Does the Australian Nationwide House Energy Rating Scheme ensure heat stress resistance?

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Abstract

Heatwaves are Australia's most deadly natural hazard and the principle driver of peak electricity demand, resulting from the dramatic increase in air-conditioning use. Increased peak demand has been causing occasional blackouts and a substantial increase in electricity prices to the community over the last decade. The escalating prices constrict the ability of energy poor population to adequately cool their homes during heatwaves. Meanwhile, the desire for more energy efficient homes will decrease overall electricity consumption but may not reduce peak demand. As a result, the heat stress resistance of buildings may not be enhanced by the current regulation. This paper investigates whether the current Australian Nationwide House Energy Rating Scheme encourages heat stress resistance.

Cooling energy consumption, peak demand and the risk of indoor overheating were assessed for a typical single-storey home in Adelaide, South Australia, and Sydney, New South Wales. Design scenarios between 6 and 8 stars, plus a traditional, uninsulated double brick and an uninsulated brick veneer building structures were simulated with the AccuRate building thermal simulation program. The results showed that a higher star rating does not necessarily coincide with a decrease in either cooling energy consumption, demand or overheating. The traditional uninsulated, double brick scenario required significantly more heating, however was able to outperform many high star rated homes during summer.

Consequently, the integration of heat stress resistance in the Nationwide House Energy Rating Scheme would be a valued addition to the existing regulations to avoid building new homes with potentially lower coping capacity and increased dependence on air-conditioning. To address the problem, a new overheating analysis is proposed that can be implemented in the AccuRate.

1 Literature review on heat stress resistant building design

Heatwaves are not just the most dangerous natural hazard to health in Australia [1] but they are also responsible for the annual peak electricity demand in cooling-focused regions [2]. Peak electricity demand increases the risk of power outages, depriving the population of air-conditioning (AC) [3]. For example, in South Australia, the average system interruption duration was 46 minutes per customer between January and March, 2012, when both planned and unplanned interruptions were considered [4]. Higher and more frequent peaks drive increases in electricity prices [5] 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’ [6]. Meanwhile, more than one third of deaths between 1956 and 2010 in Australia recorded as heat-related occurred indoors [1]. This proportion has been rising since the 1850s, showing the importance of the indoor thermal environment during heatwaves.

Consequently, more attention has recently been paid to heat stress resistant buildings to minimise indoor overheating and heat-related health problems [7]. This is particularly so, since climate change will decrease heating and increase cooling energy consumption and the risk of indoor overheating [8,9]. In general, energy efficient retrofitting can decrease the overheating risk [10] particularly in very inefficient homes. However, energy efficiency can also interfere with heat stress resistance [11]. For example, high levels of insulation and air-tightness can foster overheating in summer [7,12] without a comprehensive design leading to both energy efficiency and heat stress resistance. Heat stress resistant features include shading [13], more reflective roof colour [14], reflective foil in the roof cavity [5], slab-on ground compared to elevated structures in warmer climates [15], ceramic floor covering [8], orientation [13] and increased natural ventilation [16].

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 [17]. The NatHERS classifies buildings with stars from 0 to 10, based on the predicted annual energy consumption. The minimum requirements for new buildings had been raised gradually to six stars by 2010. As research has shown that energy efficiency with inappropriate design can decrease heat stress resistance [7,13], the NatHERS can potentially be counterproductive to heat stress resistance. Further research should be undertaken to understand the impact of the NatHERS on heat stress resistance in the Australian climate considering Australian building construction practices.

Based on the research gap identified, this paper aims to:

- evaluate whether the NatHERS encourages heat stress resistance in new residential buildings
- and compare their resilience with traditional construction methods in two Australian cities, Adelaide and Sydney.

The two cities were selected as designated case studies in an ongoing research project on urban micro climates, funded by the Cooperative Research Centre for Low Carbon Living [18].

While Adelaide is located in a temperate climate with hot and dry summers, Sydney is located in warm, temperate climate with warm and humid summers [19]. Adelaide, with a population of 1.3 million [20] is the capital city of South Australia (SA). Adelaide has had heatwaves with the highest intensities [21] and the highest normalised heat-related mortality within Australia[1]. Sydney, with a population of 4.9 million [20] is the capital city of New South Wales (NSW). Although Sydney is exposed to less severe heatwaves than Adelaide, notable heat-related hospitalisations have occurred, particularly in its outer, western suburbs [22]. In general, both Adelaide and Sydney suffer from regular, severe heatwaves.

1.1 Analysis method

The current NCC offers two pathways to comply with the minimum energy efficiency requirements, namely the elemental and the simulation compliances [17]. The elemental compliance prescribes the minimum conditions required during the selection of building elements and building design. The simulation compliance is performance guided where the verification can be completed with a simulation software. The final goal of the NCC is to move to the performance based approach from the elementary approach [23], since performance based approach supports more innovation and is also preferred to the elementary compliance by the market (Australian Building Codes Board, 2009). It is imperative, therefore, that the performance based approach in the NCC first addresses the issue of heat stress resistance.

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) that mostly excludes weather extremes such as heatwaves, is applied. A relatively long and hot period of time, nevertheless, is included in the TMY file for Adelaide in the middle of February, with a maximum temperature of 43.7 °C, which was selected for analysis. Unfortunately, a similarly long, hot period was not available for Sydney. The hottest period selected in late October and early November from the TMY for Sydney had a maximum temperature of 42.2 °C.

