Towards the development of a Home Rating Scheme for free running buildings

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Abstract

That the reduction of energy consumption in housing is one of the key components of sustainable housing strategies is well understood. House Energy Rating Schemes (HERS) have been developed for this purpose and to meet the wider objectives of Greenhouse gas reductions. However, in spite of recurring criticism, current HERS still do not deal with free running building design, arguably fundamental to encourage energy efficiency. This paper reviews the current Australian House Energy Rating Schemes and their common shortcomings. It goes on to present the necessity of introducing a complimentary basis for rating, based on free running performance and simplified comfort parameters. A particular issue is how to recognize variability of occupancies without compromising the normative nature of regulatory ratings. NatHERS has been used to simulate two main construction types (heavyweight and lightweight) of two typical residential buildings in Sydney and Canberra, in free running mode. The output annual hourly data has been statistically analyzed to determine parameters that could be considered in a rating scheme, based on both thermal comfort and energy requirements for its accuracy.

1. INTRODUCTION

The building sector is responsible for consuming about 20% - 40% of all energy consumption in many countries. ABARE (EMET, 2004) forecasts a 19.9% increase in energy consumption of the residential sector in Australia by 2014. Space heating is the largest component at 42% while the growth in cooling energy consumption (32.2%) as predicted is somewhat larger than for heating (22.2%). The growth of energy use in residential buildings points to the necessity of energy efficiency and passive architectural design.

After the Kyoto Protocol (1987) which emphasized the necessity of sustainable development to diminish energy consumption and GHG, further encouragement was given to energy efficient design in industrial products and the building sector. Numerous computer programs have been developed to estimate during the design process the energy efficiency of a building. These programs are applied to explore how design changes provide improvement measured against parameters such as decreased energy demand or improved thermal comfort. Home Energy Rating Schemes (HERS) were developed using these computer programs, to meet policy objectives to reduce energy consumption and green house gas emission.

A typical HERS provides information for assessing energy efficiency compared to archetype buildings and makes a comparison between buildings in terms of annual energy requirements. Naturally ventilated buildings cannot be rated by the current HERS. Hence, while these buildings are the best answer for energy conservation, they tend to get poor value from current rating schemes. The new generation of HERS in Australia (Accurate) accounts the positive effects of natural ventilation on the likely cooling loads of conditioned zones. However it still is unable to rate free running buildings.

It is assumed that if a building shows better free running performance in terms of thermal comfort, the energy requirement for its space heating and cooling will decrease. Moreover, a 'free running rating' scheme should encourage architects and designers toward energy efficiency in design, and to use the benefits climate responsive potential to maintain acceptable indoor temperatures for occupied spaces.

This paper reviews HERS in Australia and emphasizes the common shortcomings. In developing a framework for HRS[1] on the basis of thermal comfort, the main parameters which affect the accuracy of rating schemes have been identified. Then the sensitivity of buildings performance corresponding to those identified parameters is shown.

2. HOUSE ENERGY RATING SCHEME (HERS):

A house energy rating is a standard measure that allows the energy efficiency of new or existing housing to be evaluated, such that dwellings may be compared. The comparison basis could be the energy requirement for heating and cooling, indoor environment quality, cost efficiency or thermal comfort. HERS are widely accepted and operated in many countries. All of them are based on estimating energy requirements to provide a certificate.

In general HERS are seen as seeking a similar objective to minimum energy performance standards. Although a variety of software is applied in different countries, fundamentally they are based on simulation programs to evaluate energy efficient design. A wide range of various rating method is developed for this evaluation. The majority of methods make use of descriptive models, through which the technical data on a building is assessed and implemented in a model to simulate the thermal performance of a building. Reference climate data and standardized indoor conditions are generally utilised for the purpose of evaluation. However, research indicates that simulated results based on assumed conditions such as indoor activities and occupancy patterns can give “quite poor agreement” with the actual energy use (Santamouris, 2005).

