Regulation for comfort: an investigation of policy and practice in Australian homes

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Abstract: On average, 40% of energy consumed in residential buildings in Australia is expended towards space conditioning to ensure comfort and well-being of occupants. While national regulations have focused on the thermal efficiency of the building fabric, that is assessed in relation to predicted energy based on heating and cooling setpoints, less attention is paid to the actual practices and outcomes for occupants in these buildings. Previously published findings from a two-year monitoring study of 40 homes in western Sydney (by the authors) indicate that while some occupants adopted adaptive practices such as adjusting clothing and using ceiling fans before resorting to air-conditioning, a lower tolerance of 'imperfect' conditions and availability of air-conditioning on standby led to increased usage for others. In this paper we reflect on occupant practices as they relate to the regulatory landscape and systems such as NATHERS in Australia to investigate how thermal comfort is perceived, mandated and provided for in residential settings. We compare actual occupant practices elicited from the aforementioned study against the assumptions built into the Australian regulatory systems to identify differences. Computer-based modelling is used to study how these alternate occupancy settings impact energy, comfort and implications for the building fabric. The paper highlights the implications of rating assumptions - such as bedrooms are only occupied at night, and unrealistically low thermostat settings in winter - which are out of touch with observed and prevailing practices. The resulting underestimation of energy use has the potential to compromise the thermal performance and specifications of the building envelope by the equivalent of a one star under NATHERS. Our findings call for changes in the regulations whereby bedrooms be assessed with a night time heating set point of 18°C instead of 15°C and are also tested for comfort during the day, and that the necessary improvements to the building fabric to account for these changes are mandated.

Keywords: residential energy, comfort, rating tools, occupants.

1. Introduction

The family home ideal can be thought of as a comfortable and safe environment for its occupants. In the last few decades, the expectation of energy efficiency and net zero emissions outcomes have also been added to this list. These latter imperatives are even more critical as we see a more urgent impetus via the IPCC's latest report calling for sufficiency (reducing the energy consumed) and distinguishing this

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approach from reliance on more efficient technologies such as PV to generate the energy we need in the built environment (Cabeza et al, 2022). On average, 40% of energy consumed in residential buildings in Australia is expended towards space conditioning to ensure comfort and well-being of occupants (DISER, 2021). While national regulations have focused on the thermal efficiency of the building fabric, less attention is paid to the actual practices and outcomes for occupants in these buildings.

Sustainable performance for houses has largely been rated using the NATHERS (Nationwide House Energy Rating System) since the 1990s. The system has been embedded into Vol 2 of the National Construction Code (NCC) which deals with Class 1 (houses) buildings since 2003 and Class 10, not the subject of this paper, since 2010. In NSW, BASIX or Building Sustainability Index, was introduced by the government of New South Wales, on 1 July 2004 to regulate the energy efficiency of residential buildings, which also included a NATHERS performance pathway for compliance. As noted on its website, BASIX assesses the *'energy and water use and thermal comfort of your residential development'* (DPIE, 2023). Here the predicted NATHERS 'heating and cooling caps' or *predicted heating and cooling annual energy use* is used as a proxy for thermal comfort - evaluating the extent to which the building design and envelope would need to rely on heating and cooling to deliver thermal comfort based on stipulated heating or cooling setpoints. This approach whereby building envelope performance in residential buildings is benchmarked in terms of predicted annual heating and cooling energy is reinforced in the National Construction Code NCC Vol 2. Applicable (in various versions) across most states and territories, the predicted annual heating and cooling energy is translated to 'stars' bands or ratings.

A number of studies (Moore et al, 2015; O'Leary et al, 2016 and Miller et al, 2021) have investigated the gap between predicted and actual performance of residences and have highlighted discrepancies due a mismatch between what is built and what is modelled, occupant behaviour and expectations out of sync with regulatory assumptions, and inadequacy of the standards to deal with variations in climate.