In NSW, the energy efficiency requirements of the National Construction Code do not apply. The relevant Part 3.12 is replaced by the Building Sustainability Index (BASIX)[17]. BASIX defines maximum annual heating and cooling loads for the building to ensure a minimum indoor thermal comfort around the year, and these have been considered in the analysis.

1.1.1 Design scenarios

A typical single-storey home with floor area of 211 m^2 (Figure 1) has been modelled by AccuRate, in free-running mode, to assess the building performance during summer without AC. The house size is mostly representative for Australia. The national average of new homes was 241.1 m2 in June 2013, which is a slight decrease compared to the 248.0 m2 surveyed in February 2010. The building design chosen was adopted from an earlier report [5].

Figure 1 Floorplan and facades of the dwelling modelled

Investigating the existing residential building stock, the most frequent wall structure material is brick veneer, followed by double brick in both Adelaide and Sydney [24]. 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 [25], 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, after a rapid uptake in the recent decade (Figure 4), [26]. Double-glazed windows are still rarely used and the average level of energy efficiency [27] and heat stress resistance [28] are low in the existing building stock.

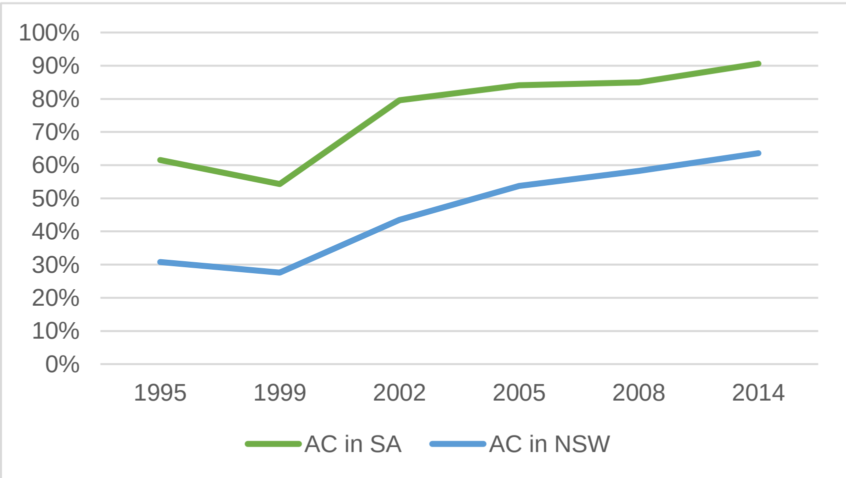

Figure 2 Air-conditioning uptake in the residential sector since 1995

As the long-term aspiration is a gradual increase of energy efficiency in the NatHERS, a shift can be expected in new residential buildings to 7 stars in the future. Initially, forty-five different scenarios were modelled to identify the ones for further analyses. In this study, 6 design scenarios between 6 and 8 stars were selected, with an 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

Star rating in Adelaide	**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**
Star rating in Sydney	**2.3 stars (double brick)**	**2.4 stars (brick veneer)**	**5.6 stars cooling-dominant**	**5.7 stars heating-dominant**	**6.7 stars heating-dominant**	**6.9 stars cooling-dominant**	**7.9 stars cooling-dominant**	**8.1 stars heating-dominant**
Roof colour, material and total solar re-flectance	light metal (0.30)	light metal (0.30)	dark 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
Internal walls	brick	plaster board	plaster board, R1.5	brick	brick	plaster board, R1.5	plaster board, R2.0	plaster board, R2.0
Windows	single, clear glazing	single, clear glazing	single, high solar gain (U=5.4 W/m^{2}K)	single, low solar gain (U=5.6 W/m^{2}K)	double, low solar gain (U=3.0 W/m^{2}K),	double, argon, high solar gain (U=2.90 W/m^{2}K)	double, high solar gain (U=2.0 W/m^{2}K),	double, low solar gain (U=2.0 w/m2k),
Roller shutters	in western bedrooms	NIL	NIL	in western bedrooms	in western bedrooms	NIL	NIL	all rooms
Floor slab	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
Floor covering	timber	ceramic & carpet	ceramic & carpet	ceramic & carpet	ceramic & carpet	ceramic & carpet	ceramic & carpet	ceramic only
Fan	NIL	NIL	NIL	NIL	NIL	NIL	NIL	in main rooms

1.1.2 Analysis of heat stress resistance

To evaluate overheating risk four 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 [5].
- Thirdly, the ratio of peak demand compared to annual heating and cooling energy consumption was calculated, showing the level of disproportionally high peak demand of the building. This figure can be informative, in case of an extensive, new residential development with similar home design configurations. In such a situation, a disproportionally high peak demand can cause burden on the local electricity network.
- Fourthly, 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 currently used in different jurisdictions. All thresholds have been developed based on perceived comfort instead of the corresponding health implications [7]. The thresholds can be classified into two groups, namely static and adaptive thresholds. The traditional static thermostat set point stipulates one threshold for heating and one for cooling. Although the static thresholds are simpler to use, they have been widely criticised in the case of free-running and mixed-mode ventilated buildings, for neglecting adaptation and acclimatisation [29,30]. In contrast to static thresholds, an adaptive threshold changes with the outdoor temperatures, based on the adaptive comfort model (ACM). The ACM has been validated globally and implemented in the standard of the American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE),[31]. The ACM has been validated for residential mixed-mode ventilated buildings in Australia [5]. This paper adopted both static and adaptive overheating thresholds. The AC set points of 25 °C and 24.5 °C, defined by AccuRate for Adelaide and Sydney, respectively, were adopted as static thresholds. The indoor thermal conditions were assumed to be perceived as acceptable by 80% of the occupants, in line with the ASHRAE standards. 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 (Equation 1), [32], instead of the monthly mean temperatures defined by the ASHRAE. With these assumptions the ACM applied allowed for indoor temperatures between 30-31 °C in Adelaide during the designated heatwave. This is notably higher than the 28.9 °C calculated for February based on the ACM from ASHRAE. In Sydney, the ACM threshold was between 26.8 -28.9 °C, compared to the set points of 26.7 °C and 27.3 °C in October and November, respectively, based on the ASHRAE.