Australian authorities developed HERS from 1990. A range of residential rating tools is available, from simple scorecards to whole building computer simulation. HERS tools predict demand for heating and cooling energy to maintain conditions of thermal comfort inside the building and rate buildings in terms of average energy consumption per square meter. Predictions are based on the extensive research and development embodied in CHEENATH, the core energy software model developed by the CSIRO for Australian climates (Ballinger, 1998). Most modelling systems, such as NatHERS, FirstRate and QuickRate, BERS, QRate and ACTHERS are based on this engine. NatHERS and BERS simulate the operational energy use in a home, while FirstRate, QRate, ACTHERS and QuickRate are correlation programs, which do not carry out simulations. ACCURate is the latest tool developed recently for HERS (Isaacs, 2005). It includes consideration of the effect of natural air ventilation on the effective indoor temperature. Although the result of ACCURate seems to be more precise compared to NatHERS, the previous shortcomings in NatHERS still apply, namely the inabilities to rate completely free running buildings.

3. SHORTCOMMINGS IN THE RATING SYSTEMS

3.1. Rating Index

The common method applied for rating buildings is normalized energy use. This index is typically derived as annual energy used divided by the conditioned floor area or volume. Based on the index a smaller house achieves a poorer value compared to a similarly constructed larger house (Thomas and Thomas, 2000), where in reality reducing house size is an effective way of reducing total energy consumption (Gray, 1998). The reason for this regressive tendency refers to a real physical phenomenon. Smaller houses have a higher proportion of envelope for a given volume; therefore the fabric heat flux per unit of floor area or volume is greater in smaller houses. Yet according to one study (Luxmoore et al., 2005), the cooling requirements of larger houses with high energy rating (5 star or more) were found to be significantly higher to those with low (3.5) star, which becomes particularly relevant in the context of predicted global warming (AGO, 2002).

[1] HERS in this paper refers to the current House *Energy* Rating Scheme. HRS refers to a House Rating Scheme that may incorporate a rating basis of *thermal comfort for free running buildings* — the main objective of the current research work.

3.2. Rating naturally ventilated buildings

One study (Soebarto, 2000), comparing the actual performance of an occupied house with the predicted performance by a rating scheme, demonstrated that although in reality the house performed reasonably well in terms of its indoor comfort condition, energy used and environmental impact, it received a low score from the rating. The reason is the inability of the rating system to assess a free running building. In his critical review of HERS in Australia, Williamson (2000) argues that the main objectives of development of HERS are therefore under question.

3.3. Occupancy scenarios

NatHERS, the rating scheme which is the subject of this study, sets a standard scenario for occupancy to simplify comparison between buildings. Living zones are usually considered to be occupied during a day for 17 hours and bed zones, 7 hours for sleeping time. This “17 hours scenario” is effectively an extremely conservative possible occupancy regime, the more especially when taken together with a completely deterministic activation of artificial heating and cooling, regardless of occupants’ behaviours or climatic seasons. Although the occupants’ behaviour is not predictable, a more realistic view might be employed to accurately evaluate a building.

Occupants’ behavior is the most significant determinant of actual energy use. It was suggested by one study that 54% of the variation of energy consumption was attributable to the building envelopes and 46% was for occupants’ behavior (Sonderegger, 1978). A similar study, (Pettersen, 1994) concluded that where inhabitants’ behavior is unknown, the total energy consumption was predicted with +15-20% uncertainty. The error for estimated heating energy use was +35-40% in a mild winter climate. A number of studies have gone further, and shown that actual energy performance depends on the way the occupants "use" the buildings and does not necessarily relate to the building design (Ballinger et al., 1991; Haberl et al., 1998). “The predicted energy use or energy cost can be off by 50% or more due to occupant behavior” (Stein and Meier, 2000).

Boland (2004) responding to the current concern about occupied times and thermostat settings, notes “the lightweight dwelling may be disadvantaged unnecessarily”. This type of building ordinarily gets lower star ratings in the current rating system, compared to the same design with heavyweight construction. However, depending on the time of occupation, a lightweight dwelling may show better performance because it responds more quickly to temperature changes. This ability, in particular for short period occupation, and especially in hot summer, is an advantage which is not addressed in a permanent “17 hours occupancy scenario”.

