

## Overheating risk in the Australian Nationwide House Energy Rating Scheme: A case study of Adelaide

Gertrud Hatvani-Kovacs<sup>1</sup>, Martin Belusko<sup>2</sup>, John Pockett<sup>2</sup> and John Boland<sup>3</sup>

<sup>1</sup> *School of Information Technology and Mathematical Sciences, University of South Australia, Mawson Lakes, Australia*

*gertrud.hatvani-kovacs@mymail.unisa.edu.au*

<sup>2</sup> *Barbara Hardy Institute, University of South Australia, Mawson Lakes, Australia*

*martin.belusko@unisa.edu.au, john.pockett@unisa.edu.au*

<sup>3</sup> *Centre for Industrial and Applied Mathematics, University of South Australia, Mawson Lakes, Australia*  
*john.boland@unisa.edu.au*

**Abstract:** Heatwaves are Australia's most deadly natural hazard and the principle driver of peak electricity demand in South Australia. The disproportionately high peak demand increases electricity prices, causes occasional blackouts and exacerbates energy poverty, all of which limit the use of air-conditioning. Meanwhile, the desire for more energy efficient homes may decrease their heat stress resistance. This paper challenges whether the current Australian Nationwide Energy Rating Scheme encourages heat stress resistance.

Cooling consumption, peak demand and the risk of indoor overheating were assessed for a typical single-storey home in Adelaide. Design scenarios between 6 and 8 stars, plus two additional, traditional building structures were simulated with the AccuRate building thermal simulation program. A new overheating analysis is proposed based on the combination of the Excess Heat Factor and the Adaptive Comfort Model. Although the uninsulated, double brick scenario required significantly more heating, that configuration also outperformed many scenarios with higher star ratings during summer. A higher star rating did not necessarily coincide with a decrease in cooling consumption, demand and overheating. Consequently, the integration of heat stress resistance in the Nationwide Energy Rating Scheme would be advantageous to avoid building new homes with potentially lower coping capacity and increased dependence on air-conditioning.

**Keywords:** Housing; energy rating scheme; indoor overheating; heat stress

### 1. Introduction to heat stress resistant buildings

Heatwaves are not just the most dangerous natural hazard to health in Australia (Coates et al., 2014) but they are also responsible for the annual peak electricity demand in cooling-focused regions (Santamouris et al., 2015). Peak electricity demand increases the risk of power outages, depriving the population of air-conditioning (AC) (Maller and Strengers, 2011). Higher and more frequent peaks drive increases in

electricity prices (Saman et al., 2013) and that aggravates energy poverty. Energy poverty refers to the 'situation of low-income households paying more than 10 per cent of their disposable income to meet energy costs' (Chester and Morris, 2011, p.443). Meanwhile, more than one third of deaths between 1956 and 2010 in Australia recorded as heat-related occurred indoors. This proportion has been rising since the 1850s (Coates et al., 2014), showing the importance of the indoor environment.

Consequently, more attention has recently been paid to heat stress resistant buildings to minimise indoor overheating and heat-related health problems (Dengel and Swainson, 2012). This is particularly so, since climate change will decrease heating and increase cooling consumption and the risk of indoor overheating (Karimpour et al., 2015; Mavrogianni et al., 2015). In general, energy efficient retrofitting can decrease the overheating risk (Alam et al., 2016) particularly in very inefficient homes. However, energy efficiency can also interfere with heat stress resistance (Zuo et al., 2014). For example, high levels of insulation and air-tightness can foster overheating in summer (Ren et al., 2014; Dengel and Swainson, 2012) without a comprehensive design leading to both energy efficiency and heat stress resistance. Heat stress resistant features include shading (Porritt et al., 2013), more reflective roof colour (Cotana et al., 2014), reflective foil in the roof cavity (Saman et al., 2013), slab-on ground compared to elevated structures in warmer climates (Lapisa et al., 2013), ceramic floor covering (Karimpour et al., 2015), orientation (Porritt et al., 2013) and increased natural ventilation (Daniel et al., 2015).