The intersection of these house performance rating systems and this paper is in the area of thermal comfort as assessed by residential rating tools in Australia. In 2018, the World Health Organisation proposed temperature limits for safe and well-balanced internal conditions for houses, the lower limit being 18°C (WHO, 2018). Their guidelines considered research on health implications like allergies. Barlow et al (2023) have recently published work that shows that more than 80% of monitored Australian houses, in temperate zones with high levels of population, have winter temperatures that are lower than this 18°C limit. Although their research does not nominate the spaces where these temperatures were monitored, another matter of interest is how comfort is assessed in various rooms, given a historic assumption of delineating spaces in homes as day time zones and others as night time zones

2. Study Approach

In a quest to understand occupant practices as they relate to the regulatory landscape within NATHERS, we compare actual occupant practices against the assumptions built into the Australian regulatory systems to identify differences. We focus on two aspects - monitored data in specific spaces (rooms) in Australian houses with a view to understanding occupancy and temperature settings, and the predicted energy consequence of mitigating thermal discomfort in bedrooms. We also provide insights to the energy penalty incurred when bedrooms are more frequently used in the daytime in the context of modern Australian family life.

Our study of occupant practices draws on real, monitored data from households from a two-year monitoring study of 40 homes in western Sydney from between 2019 to 2021 (Thomas et al 2022a). The homes form part of an 830 home estate and were all furnished with a energy efficient ground source heat pump air-conditioning system and designed to comply with the prevailing BASIX requirements of 2013. Previously published research (Thomas et al 2022b) indicates that while some occupants adopted adaptive practices such as adjusting clothing and using ceiling fans before resorting to air-conditioning, a lower tolerance of 'imperfect' conditions and availability of air-conditioning on standby can also result in increased usage of conditioning. These homes in Western Sydney were monitored for their energy use by end use including air-conditioning, with additional sensors tracking temperature, humidity, air quality as well as occupancy in the living room and the main bedroom of the house. The data collected enables us to selectively understand practices when the house is occupied, both in relation to rooms occupied, coincident temperatures tolerated or maintained in these spaces when AC is in use and when it is not during those times. The study period commenced in September 2019 prior to the Covid pandemic, and included the shut-down periods of Lockdown 1: 2020-03-23 – 2020-05-30 and Lockdown 2: 2021-06-23 – 2021-10-11, and the period in between.

Given that NATHERS heating and cooling set points are set as a proxy for thermal comfort, and most buildings tend to "just comply" with the regulatory yardstick (Moore et al, 2019), the study seeks to understand the impact any variation observed would have on the thermal performance and star rating of the house. Given the latest revisions of the NCC effective from 1 October 2023 already improve the required performance to 7 stars, in the present analysis of the monitored study, we focus on understanding observed occupant practices and compare these to those that are built in to the assumptions of NATHERS, especially in relation to the heating and cooling set points as well as occupancy patterns in the homes. Any observed tendency of the occupants to use heating or cooling to a greater extent emphasizes that the thermal efficiency of the building fabric will need to be more efficient to combat its use.

Under the current NATHERS regime, the heating set point in living rooms is 20°C between 7 am and midnight. In bedrooms, the heating set point is 18°C between 7-9am and 4pm to midnight and interestingly drops to 15°C between midnight to 7am. The upper limit for the cooling setpoint is the neutral temperature based on the adaptive model equation, which is 24.5.C for Western Sydney – climate zone 28. Across the year, with an assumption of non-occupancy, living rooms are not tested for thermal comfort between midnight and 7am, likewise bedrooms are not tested during the daytime hours of 9am to 4pm.

Findings from our study of 40 monitored homes are presented below, and are used to inform the rationale for the various changes to NATHERS settings we then investigate. Computer-based modelling is used to study how these alternate settings impact energy, comfort and implications for the building fabric. A run plan was set up to test the impact within NATHERS (see Table 1) on three selected house plans. As a starting point, the base case was considered to be each home already performing at a 7-star level as per NCC 2022 and the runs were completed using the AccuRate engine version 2.4.3.21SP1 with all settings exactly as per the NATHERS regulatory mode. Star bands are calculated from simulated energy use following the NATHERS procedure.

