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Predicted Impact of User Behaviour on Household Energy Savings

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ABSTRACT: To date government programmes to reduce household energy consumption have focussed on improving the thermal performance of the building envelope. This strategy has been underpinned by the Nationwide House Energy Rating Scheme (NatHERS). This software assumes certain temperature settings for the heating and cooling devices, and the hours of their operation. This paper describes the use of NatHERS to investigate the impact on end-use energy from changes in user behaviour. Simulations have been conducted which analyse the effectiveness of small changes in the thermostat settings of the heating and cooling devices and through reductions in their operating hours. The effectiveness of these changes is simulated for houses with 2-star and 5-star ratings. The level of end-use energy reduction is compared to that achieved by increasing levels of star rating through improvements in building envelope performance. The results of the analysis show that by encouraging small changes in the operation of household heating and cooling devices, significant reductions in end-use energy are possible. The level of reduction is often comparable to that produced by improving the thermal performance of the building envelope. Educating homeowners about the impact of their behaviour should therefore receive greater priority among strategies to reduce residential energy consumption.

Conference theme: Building and energy
Keywords: energy saving; user behaviour; thermal comfort; NatHERS.

1. INTRODUCTION
Australia’s energy consumption has risen at approximately 2.6% per annum over the last 30 years and is projected to grow by 50% by 2019-20 (PMC, 2004). At the same time, Australia has the highest greenhouse gas emission per capita in the world (Tutton, 2002). The energy used by the residential sector represents about 11.5% of Australia’s total energy use (Wilkenfeld et al., 1998). In 1995, space heating accounted for more than 40% of the energy used in the residential sector, while space cooling accounted for 1.2%. Since that time, energy use for cooling has increased.

In Victoria, for example, in the five years up to 2000, sales of air conditioners for domestic use increased by 300% (DNRE, 2002). The importance, therefore, of reducing the amount of energy used in heating and cooling homes is relevant on a national scale.

Energy rating systems can assist in the design of houses and can provide a framework for legislation via a figure of merit for new homes. In Australia, the Nationwide House Energy Rating Scheme (NatHERS) was introduced in the early 1990s. It was the result of a number of development phases, described in detail by Williamson (2000). The programme was developed to reduce the amount of energy used by new homes, and by implication, the greenhouse gases emitted by their heating and cooling devices (CSIRO, 1998). These reductions were to be achieved by improving the thermal performance of the building envelope. Ratings have been developed to inform occupants of their house’s thermal performance based on a ratio of end-use energy for heating and cooling to floor area. Thus houses built with a 5-star rating do not require as much energy for heating and cooling as a lower rated house of the same size, if conditioned in an identical way in the same location.

The NatHERS software calculates the thermal load or end-use energy (MJ m⁻² a⁻¹) to produce a certain temperature range for occupant comfort. The amount of end-use energy required for heating and cooling is determined by building design and materials, the climate, occupancy pattern and thermostat setting. The latter two variables are expressed within the NatHERS program as constants. The default setting of the standard software dictates that a temperature between 21-26°C is maintained within the whole house between the hours of 7am and midnight. Therefore, the energy rating of a house is based on the calculation that it will be kept within a temperature range of 5K for 17 hours.

In general, the promotion of the rating scheme gives the impression that a house with a higher star rating will automatically use less energy and emit less greenhouse gases than a house with a lower rating. The impact of occupant behaviour is not discussed, possibly leading to the conclusion by home-owners that the decisions they make about the operation of heating and cooling devices has little or no relevance. In Victoria, significant reductions in domestic water consumption have been achieved in recent years through a combination of financial incentives, water restrictions and public education. In 2005, Melbournians used 22% less water than the average usage in the
1990s. The hypothesis behind the analysis presented in this paper is that significant savings in energy can be made by educating homeowners, specifically about the operation of the heating and cooling devices in their homes. However, there has been no published study to assess the impact of changing the comfort zones and usage patterns to reduce a home’s level of energy use, or how resulting end-use energy reduction compares with that achieved through improving the thermal performance of the building envelope. This paper describes such an analysis using the NatHERS software.

2. NATHERS AND ACCURATE

Since its introduction in the early 1990s, the NatHERS software has been used to assess the thermal performance of Australian homes. For over 10 years the use of this software has been mandatory in many states. In April 2006, a modified version of the NatHERS programme, known as AccuRate, was released. The aim of this new programme is to address some of the limitations and criticisms of the NatHERS software (Delsante, 2005). Features of the new software include improved modelling of natural ventilation, sub-floors, roof spaces and skylights, and greater zoning capabilities.