The first energy efficiency measure, the Nationwide House Energy rating Scheme (NatHERS) was introduced in the Australian Building Codes, now called National Construction Codes (NCC), in 2003 (Australian Building Codes Board, 2016). The NatHERS classifies buildings with stars from 0 to 10, based on the predicted annual energy consumption. The minimum requirements for new buildings have been raised gradually to six stars by 2010. As research has shown that energy efficiency with inappropriate design can decrease heat stress resistance (Porritt et al., 2013; Dengel and Swainson, 2012), NatHERS can be potentially counterproductive to heat stress resistance. Further research should be undertaken to understand the impact of NatHERS on heat stress resistance in the Australian climate considering Australian building construction practices.

It has to be acknowledged that overheating is mostly under regulated worldwide (Mulville and Stravoravdis, 2016). Considering countries of the European Union, Sweden does not regulate overheating, while many countries have only recommendations, such as the UK and the Republic of Ireland (Kontonasiou et al., 2015). Where overheating is regulated, indoor temperatures are limited (Brussel, Denmark and France), or maximum solar gain (Germany, Poland) or the maximum differences between indoor and outdoor temperatures in summer (Hungary) have to be met (Kontonasiou et al., 2015). No example was found where a building is rated according to not just its energy efficiency but also its heat stress resistance.

Based on the research gap identified, this paper aims to (1) evaluate whether the NatHERS encourages heat stress resistance in new residential buildings (2) and compare their resilience with traditional construction methods in Adelaide. Adelaide, with a population of near 1.3 million (Australian Bureau of Statistics, 2015) is the capital city of South Australia (SA). Adelaide has had heatwaves with the highest intensities (Nairn and Fawcett, 2013) and the highest normalised heat-related mortality within Australia since the middle of the 19th century (Coates et al., 2014). The Adelaide metropolitan region was selected for the data analysis, as a city suffering from regular, severe heatwaves.

## 2. Analysis method of different design scenarios

A second generation NatHERS energy simulation software, called AccuRate, was used for performance compliance analysis. A limitation of AccuRate is that the typical meteorological year (TMY), which mostly excludes weather extremes such as heatwaves, is applied. An especially hot period of time was selected for analysis, nevertheless, which is included in the TMY file for Adelaide in the middle of February.

### 2.1. Design scenarios

A typical single-storey home with floor area of 211 m<sup>2</sup> has been modelled by AccuRate, in free-running mode, to assess the building performance during summer without AC. The building design chosen was adopted from an earlier report (Saman et al., 2013). Investigating the existing residential building stock in Adelaide, the most frequent wall structure material is brick veneer, followed by double brick (Australian Bureau of Statistics, 2008). This ratio of wall structure types is the result of a shift from double brick (also called cavity brick walls) to brick veneer walls in the late 1970s (Pullen, 2007), resulting in the loss of thermal mass. The loss of thermal mass in walls was, nevertheless, compensated to some extent by the longitudinally rising popularity of slab-on-ground structures used in brick-veneer homes. More than 90% of the residents own AC (Australian Bureau of Statistics, 2014). Double glazed windows are still rarely used and the average level of energy efficiency is low in the existing building stock.

As the long-term, aspiration is a gradual increase of energy efficiency in the NatHERS, a shift is expected in new residential buildings to 7 stars in the next decade. Within this study, 6 design scenarios between 6 and 8 stars were created, with extremely cooling and heating-dominant scenarios under each star rating. Two additional scenarios were included to reflect the traditional, uninsulated double brick and brick veneer construction types. These scenarios and the configuration of design features are listed in Table 1.

Table 1 Design features applied in the design scenarios

Design features	2.6 stars (double brick)	2.6 stars (brick veneer)	6.2 stars (cooling-dominant)	6.2 stars (heating-dominant)	7.1 stars (heating-dominant)	7.2 stars (cooling-dominant)	8.0 stars (cooling-dominant)	8.0 stars (heating-dominant)
Roof colour, material (total solar absorptance)	light metal (0.30)	light metal (0.30)	dark, concrete tiles (0.75)	white, concrete tiles (0.25)	white, concrete tiles (0.25)	dark metal (0.75)	dark metal (0.75)	white, concrete tiles (0.25)
Foil in roof	NIL	NIL	NIL	yes	yes	NIL	NIL	yes
Roof insulation	NIL	NIL	NIL	NIL	NIL	NIL	R2	R2
Ceiling insulation	NIL	NIL	R4.0	R4.0	R4.0	R4.0	R4.0	R4.0
External wall	double brick with cavity	brick veneer	brick veneer, R2.5	brick veneer, R2.5	brick veneer, R2.5	brick veneer, R2.5	brick veneer, R3.5	reverse brick veneer, R3.5
Foil in wall	NIL	NIL	NIL	NIL	NIL	NIL	yes	yes

