSTRALIAN NATIONWIDE HOUSE ENERGY RATING SCHEME (NATHERS)

2.1 Background

The Nationwide House Energy Rating scheme (NatHERS) is now implemented in most jurisdictions in Australia as a mandatory requirement. All new dwellings and substantial alterations must receive a minimum specified Star rating in order to obtain a building or planning approval. The Star rating is based on a computer simulation of the proposed dwelling using the CSIRO software engine called NatHERS. A new generation of this software, called AccuRate, is in the final stages of testing and is expected to be released by mid-2006. Work reported in this paper used NatHERS software version 2.31-2002. To produce a NatHERS rating the simulation uses a year of hourly weather data assumed to be the most appropriate to the location chosen from a database of 27 climate sets. A particular issue in developing a HERS for Australia as a whole is dealing with the large climate variations throughout the country such as hot-humid tropical, hot-dry desert to cool-cold temperate. Depending on the location, the dwelling is simulated to operate under a standard control regime. The assumed number of occupants (and associated casual loads) is altered as a function of the dwelling floor area. A recent amendment has introduced an adjustment factor to account for the bias of houses with a large floor area to rate higher because of the ratio of external wall area to surface area. The scale that relates the MJ/m^2 (sum of heating & cooling load) measure to the different Star levels was determined by each State and Territory Government being the relevant legal jurisdiction for the administration of the BCA but the basis of these decisions is not in the public domain.

2.2 Objective of NatHERS

Over the years NatHERS has received a deal of publicity in the popular and industry press. For example, an early statement in a newsletter from the Commonwealth Scientific and Industrial Research Organisation (CSIRO) quoting Government sources links the objectives of the scheme to reducing energy and greenhouse gases and cost-effectiveness:

“*The Nationwide House Energy Rating Scheme (NatHERS) will give houses a rating of up to five stars, according to their design, heating and cooling energy requirements. The scheme will reduce* <u>*household energy use*</u> *and* <u>*greenhouse gas emissions*</u> *by providing information on the design and selection of cost-effective energy-efficient housing*.” [our emphasis] [8]

While the political and other statements outlined above indicate that NatHERS is aimed at reducing energy consumption, greenhouse gas emissions and costs the “official” NatHERS documentation provides a significant semantically and methodologically different spin on the objective of the scheme. In describing the purpose of the scheme the NatHERS computer software manual says,

"*NATHERS provides a rating of between 0 and 5 stars, which shows the potential of the house to have low energy requirements for heating and cooling. The house is assumed to operate under a standard occupancy schedule appropriate for the given location. The resulting rating is based on a detailed computer simulation of the house using hourly weather data… NATHERS is designed to provide an energy rating for houses in any location in Australia…....*" *[our emphasis]* [9]

The argument for energy-efficiency regulations (and NatHERS in particular) is often characterised by the notion that in achieving a higher star rating, one house will use less energy (and therefore produce less greenhouse gas emissions) than another with a lower star rating, all other things being equal.

The common formulation (and we believe the politically intended aim) of the NatHERS objective is that, *a dwelling with a higher Star rating will on average use less energy (and produce less greenhouse gases) for heating and cooling compared to a house with a lower rating*. Such a statement, in common with other HERS, is capable of refutation by a survey of case-studies that correlate NatHERS ratings with actual annual energy consumption attributed to heating and cooling.

3. CORROBORATION STUDY

3.1 The Study

To undertake such corroboration, data were collected from 31 households in and around the Adelaide metropolitan area in South Australia. Each householder in the experiment answered an advertisement placed in the local daily newspaper inviting participants in an Energy-Efficient House Design research project. To qualify, each household had to satisfy a number of criteria; the house had to be less than ten years old and be more or less continuously occupied by a regular number of occupants with a stable use pattern over the last five years. Further, the householders had to be willing to participate in an interview and give permission for the researchers to have access to their utility accounts. The houses that qualified to be included in the study ranged in style from "solar-efficient" mud brick construction to "standard" project builder designs. Figures 1 to 4 illustrate a selection of the houses in the study. The sample included a range of floor areas, numbers of occupants, a variety of heating and cooling appliances and use patterns likely to be typical of the larger population. Apart from the fact that the participants self-selected for the project by answering the advertisement, they could be considered a random collection. In such an experiment there is no optimum number of participants. All that can be said is the greater the number, the greater will be the degree of corroboration (or lack of corroboration).

Once admitted to the study a detailed interview was conducted with the household. This interview covered issues such as household composition, dwelling construction, dwelling use patterns, energy appliances and their use, and attitudes to energy management and thermal comfort. For all cases working drawings were obtained for the house. These were checked for accuracy, modifications recorded and measured, and the position of trees and other shade causing elements noted. All details required for input to the NatHERS simulation were collected.