Equation 1 Adaptive comfort model threshold, where $T_{outdoor}$ is the exponentially weighted running mean of the recent 7 days

$$T_{ACM} = 0.31 * T_{outdoor} + 21.3$$

To connect indoor overheating risk with its health implications, a novel combination of the ACM and a heatwave intensity factor was used in Adelaide. The excess heat factor (EHF) was devised by Nairn et al. [33] to assess the heatwave intensity and predict heatwave risks to the community. The EHF is calculated as the deviation of the daily mean temperatures over the most recent three days ($T_i \ldots T_{i-3}$) compared to the recent thirty days ($T_{i-1} \ldots T_{i-30}$), (EHIsig) and the 95th percentile of the recent thirty years (T_{95}), considering long-term acclimatisation (EHIaccl), (Equation 2). The unit of the EHF is °C^2. A refined version of the EHF was used in this paper, where the daily mean temperatures were calculated as the average of the minimum temperature recorded in the preceding 24 hours up to 9 a.m. and the maximum temperature recorded in the following 24 hours from 9 a.m. A more elaborate description of the calculation is provided in an earlier study [34].

Equation 2 Excess heat factor

$$EHF = EHIsig * \max(1, EHIaccl)$$
$$EHIsig = (T_i + T_{i-1} + T_{i-2})/3 - T_{95}$$
$$EHIaccl = (T_i + T_{i-1} + T_{i-2})/3 - (T_{i-1} + \ldots + T_{i-30})/30$$

The EHF was validated as a superior predictor of excess mortality [35] and morbidity in Adelaide [34] but not in Sydney. The EHF can also better differentiate days with excess morbidity compared to normal summer days than earlier weather metrics used [34]. 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 95th percentile of the recent 30 years was adopted from an earlier study [34]. The strength of the heatwave analysed from the TMY between 12nd and 17th February, identified as days with positive EHF, was in the average range, considering the range of heatwaves since 1970s in Adelaide [21]. Note that heatwave days, calculated as days with positive EHFs are usually lagged by 2-3 days behind compared with the peak in daily maximum temperatures (Figure 3).

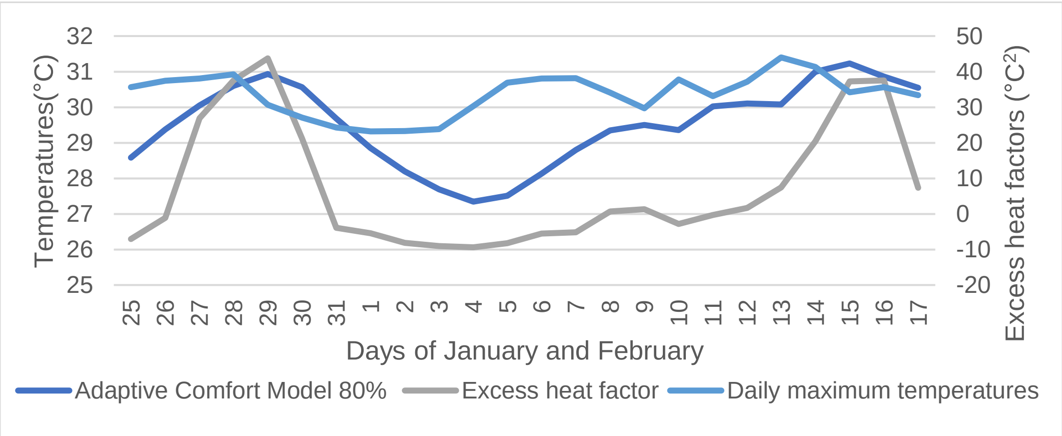

Figure 3 Heatwave days in Adelaide based on the typical meteorological year between 25 January and 17 February

2 Building simulation results

Firstly, the ratios of cooling and annual cooling energy consumption were compared across scenarios in Adelaide (Figure 4). 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.

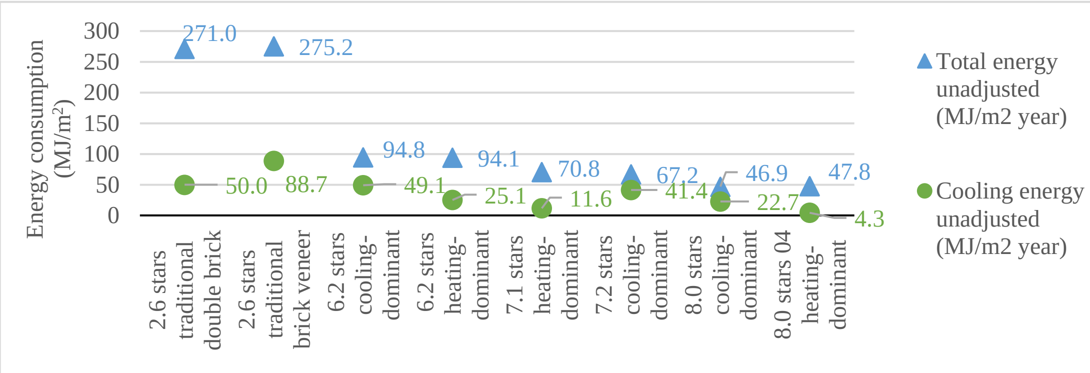

Figure 4 Total annual energy and cooling energy consumption of the design scenarios in Adelaide