<b>Internal walls</b>	brick	plaster board	plaster board, R1.5	brick	brick	plaster board, R1.5	plaster board, R2.0	plaster board, R2.0
<b>Windows</b>	single, clear glazing	single, clear glazing	single, high solar gain (U=5.4 W/m2K)	single, low solar gain (U=5.6 W/m2K)	double, low solar gain (U=3.0 W/m2K),	double, argon, high solar gain (U=2.90 W/m2K)	double, high solar gain (U=2.0 W/m2K),	double, low solar gain (U=2.0 w/m2k),
<b>Roller shutters</b>	in western bedrooms	NIL	NIL	in western bedrooms	in western bedrooms	NIL	NIL	all rooms
<b>Floor slab</b>	suspended timber floor	slab-on-ground	slab-on-ground	slab-on-ground	slab-on-ground	225 mm waffle pod	225 mm waffle pod	slab-on-ground
<b>Floor covering</b>	timber	ceramic & carpet	ceramic & carpet	ceramic & carpet	ceramic & carpet	ceramic & carpet	ceramic & carpet	ceramic only
<b>Fan</b>	NIL	NIL	NIL	NIL	NIL	NIL	NIL	in main rooms

## 2.2. Heat stress resistance analysis of the scenarios

To evaluate overheating risk three approaches were applied. Firstly, the annual cooling energy consumption of each scenario was calculated and graphed against the energy star rating. Secondly, the procedure was repeated for the peak cooling demand. AccuRate calculates the hourly peak load demand, however, predicated on the assumption that the capacity of the cooling system is infinite. Consequently, the peak demand was calculated from the three-hourly running mean, which is more representative of the capacity of a real cooling system (Saman et al., 2013). Thirdly, the numbers of hours with discomfort were assessed. To evaluate the overheating risk, a north-facing bedroom was selected since beyond its poor orientation, overheating risk in a bedroom can be particularly dangerous, because of both the lower temperatures required for sleeping and the deprivation from sleep due to thermal discomfort.

Note that several static and adaptive overheating thresholds exist and are used in different jurisdictions at the time of writing. All thresholds have been developed based on perceived comfort instead of the corresponding health implications (Dengel and Swainson, 2012). Two approaches exist to determine overheating, namely the static and the adaptive thresholds. The traditional static thermostat set point stipulates one threshold for cooling and heating each. Although the static threshold is simpler to use, they have been widely criticised in case of free-running and mixed-mode ventilated buildings, for neglecting adaptation and acclimatisation (Nicol et al., 2012). In contrast to the static thresholds, an adaptive set point changes with the outdoor temperatures, based on the adaptive comfort model (ACM). ACM has been validated globally and implemented in the standard of the American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE),(ASHRAE, 2010). The ACM was, furthermore, validated for residential mixed-mode ventilated buildings in Australia (Saman et al., 2013). This paper adopted both static and adaptive overheating thresholds. The AccuRate AC set point of 25°C, defined for Adelaide, was adopted as the static threshold. To increase the accuracy of the adaptive comfort model, a version of the model based on the exponentially weighted running mean of the recent 7 days was adopted (Morgan and de Dear, 2003). The indoor thermal conditions, furthermore, were assumed to be perceived

as acceptable by 80% of the occupants, in line with the ASHRAE standard. With these assumptions the ACM applied here allowed for indoor temperatures between 30-31 °C during the designated heatwave, which is notably higher than the 28.9 °C calculated for February based on the ACM from ASHRAE.