Figure 1: "Solar-efficient" mud brick construction

Figure 2: A standard project home

Figure 3: Housing Apartments

Figure 4: Suburban House

Each participating household signed a document giving the researchers permission to access their utility bills. This data identified;

- Electricity Consumption – Quarter number, date of issue, bill period, units used (kWh), and off peak units used (kWh) where applicable.
- Gas Consumption – Quarter number, date of issue, bill period, units used (MJs)
- Oil – Date of issue, bill period, total amount, litres

Actual household energy consumption for at least a 3-year period was obtained for each house from the appropriate electricity, gas and oil retailers. Other fuel was assessed during the energy audit and recorded. For example, fire wood consumption was identified along with the type of wood heater, how regularly this was used, the amount of wood used (tonnes per year) and the type of wood.

3.2 Heating and Cooling Energy Use

Heating and cooling related energy consumption was disaggregated from total consumption data using a least squares correlation methodology that in other research was shown to produce a good degree of accuracy.

For a household where electricity supplies both heating and cooling energy we can write,

$$a_1 x + b_1 y + c_1 z = d_1 \quad \ldots\ldots..(1)$$

$$a_2 x + b_2 y + c_2 z = d_2 \quad \ldots\ldots..(2)$$

$$a_3 x + b_3 y + c_3 z = d_3 \quad \ldots\ldots..(3)$$

..

$$a_i x + b_i y + c_i z = d_i \quad \ldots\ldots\ldots..(i)$$

Where: ***x*** = total consumption for the household attributable to heating over all periods of analysis

y = total consumption for the household attributable to cooling over all periods of analysis

z = total other household electricity consumption over all periods of analysis

a, b, c = coefficients expressing the fraction of the relevant components x, y and z for each individual period.

d = total electricity consumption for individual periods.

To estimate the coefficients ***a*** and ***b*** it is assumed that heating and cooling use (and therefore energy consumption) is climate dependent and a function of heating degree days or cooling degree days.

The over-determined system of equations formed from this data is reduced to a well-defined set of normal equations with three variables by least squares best fit. The normal equations to be solved are of the form,

$$\alpha_1 x + \beta_1 y + \gamma_1 z = \delta_1$$

$$\alpha_2 x + \beta_2 y + \gamma_2 z = \delta_2$$

$$\alpha_3 x + \beta_3 y + \gamma_3 z = \delta_3$$

The solution values of x, y and z are converted to annualized values of energy consumption by multiplying by 365/TotalDays.

4. THE RESULTS

Space in this paper precludes showing all results but Figures 5 to 7 show the main findings. Because the Star rating in NatHERS is derived directly from the sum of heating and cooling load, expressed as MJ/m^2, it is this figure, taken from each simulation run, that is compared to the actual values derived from energy use records.

NatHERS software version 2.31 was used in this study. An important aspect in generating the results was a cautious consideration of the inevitable assumptions made in fitting non-standard construction and other details to the required computer software input format. In each case, assumptions were carefully noted, and where the software manual gave insufficient or conflicting guidance, advice was sought from the software developers at CSIRO. For each household, the sensitivity of assumptions was tested in order to gain the most credible simulation result.

Figure 5 shows the relationship between the NatHERS energy load (heating and cooling summed) and the actual household heating and cooling energy consumption. The "common" expectation is that a lower NatHERS energy load (meaning a higher Star Rating) would correspond to a lower household (heating and cooling) energy consumption. This study found, however, that the data trendline and the correlation statistics indicate that no significant correlation exists.

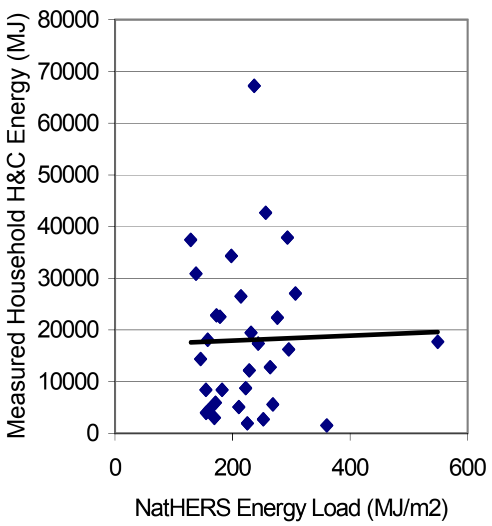

Figure 5: NatHERS (MJ/m^2) vs Total Household Consumption for Heating & Cooling (MJ)
Note: N=31, R^2=0.0007, p>0.8