4. TOWARD A DEVELOPMENT OF HRS FOR FREE RUNNING BUILDINGS

Free running buildings can be evaluated on the basis of thermal comfort. Thermal comfort is affected by environmental variables such as air temperature, air velocity, humidity and the radiant environment. In naturally ventilated buildings, an adaptive comfort model is appropriate to define the comfort criteria. ASHRAE Standard 55, based on the adaptive model (de Dear and Brager, 2002) defines the range of acceptable operative temperature for naturally conditioned spaces; it does not require humidity or air velocity limits.

One cannot ignore the effect of humidity on temperature sensation in hot humid climate; however humidity is not a major factor in a moderate climate. This standard could be further extended to take account of the physiological effect of cooling, if sufficient air movement is available. Air velocity is a main parameter to moderate the effect of high temperature and high humidity. However, air movement through a house is a complex function of internal space arrangement and operable doors and windows. There is no suitable tool available to investigate cross ventilation accurately. Even if the air speed could be calculated at one point, this is not necessarily where occupants might be sitting. For these reasons, in this study temperature is considered as the main indicator of a thermally comfortable condition to define a framework for HRS on the basis of thermal comfort.

5. THE EFFECT OF SEASONAL OCCUPANT BEHAVIOR AND MULTIPLE OCCUPANCY SCENARIOS ON THE ACCURACY OF HRS

The following preliminary investigation shows the sensitivity of a rating system responding to multiple occupancy scenarios and seasonal occupants' behaviour. To find the main parameters which affect the accuracy of HRS for free running buildings based on thermal comfort two typical residential buildings, single storey (F) and double storey (S), with similar building envelopes were simulated for the Sydney climate. The investigation was undertaken for two constructions, heavyweight (H) and lightweight (L). A general description of the samples is given in table 1.

Table1. Samples description

Samples	Number of floors	Conditioned floor area(m^2)	Total floor area(m^2)	Window to wall ratio
F	1	119.9	130.4	0.28
S	2	245.1	259.9	0.23

The NatHERS software was used for simulation to investigate the performance of each conditioned zone in a particular period of time, the performance of a conditioned zone in different duration of occupancy and seasonal buildings performances. Thermal comfort temperature for free running buildings was defined as 90% occupants acceptability based on ASHRAE Standard 55 (ASHRAE, 2004) separately for each month. The degree temperature method was applied to compute the annual discomfort degree temperature hours.

6. HRS AND THE EFFECT OF SEASONS

Ignoring seasonal occupants behaviours responding to the psychological effect of cold and hot months diminishes the accuracy of HERS. To predict the annual energy requirement, in HERS it is assumed that occupants use energy to maintain indoor temperature in the comfort range, whenever the temperature is out of comfort zone. In real life, reasonably, there is no tendency from occupants to mechanically heat a space during summer (hot months) even if indoor temperature goes down for a few hours. Analogously, the opposite happens for over heating times during winter. However this issue has been ignored in the procedure of calculating or simulating annual energy demand in dwellings.

The number of heating and cooling degree hours over summer and winter respectively in the living zone for the NatHERS 17 hours occupancy were considerable (Fig. 1). The total hours for Sydney climate were significant, though the cooling degree hours during winter were not large. Also it was observed that during summer the temperature may come down from the comfort range just in the period midnight to sunrise, and in winter it may rise up around midday just for 2 or 3 hours. These two particular discomfort conditions not only are not critical but psychologically occupants may accept them as a desirable condition. To predict annual energy requirements this issue needs to be considered. To evaluate a building based on thermal comfort these times should not be considered as a discomfort condition.

The problem is obviously not unknown, but to define the relevant periods for exclusion appears to need further study. The "heating and cooling degree day method" is a common method to determine the length of heating and cooling seasons (Santamouris, 2005). But heating and cooling months differ for various climates and also may be different from seasons. Heating and cooling dates should probably be defined based on weather, or daily temperature[2], not climate data.