To connect indoor overheating risk with its health implications, a novel combination of standard thermostat set point temperatures and a heatwave intensity factor was used. The excess heat factor (EHF) was devised by Nairn and Fawcett (2013) to assess the heatwave intensity and predict the excess number of mortality and morbidity cases during heatwaves. The EHF is calculated as the deviation of the daily mean temperatures over the most recent three days compared to the recent thirty days and the 95<sup>th</sup> percentile of the recent thirty years, considering long-term acclimatisation. The unit of the EHF is °C<sup>2</sup>. A more elaborate description of the calculation is provided in an earlier study (Hatvani-Kovacs et al., 2015). The EHF was validated as a superior predictor of excess mortality (Langlois et al., 2013) and morbidity (Hatvani-Kovacs et al., 2015) in Adelaide. The EHF can also better differentiate days with excess morbidity compared to normal summer days than earlier weather metrics used (Hatvani-Kovacs et al., 2015). Consequently, the EHF was used to identify days with higher than average health risk due to the elevated indoor (and outdoor) overheating. To assess the intensity of the heatwave included in the TMY, the 95<sup>th</sup> percentile of the recent 30 years was adopted from an earlier study (Hatvani-Kovacs et al., 2015). The strength of the heatwave analysed from the TMY between 12<sup>nd</sup> and 17<sup>th</sup> February, identified as days with positive EHF, was in the average range, considering the range of heatwaves since 1970s in Adelaide (Nairn and Fawcett, 2013). Note that heatwave days, calculated as days with positive EHF are usually lagged by 2-3 days behind compared with the peak in daily maximum temperatures.

### 3. Results and discussion

Firstly, the ratios of cooling and annual energy consumption were compared across scenarios (**Error! Reference source not found.**). Since the star rating is based on annual energy consumption, a home with 6 stars could have nearly the same cooling energy consumption as an energy inefficient double brick home with 2.6 stars. A scenario with 7.2 stars, meanwhile, used more energy for cooling than a scenario with only 6.2 stars. Similarly, one scenario with 8.0 stars used almost twice as much energy for cooling as a scenario with only 7.1 stars. To summarise, star rating did not indicate the cooling energy consumption of a building.

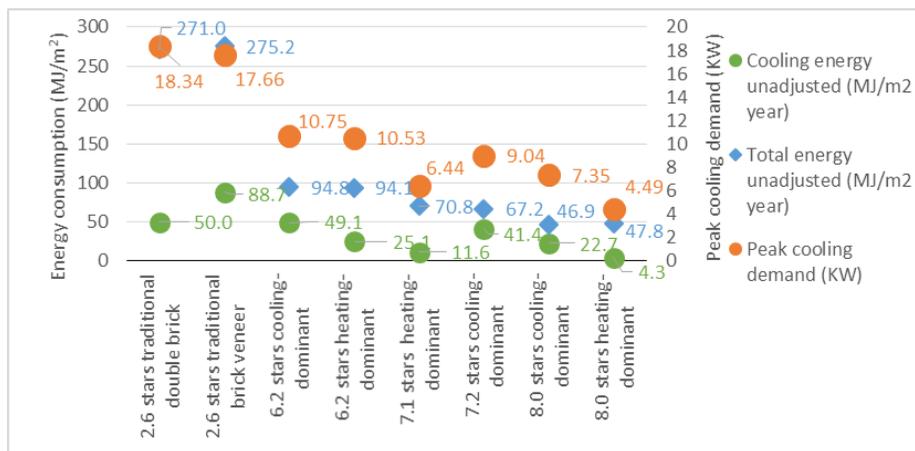


Figure 1: Total annual and cooling energy consumption and cooling demand of different scenarios

Secondly, the peak cooling demand was compared in **Error! Reference source not found.** across the scenarios. Although the double brick home had a higher peak cooling demand than any new construction with 6 or more star ratings, a home with 8 stars had a higher peak demand than a home with 7.1 stars. An increase in the star rating did thus not necessarily result in a decrease in peak demand.