3. A Review of monitored practice from 40 homes in Western Sydney

3.1. Observed Temperatures

The box and whisker plots in Figure 1 and Figure 2 provide an indication of the temperatures observed in the bedrooms and living rooms across all 40 study homes when these spaces are occupied. Coincident hourly internal temperatures from comfort sensor monitoring and the on/off status of the AC system based on submeter energy monitoring for the AC channel for all 40 houses are shown. Spaces are deemed occupied when the coincident IR occupancy sensor registers motion. Our analysis includes both Covid and non-Covid periods as this is not expected to influence occupant practices in relation to resorting to AC or the temperatures maintained or tolerated with or without it. The plots are separated for Winter months of June July and August and Summer months of December January and February during the two-year study period, and broken down into the hour blocks currently used in NATHERS for thermostat setpoints in these rooms to allow for easy comparison.

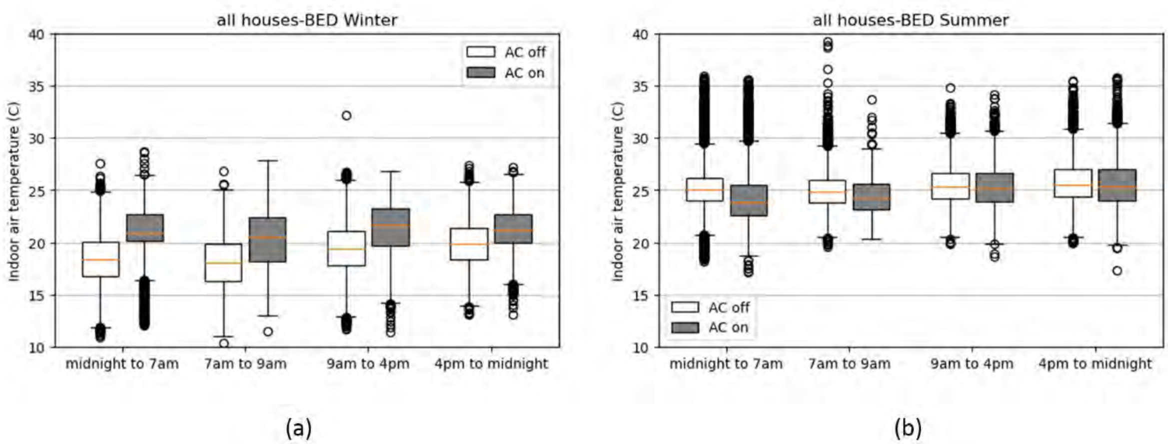


Figure 22: Box and Whisker plot of indoor air temperature observations during Winter and Summer in the Bedrooms (data source: Fairwater Living Laboratory)