Delsante (2005) compares the results of using the old (NatHERS) and new (AccuRate) ventilation models for two houses in Brisbane. The new model was found to reduce the cooling load on one of the houses by 23%. This variation in results between the two programmes demonstrates that some caution is required in interpreting the results shown in this paper, particularly with respect to cooling load. No comparisons of predictions of heating demand have been published. They are likely to be different particularly because of changes in the climatic data files, thermostat settings and hours of operation of heating and cooling devices in the bedrooms. The focus of this paper, therefore, is on houses located in Melbourne, where cooling demand is much lower than in the warmer climates of Australia. These climatic differences mean that houses in Melbourne consume proportionally more energy for heating than for cooling, and therefore the results obtained using the NatHERS software are still relevant. Although many changes to the earlier software have been made, it is believed therefore that the results obtained from using the original NatHERS software are still useful because they are indicative of the scale of the end-use energy reduction that can be made when non-standard user behaviour is adopted.

3. THERMAL COMFORT

A home’s energy use is largely determined by the type and operation of its heating and cooling devices. The building envelope affects the level at which these devices must be operated to achieve the thermal comfort desired by the occupants. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) defines the comfort-zone as “a range of operative temperatures that provides acceptable thermal environmental conditions or in terms of the combinations of air temperature and mean radiant temperature that people find thermally acceptable” (ASHRAE 2003). This range of temperatures is determined from values of humidity, air speed, metabolic rate and clothing insulation.

But thermal comfort is not a fixed condition, interpreted universally in the same way. Chappells and Shove (2003) argue that “connotations and realisations of comfort are culturally, historically, technically, seasonally and climatically contingent.” From this perspective, it is interesting to note that the average temperature of centrally heated homes in the UK rose from 17°C in 1950 to 20°C by 1976 (Leach, 1982). Variations between people also make it difficult to satisfy everybody’s comfort needs in any particular environment. The environmental conditions that are required to feel comfortable are not the same for everyone. In addition, and of relevance to this study, the users of a building are not passive recipients of their environment, as implied by the ASHRAE Standard. De Dear and Brager (2001) argue that this ‘static model’ of thermal comfort is inadequate, particularly in hybrid and naturally ventilated buildings, and that occupants ‘play an active role in creating their own thermal preferences’. Laboratory and field data collected by ASHRAE provided the necessary statistical data to define the conditions which 80% of occupants perceive themselves to be thermally comfortable (ASHRAE, 2003). The comfort zone for Melbourne, as defined within the NatHERS software, is between 21-28°C. Acceptable levels of thermal comfort may still be achieved, however, when surrounding temperatures are outside the prescribed range through changes in clothing level. For example, an occupant may heat their home to 20°C, instead of 21°C, and increase their clothing level to maintain comfort. However, if the temperature falls outside of the prescribed range, the likelihood of dissatisfaction is likely to increase despite adjustments in clothing.

The comfort zone settings, in terms of the temperature and hours to be maintained, are set as at default values within NatHERS. As this research required the expansion of the comfort zone it was important initially to determine the level of dissatisfaction of occupants as a result of lowering or raising indoor temperatures. In this research, it was proposed that these temperatures would be reduced in single degree increments from 21°C to 18°C at the lower band of the comfort zone, and raised in single degree increments from 26°C to 29°C at the higher band of the comfort zone. Assessing the level of comfort satisfaction, especially at temperatures of 18°C and 29°C, was critical because if occupants do not find these conditions acceptable, then possible reductions in energy consumption are irrelevant, as nobody would live in such conditions. ASHRAE’s thermal comfort program, Wincomf, described by Fountain and Huizenga (1996), was therefore used to predict the occupants’ satisfaction at these temperatures.