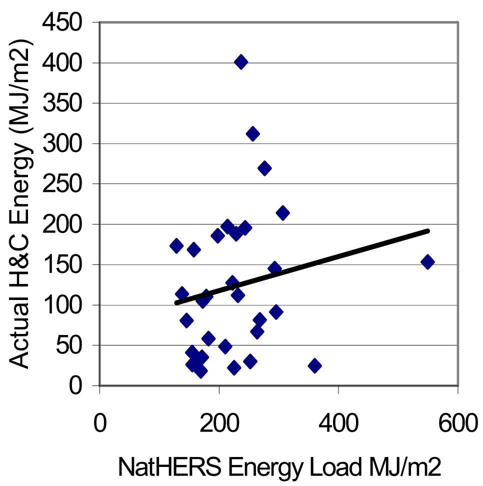

Figure 6: NatHERS (MJ/m2) vs Total Household Heating and Cooling per Conditioned Floor Area (MJ/m2)
Note: N=31, R^2=0.035, p>0.30

The second comparison, Figure 6, is with the NatHERS rating energy load (MJ/m2) and the sum of the heating and cooling consumption divided by the measured conditioned floor area. Again no significant correlation is observed. When the NatHERS rating is compared to the "measured" level of total CO_2 emissions, based on the full fuel cycle, again as seen in Figure 7, no significant correlation is observed. The negative slope means that, if anything, a higher rating could correspond to a higher emission level. These results indicate that the commonly held purpose of NatHERS, that a higher Star rating will mean reduced household energy consumption and greenhouse gas emissions, can not be corroborated. One reason for the lack of corroboration would appear to be the early decision that the rating scheme should be fuel neutral. (This decision is akin to specifying the fuel performance of a car based solely on the aerodynamic properties of the body, ignoring the engine.)

If however the efficiency of the actual heating and cooling appliances is taken into account, then a tentative NatHERS 'equivalent' site energy consumption figure can be estimated. It is tentative because it is based on fictitious occupancy assumptions (excessive heating and cooling schedule, etc) that over-estimate the "actual" energy consumption by a factor of approximately two. This 'equivalent' figure can however be compared with the actual heating and cooling energy use. A suitable statistic to measure the strength of correlation between simulated and actual is Kendall's tau_b that tests for rank correlation between the two data sets. In this case r^2=0.082 (p<0.05) meaning that over 90% of the actual variation in heating and cooling energy consumption is not assessed by the NatHERS model.

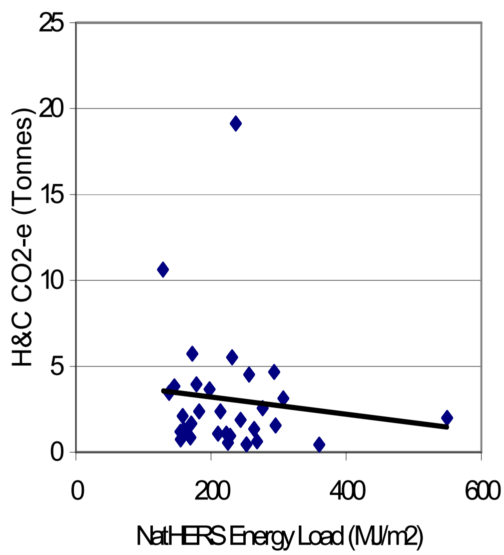

Figure 7: NatHERS (MJ/m^2) vs Total Greenhouse Gas Emission for Heating and Cooling (Tonnes)
Note: N=31, R^2=0.013, p>0.50

5. CONCLUSION

An evidence-based approach to policy making ensures firstly that the policies fit the evidence, and secondly that there is a clear link between policy objectives and outcomes [10]. There is little indication that HERS worldwide are based on robust evidence and may suffer the same problems as demonstrated with NatHERS.

In fact a likely source of paradigmatic error can be recognized in all HERS. Rather than producing policy framings on the basis of actual energy consumption, as recorded in 'real' households, policy makers and their advisors have focused on specifying the physical properties of construction (and appliances, etc) informed by data developed by simulation with the building theoretically emptied of their unruly occupants and replaced by model 'virtual' inhabitants.

Differences between theoretical results and the real outcomes 'out there' if detected are attributed almost entirely, with negligible evidence, to the 'take-back' or 'rebound' effects. Research by social scientists looking at this issue tells us, not surprisingly, that the difference most likely lies in the fact that houses are inhabited and controlled by real (not virtual) people [11]. They show that the imputed intentionality of the occupants in the simulated system inherent in a HERS in general does not exist and that thermal comfort rather than being an absolute condition for living is largely a socially constructed consumer expectation.

A recent enquiry by the Australian Government's Productivity Commission into Energy Efficiency found that, "*There is considerable uncertainty about the extent to which building standards have reduced energy consumption and emissions.*" [12, p232]

And recommended,

"*The Australian Building Codes Board should, as a matter of urgency, commission an independent* ex post *evaluation of building energy efficiency standards to determine: • how effective the standards have been in reducing actual (not simulated) energy consumption….*" [12, p237]

Such a recommendation could well be applied to all HERS.

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