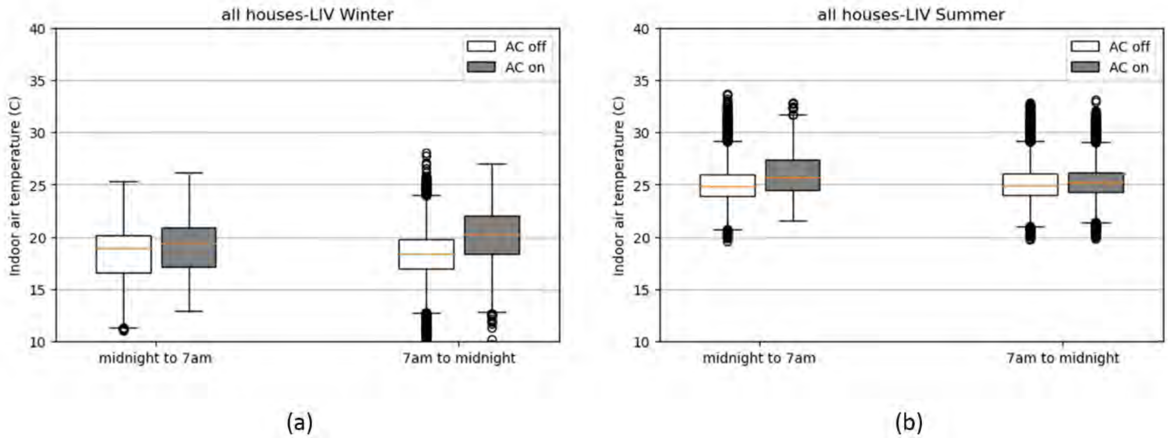


Figure 23: Box and Whisker plot of indoor air temperature observations during Winter and Summer in the Living Rooms (data source: Fairwater Living Laboratory)

In winter, the observed median bedroom temperature at night (midnight to 7am), whether AC is on or not, is higher than the NATHERS assumed overnight heating setpoint of 15 °C (Figure 1), and 75% of the occupied nighttime hours are above ~16°C without AC and above ~20°C with AC on. If the AC thermostat in the bedrooms was set to 15°C overnight, as assumed by NATHERS, the night-time temperatures coincident with the AC operating would be clustered below or close to the thermostat setpoint temperature of 15°C. This is not consistent with the monitored data which shows that almost all nighttime bedroom temperatures with the AC on are well above 15°C, indicating the thermostat setting for the AC must be considerably higher in practice. In the periods 7am-9am and 4pm-midnight where the NATHERS bedroom thermostat assumption is 18°C, more than 75% of observed hours with the AC on are above this temperature, indicating that the actual bedroom thermostat setting is higher than 18°C.

In summer, the NATHERS cooling setpoint is 24.5°C for climate zone 28 as per NATHERS adaptive comfort settings. If occupant practice was consistent with this assumption, room temperatures with AC on would be clustered close to or below this temperature. The observed temperatures at night in summer in the bedrooms whether AC is on or not are below 26°C 75% of the time, indicating reasonable agreement with the assumption.

In the living room, the daytime NATHERS assumed thermostat settings are 20°C for winter and 24.5°C in summer. As seen in Figure 2, 75% of daytime hours with the AC on are above 18°C in winter and below 26°C in summer. There are limited instances where the living room is occupied between midnight and 7am, however the pattern observed in the bedrooms is similar here.

3.2. Occupancy

Figure 3 shows the average percentage of houses across the 40 study homes where occupancy sensor readings were observed by time of day in the Living Rooms and main Bedroom, regardless of AC on/off status. As the study period extended before during and after Covid lockdowns a breakdown is provided - during the pre Covid-19 lockdown period from 1 September 2019 to 21 March 2020 (a and b); Lockdown 2 from 23 June 2021 to 11 October 2021 (c and d) and the period between lockdowns from 1 June 2020 to 22 June 2021 (e and f). It should be noted that the results for Lockdowns 1 and 2 are very similar, and only Lockdown 2 is shown below as this was the longer of the two periods and the mandated restrictions on movement and gathering were more consistent across this period.

The monitored data clearly indicates that on average there is high level of occupancy across the study houses – in the living rooms (plots a, c and e) for all hours (typically 60 to 80%) between the period of 7am and midnight. This is consistent before and during covid lockdowns and also across the two year study period. This level of occupancy validates the approach under NATHERS to test for comfort in living rooms for all "waking hours" in the living rooms zones. Night time occupancy of the living zones indicates occupancy levels remain low in all scenarios (below 20%.)

With respect to occupancy in the bedrooms it should be noted that the night time movement in the bedrooms is grossly under reported by occupant sensors which relied on occupant movement as occupants remain motionless for much of the time that they are asleep. Consequently, we have also included the calculated occupancy between midnight and 7am in the bedrooms based on whether the houses were occupied for the previous evening – these are depicted as crosshatched areas (See Figure 3 b, d and f). These observations consistently suggest 85-90% occupancy overnight.