The same analysis was repeated in Sydney. All scenarios with 5.6 stars and above passed the maximum heating (51.0 MJ/m^2) and cooling (45.0 MJ/m^2) thresholds, defined by BASIX according to their climate zones. Unexpectedly, the maximum cooling threshold was passed by both traditional scenarios, highlighting how lenient the requirement is. The 6.9-star home had higher cooling energy consumption than the 2.3-star, double brick home in Sydney. Furthermore, the same amount of cooling energy was used by the 5.7-star and the 7.9-star homes. To summarise, star rating did not indicate the cooling energy consumption of a building either in Adelaide or Sydney.

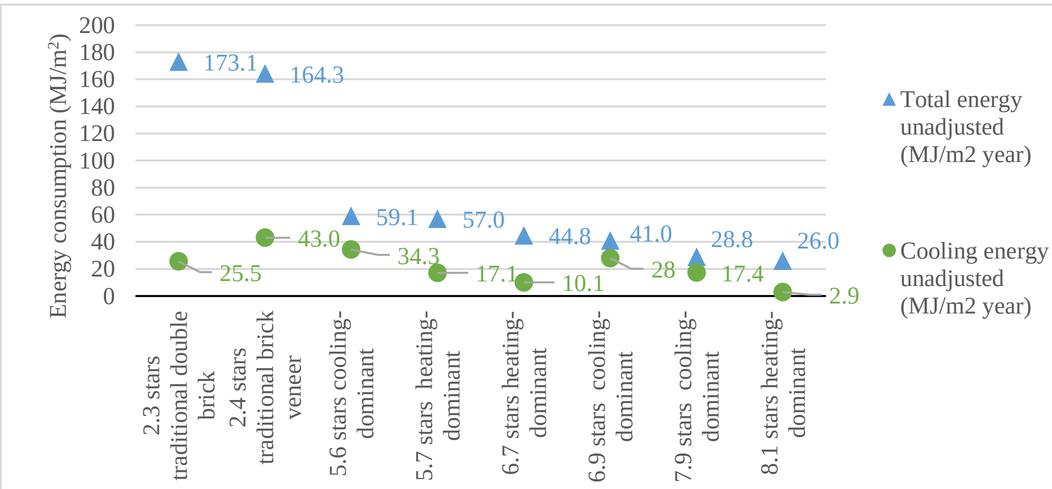

Figure 5 Total annual energy and cooling energy consumption of the design scenarios in Sydney

Secondly, the peak cooling demand was compared in Figure 4 across the scenarios. Although the double brick home had a higher peak cooling demand than any new construction with 6 or more star ratings, one home with 8 stars had a higher peak demand than a home with 7.1 stars.

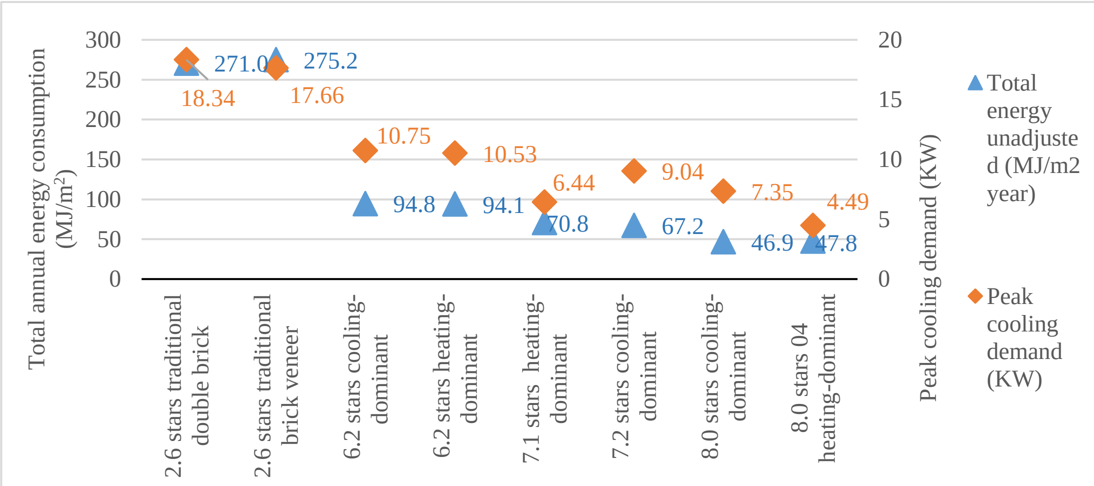

Figure 6 Total annual energy consumption and cooling demand of the design scenarios in Sydney

A similar pattern was found in Sydney, where the 6.9-star home had higher peak demand than a 5.7-star home by 26%. In summary, an increase in the star rating thus did not necessarily result in a decrease in peak demand in either city. All new constructions, nevertheless, had lower peak demands than older homes.