Thirdly, the numbers of hours with discomfort was evaluated in the selected north-facing bedroom, considering the whole year. Figure 2 shows that overheating in most of the buildings with 6 stars or above was higher than in a traditional home with only 2.6 stars. Three homes with 6, 7 and 8 stars even reached indoor temperatures above 35 °C. The indoor temperatures in the north-facing bedroom was investigated further during the heatwave period. Heatwave days were identified from the TMY as days with positive EHF<sub>s</sub>. The highest EHF<sub>s</sub> occurred on 15<sup>th</sup> and 16<sup>th</sup> February, indicating the highest level of heat-related hospitalisation, when indoor overheating can potentially be the most dangerous. Figure 3 demonstrates that indoor temperatures in the bedroom would be higher in many scenarios with 6 stars or more than in a traditional double-brick home with only 2.6 stars. If AC was not available, overheating would, nevertheless, occur across all scenarios, on each day of the heatwave according to the static threshold of 25 °C (Figure 3). The highest levels of indoor overheating occurred on the first and second days, simultaneously with the outdoor temperature peaks. On the most dangerous third and fourth days, scenarios with the 8 stars and the double brick home only exceeded the static but not the adaptive thresholds. Meanwhile all other scenarios also exceeded the higher adaptive threshold. Indoor temperatures, nevertheless, remained the most above the static overheating threshold in the double brick homes and the least in the brick veneer home, at night during the most dangerous days. This result can be explained by the thermal inertia of the building mass and the missing insulation, showing that thermal mass can be counterproductive at night, during long heatwaves.

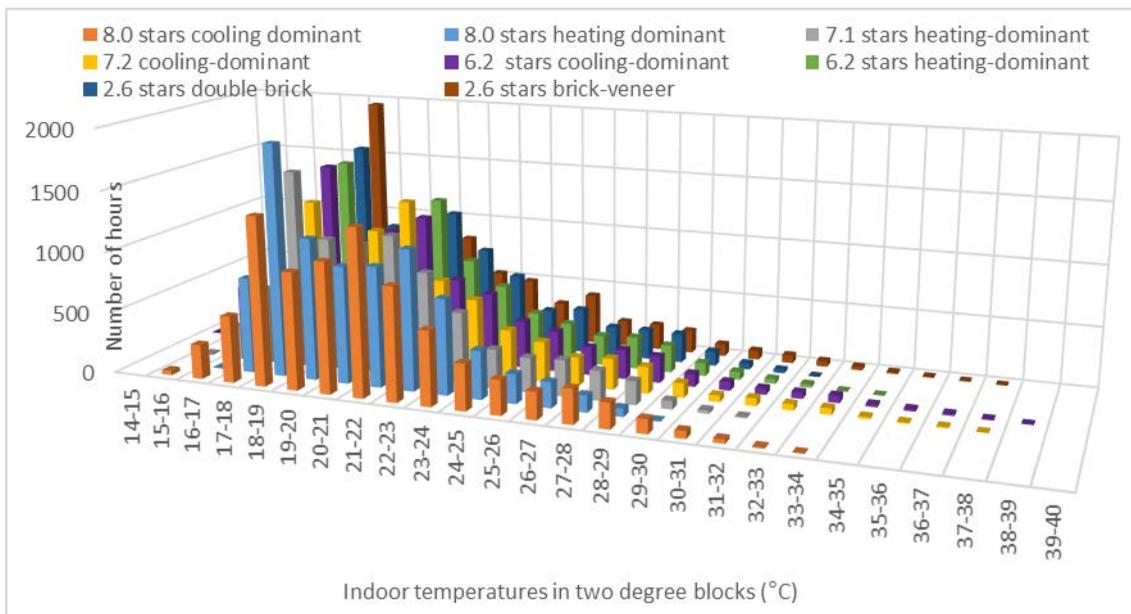


Figure 2: Overheating analysis of a north-facing bedroom for the whole year

These results demonstrate that the negative impact of thermal mass on overheating is the most tangible at night, during prolonged heatwaves and coincides with the peak in negative health problems. Note that these aspects would have not been investigated, if the designated heatwave was defined based on the temperature peaks. Consequently, the use of light-weight structures would be more recommended in bedrooms, while heavy-weight structures would be preferred in rooms with daytime functions, potentially without compromising the annual energy consumption. Such a hybrid construction would require substantial changes from the building industry. Cool retreats (Saman et al., 2014), when only one room is used for different functions during heatwaves, is an alternative form of the same concept. Furthermore, there is a lack of knowledge about the importance of the combination of the length and strength of overheating on health. Future research should explore whether the higher overheating occurring during the first half of a medium heatwave, or the relatively lower overheating during days with the highest number of health implications have a stronger impact on human physiology.