There are some inputs (temperature, clothing level) required by Wincomf, which are ‘known’ with certainty in the proposed scenarios, whereas others (relative humidity, air velocity, activity level) can only be estimated. The temperatures, which were evaluated for occupant comfort, were 27-29°C for summer and 18-20°C for winter. Air temperature and mean radiant temperature were assumed to be the same. Relative humidity levels of 50% were selected as an average for both scenarios. The air velocities of summer and winter were changed to reflect the realistic behaviour of keeping windows and external doors closed in winter, and open or operating a fan in summer.
The selected air velocity for winter was the minimum 0.10 ms\(^{-1}\), whereas the air velocity selected for summer was raised to 0.20 ms\(^{-1}\). An activity level (metabolic rate) of 1.2 was used in the evaluation because this rate is the equivalent activity level of standing relaxed, or slightly more than sitting and reading or writing. This level of activity remains constant between the two scenarios as it was assumed that the changes to air temperature alone should not force a change in the occupant’s behaviour.

A change in clothing level (CLO value) was the most important behavioural response of the occupant to the change in air temperature. For a cooler room, it was assumed that the occupant would wear additional layers of clothing rather than turning on the heater. Similarly, in a warmer room i.e. above 26°C, the occupant would reduce their level of clothing rather than turning on the cooling system. However, it is important that the new level of clothing required to maintain thermal comfort is realistic. The CLO value selected for summer was 0.22. This represents a person wearing briefs, t-shirt, walking shorts and sandals. The CLO value selected for winter was 1.18, which represents a person wearing briefs, t-shirt, thick trousers, long-sleeve shirt, long-sleeve sweater, thick socks and shoes. Wincomf predicts that the occupant would be generally comfortable in both scenarios. As expected, not all occupants, however, would remain comfortable in the revised conditions. In winter, the highest the level of Predicted People Dissatisfied (PPD) was 10%, whereas in the summer the dissatisfaction level increased to 16% (Table 1).

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>PPD (%)</th>
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<tbody>
<tr>
<td>18</td>
<td>10</td>
</tr>
<tr>
<td>19</td>
<td>7</td>
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<tr>
<td>20</td>
<td>5</td>
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<td>27</td>
<td>5</td>
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<tr>
<td>28</td>
<td>7</td>
</tr>
<tr>
<td>29</td>
<td>16</td>
</tr>
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4. EXTENDED STAR RATING SYSTEM

The star-rating method is currently used to determine the thermal performance of a home. The scale ranges from 0 to 5 stars and increases in half star increments. A zero star rating means that the house has a poor thermal performance, while a five star home is regarded as one of higher thermal performance. The star-ratings equate to different levels of end-use energy within the various states of Australia due to the different climates which affect both the performance of a building and the need to use heating and cooling devices to maintain the internal temperature to within the predetermined comfort zone. Currently Victorian regulations require that a newly-built house must conform to a rating of five stars. The average Victorian house is rated at just below two stars (DPC 2002).

![Figure 1: Relationship between end-use energy and star rating](image-url)
This rating system does have one limitation, which affects the comprehension and comparison of the results described later in this paper. While it is possible to compare the exact values of end-use energy, it would also be convenient to be able to compare the results of the simulations using the rating scale. This is because the impact of changing occupant behaviour can then be readily understood in the terms that are now commonly used in the market place. Unfortunately, the current star-rating scale has a maximum value of five stars. Thus any changes made to the operation of a 5-star house to reduce end-use energy would still be regarded as a 5-star house. To overcome this limitation, the current values of end-use energy and corresponding star-rating for houses located in Melbourne, as used by the NatHERS software, were plotted and a curve was fitted (Figure 1). This was then used to determine the values of end-use energy corresponding to further increases in star rating, up to 9.5, in half-star increments. Table 2 shows the annual end-use energy (MJ m\(^{-2}\) a\(^{-1}\)) and the corresponding star rating values determined using the above procedure and referred to in later discussion in this paper.

<table>
<thead>
<tr>
<th>End-use energy (MJ m(^{-2}) a(^{-1}))</th>
<th>Star Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>340</td>
<td>2</td>
</tr>
<tr>
<td>310</td>
<td>2.5</td>
</tr>
<tr>
<td>280</td>
<td>3</td>
</tr>
<tr>
<td>255</td>
<td>3.5</td>
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<tr>
<td>230</td>
<td>4</td>
</tr>
<tr>
<td>208</td>
<td>4.5</td>
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<tr>
<td>185</td>
<td>5</td>
</tr>
<tr>
<td>163</td>
<td>5.5</td>
</tr>
<tr>
<td>147</td>
<td>6</td>
</tr>
<tr>
<td>132</td>
<td>6.5</td>
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<td>119</td>
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<td>107</td>
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<td>96</td>
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</tr>
<tr>
<td>84</td>
<td>8.5</td>
</tr>
<tr>
<td>78</td>
<td>9</td>
</tr>
<tr>
<td>70</td>
<td>9.5</td>
</tr>
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</table>

5. METHOD

A single storey 152 m\(^{2}\) brick veneer house design was chosen for this analysis. The insulation levels in the house were decreased or increased to represent a typical 2- or 5-star home respectively. Using the same house design and only varying the insulation levels limited the possibility that other unknown factors in the house design might influence the results and hence comparisons. The end-use energy of these 2- and 5-star homes was then predicted assuming that they were located in Melbourne.