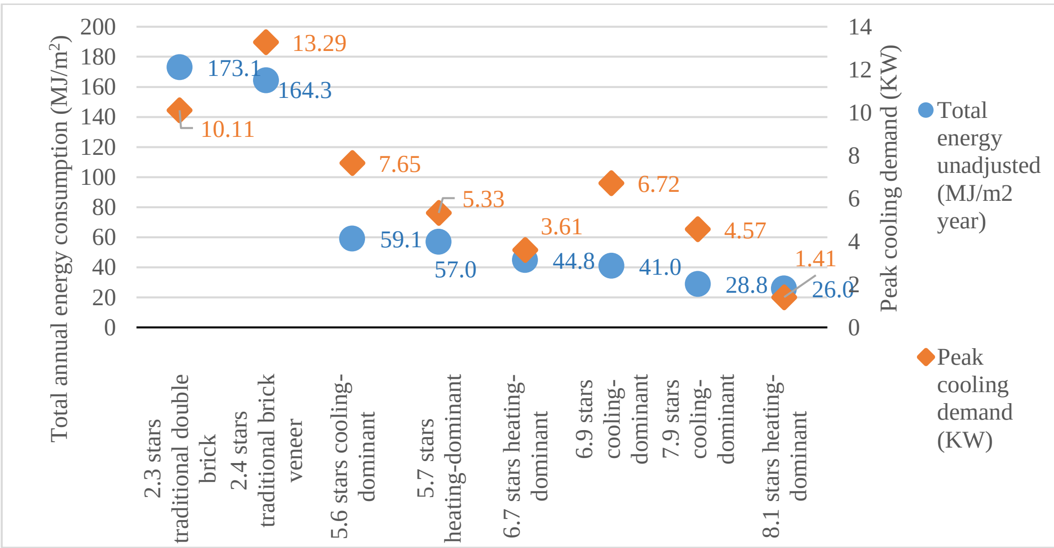

Figure 7 Total annual energy consumption and cooling demand of the design scenarios in Adelaide

Thirdly, the ratio of peak demand compared to annual heating and cooling energy consumption was calculated. On average, the ratio was higher for new rather than old buildings in both Adelaide (Figure 8) and Sydney (Figure 9). The highest ratios were among the 7 and 8-star cooling-dominant scenarios in both cities.

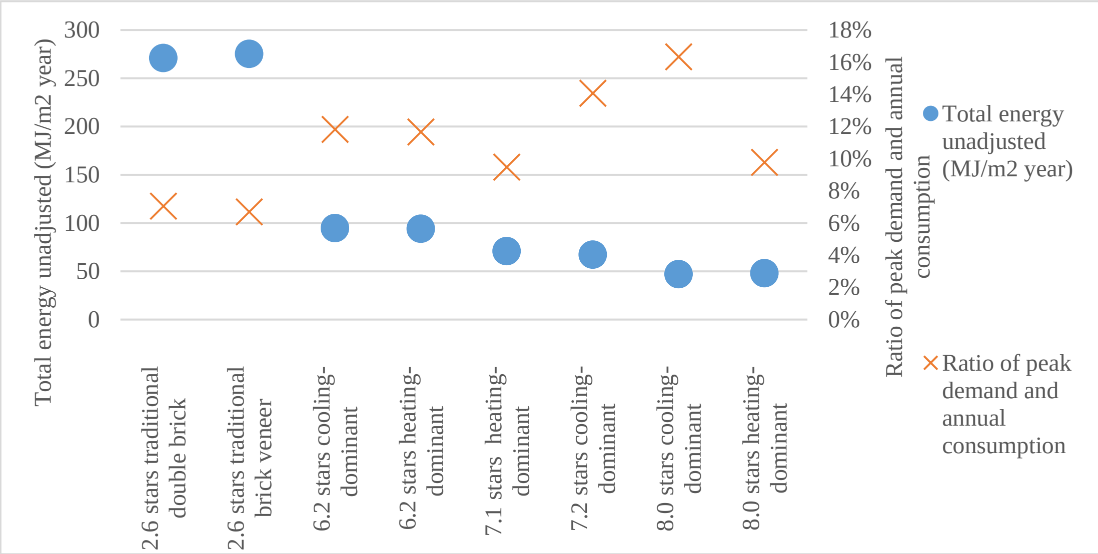

Figure 8 Ratio of peak cooling demand and annual energy consumption of the design scenarios in Adelaide