[2] *"Weather is the set of atmospheric conditions prevailing at given place and time. Climate can be defined as integration in time of weather conditions, characteristic of a certain geographical location."* Szokolay, S. V., 2004, *Introduction to Architectural Science: The Basis of Sustainable Design*, Architectural press,

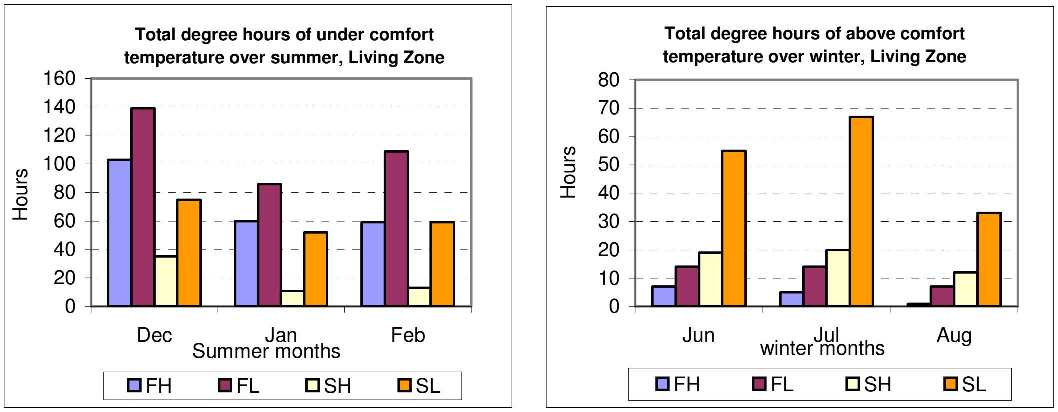

Figure1. Total degree hours above comfort range over winter and under comfort range over summer, Sydney

FH: Single story building with high weight construction

FL: Single story building with light weight construction

SH: Double story building with high weight construction

SL: Double story building with light weight construction

7. DEFINING MULTIPLE SCENARIOS FOR OCCUPANCY PATTERNS

Predicting the occupants' behaviour to incorporate in HRS is most likely impossible. Authors agree that the house itself has to be rated (Szokolay, 1992). The issue is that when buildings are unoccupied, it should not matter what the indoor condition is.

Multiple scenarios for occupancy can be defined based on probability of periods when a dwelling is occupied. It was observed that different conditioned zones at different times have different performance. This behaviour of the building depends on the orientation of a zone and the proportion of windows to the external wall. Therefore, it is important to know which zones (spaces) are occupied in a particular time.

The probability of being occupied in any one hour for each zone is 24!. A rating scheme cannot come with a large range of occupancy scenarios which have been determined based on probability of occupied time. To make it simpler, multiple scenarios can be defined based on a categorization of the time of day. It is suggested that four periods can capture the relevant major variables of occupancy: morning routine, daytime activity, evening activity and bed sleep. For this preliminary investigation, the following periods of time were assigned for each category:
0-6 6-12 12-18 18-24
In which 0 – 6 is defined as bed time for the sleeping zone.

The potential contribution of predicted discomfort degree hours to a rating can vary significantly with the duration of occupied and unoccupied period. The total discomfort degree hours in living zones over 3 different periods in the two climates were compared.

Generally between 12-18 all samples showed better day time indoor environment. However this does not contribute positively to the evaluation of a building if it is unoccupied at this time. To illustrate, it can be seen that although FH and SL samples showed same performance between 6-12, the total discomfort degree hours in SL was less than that in FH during 18-24. Hence a buildings' score may vary depended on the occupied and unoccupied periods.