Four sets of simulations were carried out. In the first set, the lower and upper thermostat settings were changed. The lower setting i.e. when the heating would commence was lowered progressively by one, two and three degrees. Heating would therefore only be provided if the house temperature fell below 20°C, 19°C and 18°C respectively. The upper setting i.e. when the cooling device would operate was increased progressively also by one, two and three degrees. Cooling would therefore only be provided if the house temperature rose above 27°C, 28°C and 29°C respectively.

In the second set of simulations, the hours of operation of the heating and cooling devices were changed from the default setting. The hour at which heating and cooling devices were turned "on" was delayed progressively by one, two and three hours respectively. Heating or cooling thus commenced at 8am, 9am and 10am respectively. The devices were turned "off" using the NatHERS default setting of midnight.

In the third set of simulations, the NatHERS default starting time i.e. 7am was restored but now the hour at which heating and cooling devices were turned "off" was advanced progressively by one, two and three hours respectively. Heating or cooling thus terminated at 11pm, 10pm and 9pm respectively.

In the fourth set of simulations, the effect of reduced hours of operation of both heating and cooling devices was combined. This meant that operating hours of the heating and cooling devices was progressively reduced from the default setting of 17 hours to 15, 13 and 11 hours respectively. The results of these simulations are discussed in the next section of the paper.

6. RESULTS

6.1. Melbourne 2-star house

Figure 2 shows how effective changing the thermostat setting of the heating and cooling devices can be to reduce end-use energy in a 2-star house located in Melbourne. In all cases, the changes proved to be of some significance and were shown to reduce end-use energy. In judging the effectiveness of adjusting the thermostat of either the heating or the cooling device, it is evident that in terms of the thermal load, reducing the heating device thermostat
setting by one degree saves more end-use energy than increasing the cooling device thermostat setting by one degree. In approximate terms, every 1°C that the heating thermostat setting is reduced from the default setting, the end-use energy reduction is the equivalent of that achieved by increasing the house’s rating by one star. As a result, reducing the heating thermostat from 21°C to 18°C enables the 2-star home now to have the same level of thermal load as would occur if the house had been upgraded to a 5-star home and operated at the default thermostat settings.

![Figure 2](image)

Figure 2: Effects of adjusting thermostat in a 2-star house in Melbourne

A similar trend in results was predicted when changes were made in the thermostat setting of the cooling device. However, the reduction is less significant than that achieved by altering the heating device thermostat. This result could be expected in the southern Victorian climate because using the NatHERS default conditions, the cooling load was only about 28% of the heating load. As expected, when both the heating and cooling device thermostats are adjusted, a higher reduction in the overall conditioning load is achieved than occurs when only one strategy is adopted. In a society where it appears to be difficult to persuade people to save energy, it is encouraging to see that simply by adjusting the thermostat a single degree in each direction enables a 2-star house to have the equivalent end-use energy of a 3.5-star house. The thermal load is reduced by approximately 73 MJ m² a⁻¹ by a single adjustment.

![Figure 3](image)

Figure 3: Effects of adjusting operating times in a 2-star house in Melbourne
The results of the simulations for the 2-star Melbourne house with reduced operating hours for the heating and cooling devices indicate that this is not such an effective strategy to reduce end-use energy as adjusting the thermostat set-points. Figure 3 indicates that by waiting for the full three hours every day before turning the devices "on", an end-use energy reduction equivalent to a single star can be made. Tuning the devices "off" earlier can achieve a similar reduction. As a result, combining both strategies i.e. by turning "on" the devices three hours later and "off" three hours earlier results in the in a thermal load equivalent to that of a 4-star house with unchanged occupant behaviour. These results are perhaps counter-intuitive, at least in the minds of some homeowners. Statements such as "going to bed earlier in winter to save energy" are sometimes heard. However, the results of the simulations suggest that in Melbourne at least the end-use energy reduction is likely to be less than that achieved by small adjustments to the temperature settings of the heating or cooling devices.