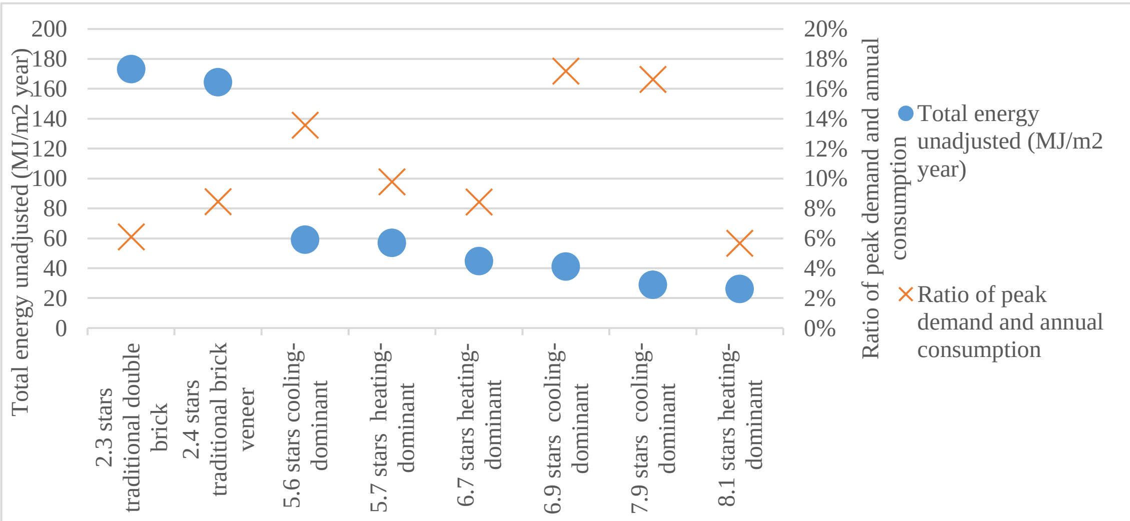

Figure 9 Ratio of peak cooling demand and annual energy consumption of the design scenarios in Sydney

Fourthly, the numbers of hours with discomfort was evaluated in the selected north-facing bedroom, considering the whole year. Figure 10 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 in Adelaide. Three homes with 6, 7 and 8 stars even reached indoor temperatures above 35 °C.

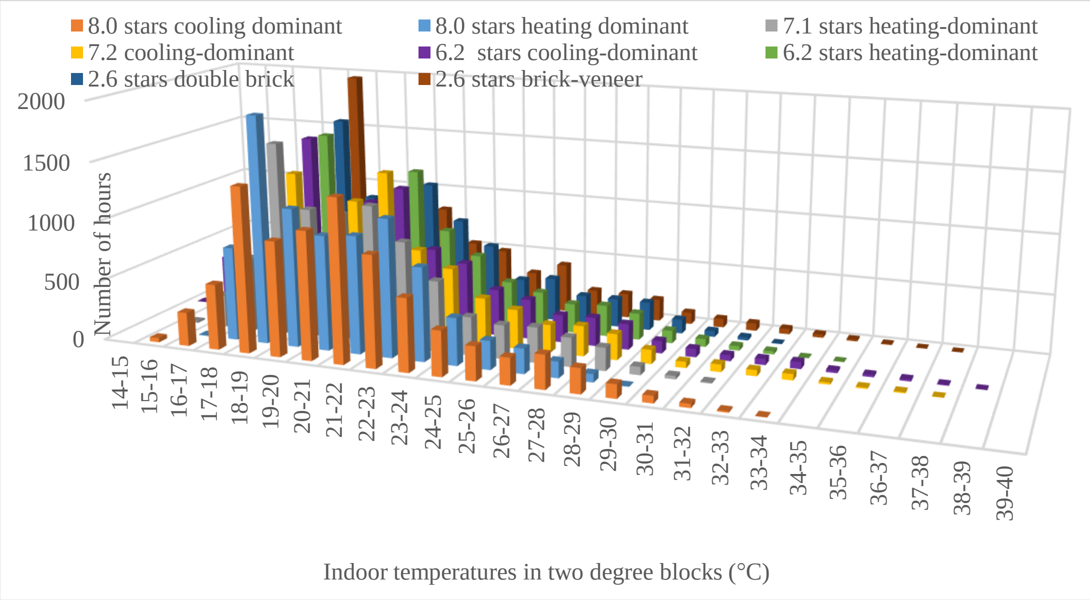

Figure 10 Overheating analysis of a north-facing bedroom for the whole year in Adelaide

When the overheating analysis was repeated in Sydney, more hours occurred with discomfort during summer in most of the new than the traditional homes (Figure 11). Overheating even exceeded 35 °C in the 5.6-star home, and 30 °C in almost all scenarios. This overheating is very significant, considering the high humidity in Sydney.