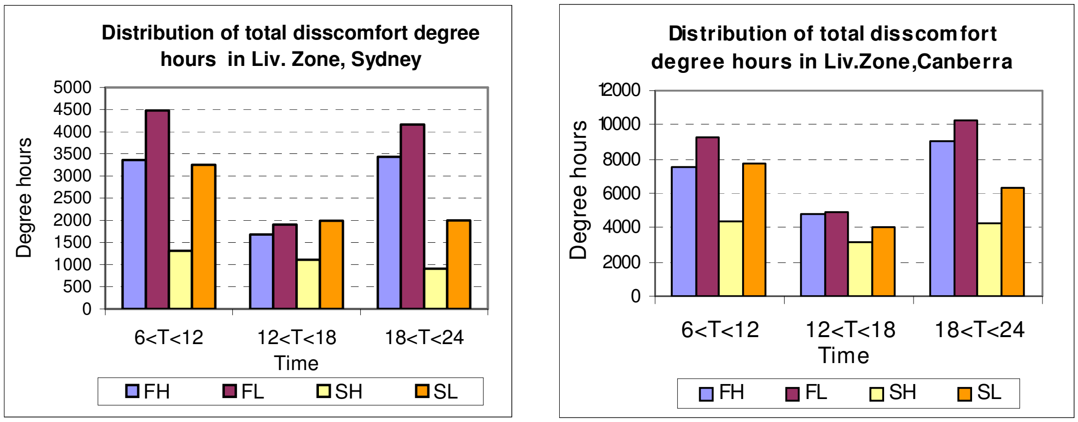

Figure2. A comparison of discomfort degree hours of each conditioned zone for different diurnal periods. For definition of terms, refer Fig. 1

The performance of each conditioned zone at the same time is also different from other conditioned zones depending on its orientation. It is desirable to have a comfortable condition in a zone when it is occupied. Depending on the occupants, notably family type, the probability of being occupied for each zone varies. Considering bed zones as occupied spaces just over the bed time is not accurate. For various family types this zone may be occupied during the day, owing to age and the occupants' occupation. For instance, a bed zone may be occupied by a teenage student at home studying, more than the living zone.

Under the "17 hours scenario" SH achieved a higher NatHERS rating in comparison to the other three samples. Figure 3 shows the performance of 2 conditioned zones between 12-18, 18-24 and 6-12. Although SH performed generally better for indoor conditions in terms of both total energy requirement (MJ/M^2) and annual degree discomfort hours, it was because of the situation and condition of the living zone. It can be seen that the result of rating generally depends on the performance of living zone. In a different occupancy scenario in which the bed zone is occupied over the day time, the result of rating may change. Therefore it is not safe to evaluate SH as a better designed and constructed sample.

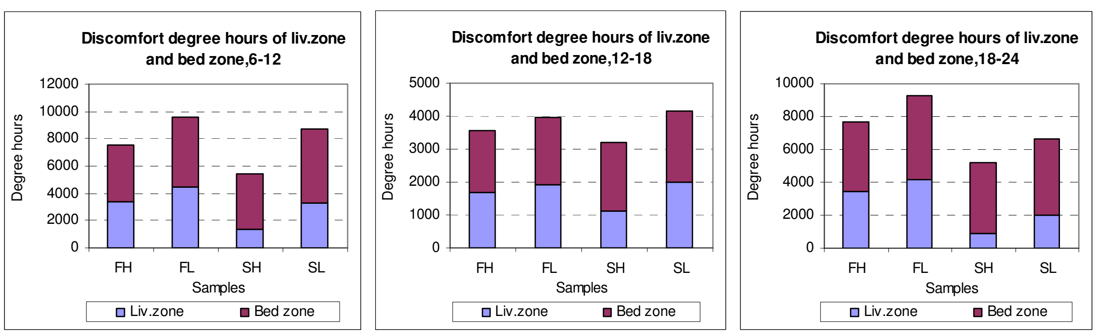

Figure3. A comparison of living and bed zone performances

Considering two main conditioned zones in a dwelling and four categories of time with 6 hours duration, 48 (2!*4!) occupancy scenarios can be defined. However not all of these would be equally valid. The sensitivity of a rating scheme based on predicting annual energy requirement and annual degree discomfort hours for six scenarios have been investigated. These six scenarios were defined based on an assumption of what may happen in reality, and are considered likely to be sufficient differentiation for rating purposes. The first one is close to the current standard scenario in NatHERS. Scenarios 5 and 6 are created to examine the probability of having better indoor conditions in the lightweight buildings under some occupancy patterns.