6.2. Melbourne 5-star house
The 5-star Melbourne home represents the current mandatory level of thermal performance required for newly-built houses in Victoria. It is important to judge what effects changing user behaviour may have on the end-use energy in these new homes. As in the case of the 2-star Melbourne home, an adjustment of the thermostat of the heating device results in greater reductions in end-use energy than adjusting the cooling device by the same amount (Figure 4). In fact, changing the heater thermostat settings proved to be nearly twice as effective in reducing the thermal load as changing the settings on the cooling device. By adjusting the heating thermostat by the full three degrees, the reduction in end-use energy is the equivalent to a gain of two stars, raising the house to a hypothetical 7-star rating level. Changing the cooling device thermostat setting only resulted in an equivalent end-use energy of a 6-star design.

Figure 4: Effects of adjusting thermostat in a 5-star house in Melbourne

Figure 5 shows that turning the heating or cooling device "on" later and "off" earlier has a small impact on the end-use energy of the 5-star home. By turning the heating device "on" later, approximately 10 MJ m\(^{-2}\) a\(^{-1}\) is saved per hour, and after a three hour delay the reduction in end-use energy is only the equivalent of a half-star increase in the rating of the home. The results for the decreased operating hours of the cooling device were even less significant. The end-use energy is reduced by approximately 12 MJ m\(^{-2}\) a\(^{-1}\) when the operation of the cooling device is delayed by three hours. This reduction is insufficient to change the rating of the 5-star house. Reducing the operating time by three hours at both the start and end of the default period reduces the thermal load by 42 MJ m\(^{-2}\) a\(^{-1}\). This represents 22% of the total heating and cooling end-use energy under default conditions. This reduction in end-use energy increases the rating of the house to six stars.
7. CONCLUSIONS
In 2004, the Victorian Government introduced an energy-rating scheme for new homes. The current requirement is that all new homes must achieve a 5-star rating. Considerable effort and financial investment has been made to implement the scheme. This has included the development of software, training and an accreditation system for raters. This effort and expense continues with the introduction of AccuRate, which requires retraining of raters in the workings of a more complex programme. Implicitly, great emphasis has been placed on the role of the building envelope to reduce energy consumption.

There are many methods of reducing household energy use, such as increasing thermal mass, natural ventilation, shading and increasing insulation levels. Most of these strategies are already being used to reduce household energy consumption. The quality of housing construction also plays a key role in energy reduction as do the energy efficiency of the heating and cooling devices. However, occupant behaviour is also an important factor, which is currently not being adequately addressed.

The aim of this paper was to compare the effectiveness of small adjustments in user behaviour to achieve reductions in end-use energy, which could be used together with current methods of increasing energy efficiency, and to reduce energy consumption even further. Six adjustments to user behaviour were simulated for two houses of different star ratings located in Melbourne to determine the level of end-use energy reduction. These reductions were compared to houses with unaltered behaviour. Adjustments were made in thermostat setting and device operating times.

It was shown that altering the thermostat setting achieved a much greater reduction in end-use energy demand than adjusting the devices’ operating hours at the start or end of each day. The thermostat setting adjustment is also considered to be the most achievable because the change in user behaviour would effectively be spread evenly throughout the day, only marginally expanding the comfort zone. Making changes to the operating pattern of the conditioning devices, however, would leave the occupant without heating and cooling for between one and six hours each day. It was also shown that there appears to be no advantage in advocating either of the energy saving strategies for houses with either a low or high star rating. Houses of both 2-star and 5-star ratings were shown to benefit from the changes in user behaviour.

Recently, the Victorian Government launched an advertising campaign to encourage homeowners to reduce their household energy consumption (Age, 2006). One of the aims of the campaign is to encourage householders to use heaters and air-conditioners more wisely. The results reported in this paper indicate that there is scope to achieve significant energy savings by altering occupant behaviour. In some cases, these are equivalent to the reduction predicted by upgrading from a 2-star to a 5-star home. It is to be hoped that the Government recognises the importance of educating occupants about these opportunities to reduce energy use. Ultimately, it will be only be low energy users that will make low energy homes successful.

REFERENCES
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