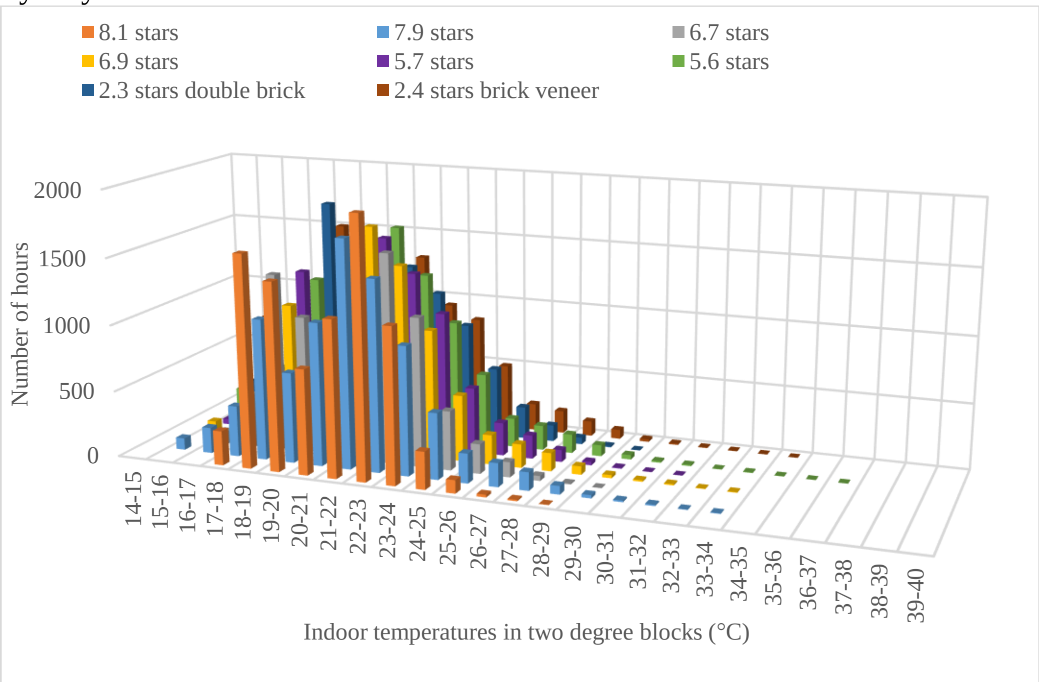

Figure 11 Overheating analysis of a north-facing bedroom for the whole year in Sydney

The indoor temperatures in the north-facing bedroom was investigated further during the heatwave period, considering all hours of the days. Heatwave days were identified from the TMY as days with positive EHFs in Adelaide. The highest EHFs occurred on 15th and 16th February, indicating the highest level of heat-related hospitalisation, when indoor overheating can potentially be the most dangerous. Figure 12 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 12).
The highest levels of indoor overheating occurred on the first and second days, simultaneously with the outdoor temperature peaks. On the most dangerous fourth and fifth 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 significantly exceeded the higher adaptive threshold. Although indoor temperatures peaked at lower values in the traditional, double brick than in many new homes, indoor temperatures remained the most above the static overheating threshold in the traditional, double brick homes and the least in the traditional, brick veneer home, considering only nights during the most dangerous days. This result was a consequence of the thermal inertia of the building mass and the missing insulation, showing that thermal mass can be counterproductive at night, during long heatwaves.

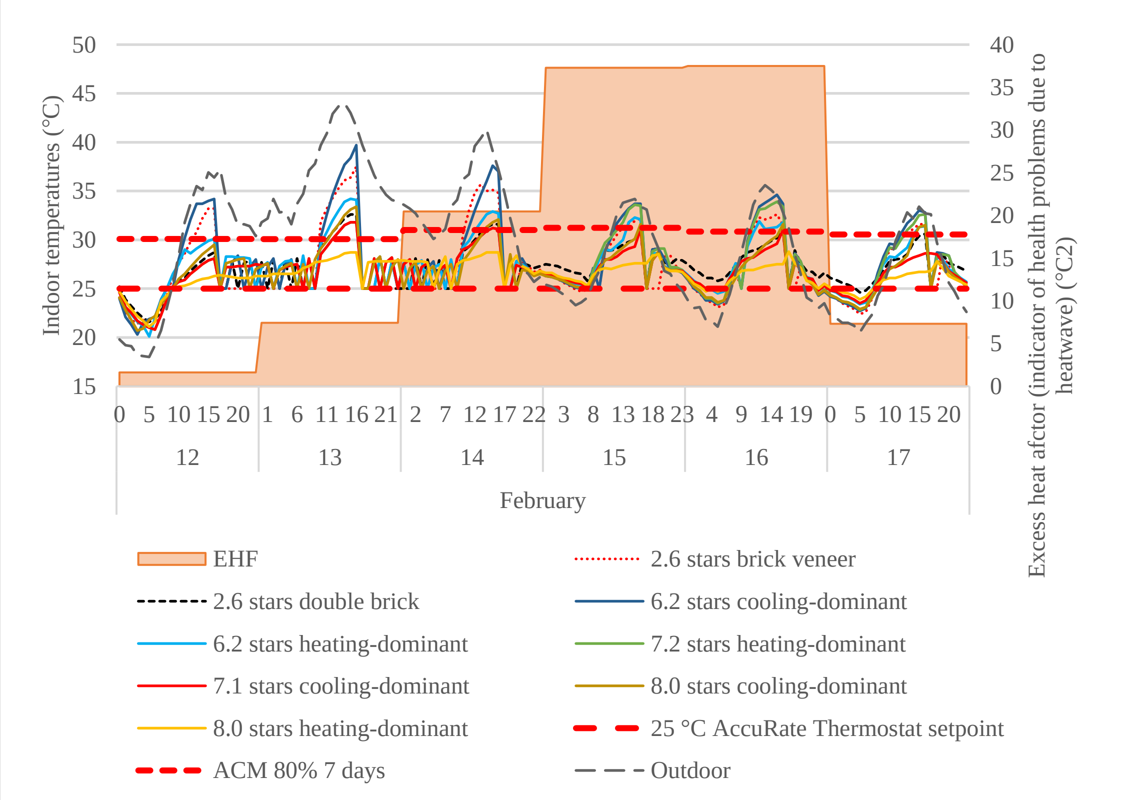

Figure 12 Overheating analysis of a north-facing bedroom during a medium heatwave period in Adelaide

In Sydney, current research has shown that the EHF was not a superior predictor of heat-related morbidity compared with daily maximum temperatures, presumably due to the impact of humidity that is neglected in the EHF. In the overheating investigation during a designated heatwave period, only the ACM and the AccuRate thresholds were adopted. The thermostat set point was stipulated at 24.5 °C for Sydney by AccuRate.

Similarly to Adelaide, the indoor temperatures were higher in many scenarios with 5 stars or more than in a 2.3-star double brick home.