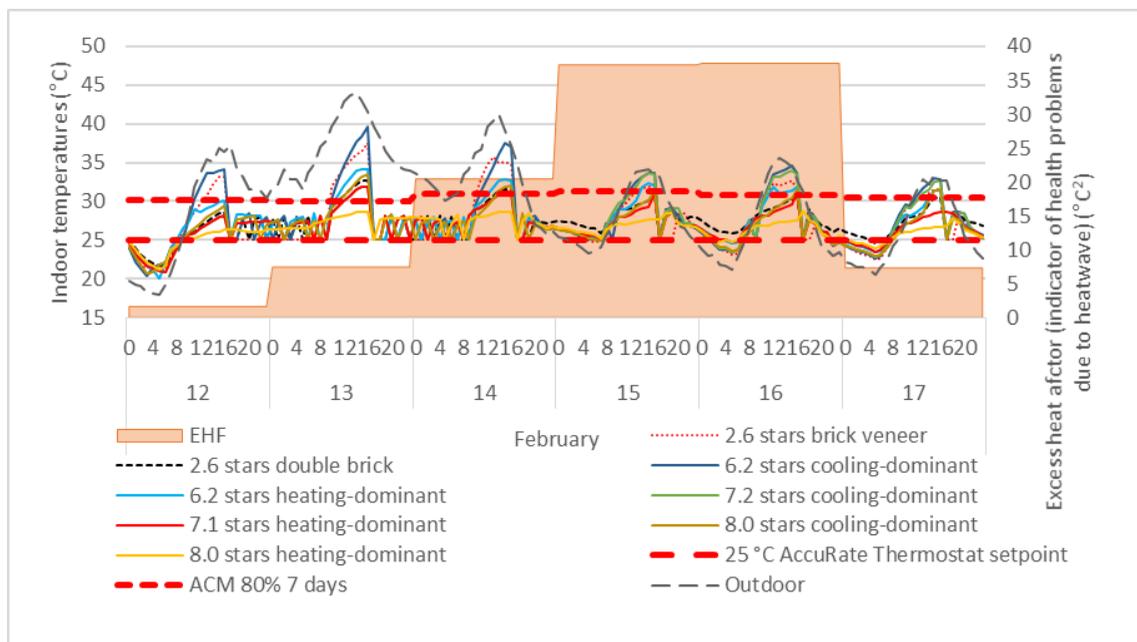


Figure 3: Overheating analysis of a north-facing bedroom during a medium heatwave period

#### 4. Conclusion and policy implications

The paper demonstrated that the NatHERS increasing energy efficiency does not encourage heat stress resistance in new homes, and traditional double brick homes can even outperform some new constructions with 6 stars during heatwaves. Note that the two aspects of building design, namely energy efficiency and heat stress resistance do not inevitably interfere. A comprehensive design approach considering both aspects simultaneously is, nevertheless, an imperative, particularly considering future

increases in population vulnerability and climate change. Current building construction methods rely greatly on AC, increasing the population dependence on it. This trend overlooks the problem of blackouts, energy poverty and the many negative consequences of AC. Although AC is acknowledged as an efficient, preventative measure during heatwaves (Hajat et al., 2010) it also has several negative impacts. AC creates a feedback loop with the waste heat generated increasing local ambient temperatures (Salamanca et al., 2014), contributes to energy poverty (Santamouris and Kolokotsa, 2014), might cause addiction (Cândido et al., 2010) and potentially decreases other means of adaptation (Bélanger et al., 2015; Hatvani-Kovacs et al., 2016). The implementation of heat stress resistant measures in the NatHERS would be warranted to decrease the population's dependence on AC.

The combination of the EHF and thermostat set points is the first of its kind to assess overheating risk beyond comfort preferences in relation to health risks. A limitation of the study is that buildings were tested only during a medium heatwave. Increased thermal mass, however can be potentially more detrimental to the indoor thermal comfort during extremely long heatwaves. Future research should focus on the energy model simulation of different scenarios during long and extreme heatwaves and evaluate the combined influence of the length and strength of overheating on human physiology.

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