Table2. Occupancy scenarios (shaded cells shows the occupied times)

Zone / Scenarios	Living Zone				Bed Zone			
	0-6	6-12	12-18	18-24	0-6	6-12	12-18	18-24
Scenario 1		*	*	*	*			
Scenario 2		*	*	*	*			*
Scenario 3				*	*			
Scenario 4		*	*	*	*	*	*	*
Scenario 5		*		*	*	*		*
Scenario 6			*		*		*	

Figure 4 shows the buildings' simulated performance for the different scenarios. On some scenarios such as Scenarios 3 and 6, all samples received the same score in discomfort degree hours and energy loads, while with current NatHERS rating they achieve completely different values. For other scenarios, the relative performance changes with the change of basis of assessment. On a comfort base rating, the dwelling types could be ranked in the order SH, FH, SL and FL for all occupancy scenarios. This ranking altered for SL and FH when the basis of assessment changed to the current rating scheme (MJ/M^2). On the other hand the total energy demand for FH was less than for other dwelling types on four scenarios.

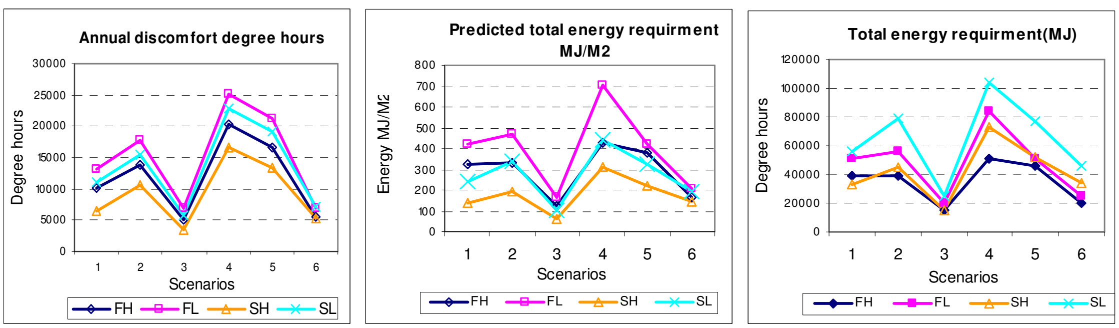

Figure4. A comparison of buildings performance for 6 occupants' scenarios on the basis of (1) annual degree discomfort hours (2) predicting annual energy requirement per square meter(MJ/M^2) (3) Predicted annual energy requirement (MJ).

This preliminary investigation suggests that generally, it is more reliable to evaluate a dwelling taking into account multiple occupants scenarios, although in a simplistic sense 17 hours occupancy may be seen as the conservative solution for a rating scheme. Determining multiple scenarios for occupancy gives an opportunity to design a dwelling more appropriate to its permanent occupants or family type. However, buildings need to be evaluated and compared to each other under the same conditions, so any rating methodology will have to include the means to combine the influence of the multiple occupancy scenarios. Although over the long time actual occupants may vary, arguably such a rating system can give more information for particular occupants to chose or amend the dwelling design in order to reduce energy consumption as far as possible.

Also, as noted previously, lightweight dwellings appear to be disadvantaged unnecessarily under the current energy load rating scheme (Boland, 2004). Depending on the time of occupation, a lightweight dwelling shows better performance because it responds more quickly to temperature changes. This attribute, for relevant short period occupation, particularly in hot summer, is an advantage which is not apparent in a fixed "17 hour's occupancy scenario".

The preliminary study showed a rating with multiple occupants' scenarios has the potential to compensate for this trend and promote lightweight constructions. While these types of buildings have advantages in terms of embodied energy and environmental impact, the current rating scheme appears to favour heavyweight constructions. In the current rating system, these types of buildings generally get higher star rating compared to a same design in lightweight construction. This phenomenon is in contrast to empirical performance evidence that claims both construction types can provide acceptable level of thermal performance (Hyde, 2000).

The preliminary investigation also showed that for some scenarios the same samples with different construction had similar performance in terms of both energy consumption and indoor temperature in naturally ventilated buildings. However, this needs more investigation by the application of other probabilistic occupants' scenarios.

8. CONCLUSION

As part of development of a framework for HRS on the basis of thermal comfort, multiple occupants' scenarios and seasonal occupants' behaviours could be taken into account to enhance the accuracy of the rating scheme. Although a building may need just a single score for both compliance and marketing purposes, the potential contribution of a rating scheme to reduce energy consumption can increase with the use of multiple occupancy scenarios for both the refined calculation of such a score, and as a consequence of better information about likely real world performance generated by the rating process.

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