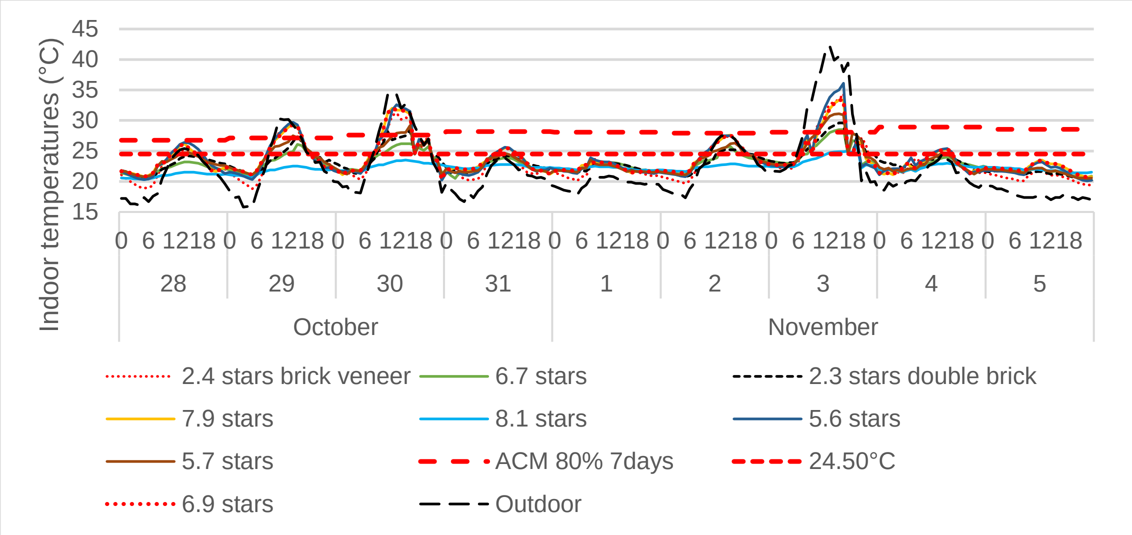

Figure 13 Overheating analysis of a north-facing bedroom during a medium heatwave period in Sydney

3 Discussion

The findings show that current energy efficiency measures of the NatHERS cannot necessarily ensure lower cooling energy consumption, peak demand and overheating during heatwaves in new homes. Additionally, a home with high star rating can have decreased heat stress resistance and increased reliance on AC during heatwaves compared to a traditional, double brick home. This overreliance on AC can represent a public health hazard should a blackout occur or for those who are energy poor. Although AC is acknowledged as an efficient, preventive measure for health during heatwaves [36] it also has several negative impacts. At a community level, AC creates a feedback loop with the waste heat generated increasing local ambient temperatures [37], contributes to energy poverty [38], can cause dependence [39] as it potentially decreases other means of adaptation [40].

It is important to note that AccuRate underrepresents the level of overheating. AccuRate neglects real-world factors that affect the building energy use due to insufficient Australian building energy efficiency standards compared to leading jurisdictions internationally and non-compliance issues [41]. Such factors include the neglecting of thermal bridges or building leakage and the use of poor quality ducting in case of ducted AC. Furthermore, consideration is not given to reduction in efficiency heatwave conditions have on AC [5].

The findings demonstrated that design decisions can improve heat stress resistance of a building without necessarily changing its energy efficiency. Such design features include, roof colour with higher total solar reflectivity, reflective foil under roof cladding, shading, particularly on northern and western facades, windows with low solar gain, ceramic floor covering and slab-on-ground structure without insulation [5,8]. The combination of the ACM and EHF to evaluate overheating highlighted that there is insufficient knowledge about the importance of the length and strength of overheating on health. Future research should explore whether higher overheating occurring during the first half of a heatwave, or the relatively lower overheating during days with the highest number of health implications has a stronger impact on human physiology.

4 Conclusion and policy implications

The report demonstrated that NatHERS does not directly encourage heat stress resistance in new homes. Energy efficiency and heat stress resistance can, nevertheless, be both achieved in the design process. A design approach that considers both aspects is recommended, particularly considering future increases in population vulnerability and climate change. Current building construction methods, furthermore, rely greatly on AC, increasing the population's dependence on it. New homes, compliant with the current NCC, can potentially be more hazardous without AC than traditional, double brick buildings. The implementation of heat stress resistant measures in the NatHERS would decrease the population's dependence on AC, ensure thermally safe indoor environment and provide other community benefits, such as reduced pressure on electricity prices.

The current initiative in BASIX regarding thresholds for maximum heating and cooling energy consumption provides a basis for regulating the heat stress resistance of buildings. The current thresholds defined are, however, too lenient to have an adequate impact. It is recommended that as a first step, thresholds for annual cooling energy consumption should be implemented across climate zones in AccuRate. In case the threshold was exceeded during the design process, small design adjustments that increase heat stress resistance but do not decrease energy efficiency should be made. Alternatively, compulsory heat stress resistant design features could be introduced through the deemed-to-satisfy provisions. Into the future, more refined measures can be adopted in Adelaide, which is a city exposed to particularly extreme heatwaves and where the EHF is a validated predictor of morbidity. A more accurate, overheating measure would be suggested based on the EHF and ACM approach.

A limitation of the study is that buildings were tested only during a medium heatwave, and more extreme heatwaves would give better quantitative assessments. Furthermore, additional research is needed to better understand the combined influence of the length and strength of overheating on human physiology, and apply this knowledge to the development of future overheating measures.

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