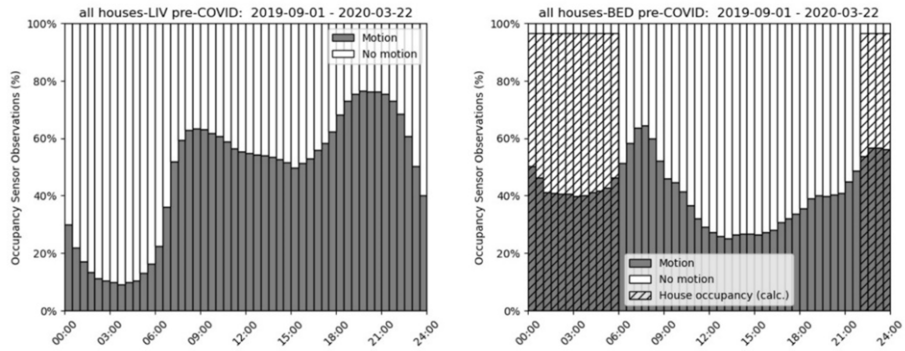
While day time occupancy in the bedrooms is highest between 7am and 9am and 4pm and midnight, the sensor data also shows that occupancy in the daytime 9am to 4pm is consistently above 30% on average even prior to Covid. Analysis of the data for individual houses shows that the bedroom only appears to be consistently unoccupied (<20% occupancy) in two houses between 9am and 4pm in the period prior to Covid. In addition, approximately 20% of the houses have a bedroom occupancy above 60% for several hours between 9am and 4pm.

The exact reasons for occupancy in bedrooms are unclear, but household surveys across the 40 households prior to Covid are suggestive of a high level of occupancy of homes at various hours of the day. Only 47% of the household members nominated typical "out of home" daytime occupations such as "employed full time away from home" or "full time student". 36% of all the household members were nominated as "stay at home", or "work from home" or "pre-schooler at home". Our results already call in to question the implied assumption of non-occupancy of bedrooms within NATHERS and its settings whereby comfort is not tested between 9am and 4pm in the bedrooms.

As can be seen in Figure 3, average daytime occupancy in bedrooms is above 40-50% during the Covid-19 lockdown and at least 35-40% when considering homes in the periods between the two lock downs. Examination of the individual house occupancy results indicates that there are no houses with daytime bedroom occupancy levels below 20% during lockdown, only two houses with low bedroom occupancy between lockdowns, and there are several houses with high day time bedroom occupancy (>60%) during both these periods.

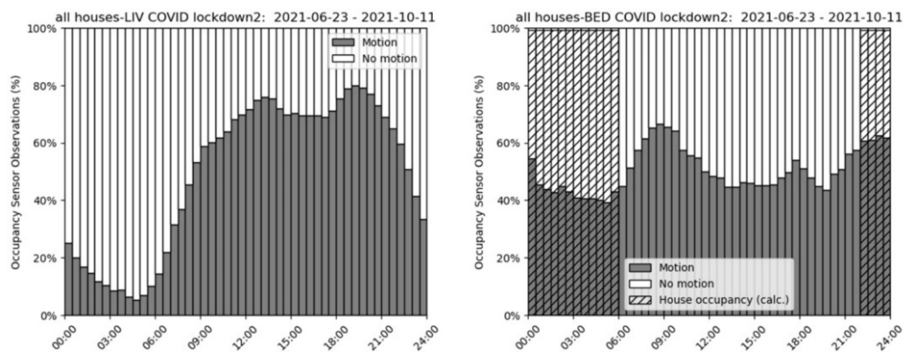
The Covid-19 lockdown, and 'between lockdown' occupancy sensor results seen in the study (Figures 3 d and f) point to the new normal of increased occupancy of zones typically considered as night time zones, in addition to the living zones especially as work from home increases. This practice of occupying and adapting bedrooms and alternate spaces in the home for work was also corroborated in our occupancy survey. These observations highlight a further shift in the way bedrooms are used and further emphasise that day time comfort in these spaces must not be ignored.

Pre-Covid Lockdowns



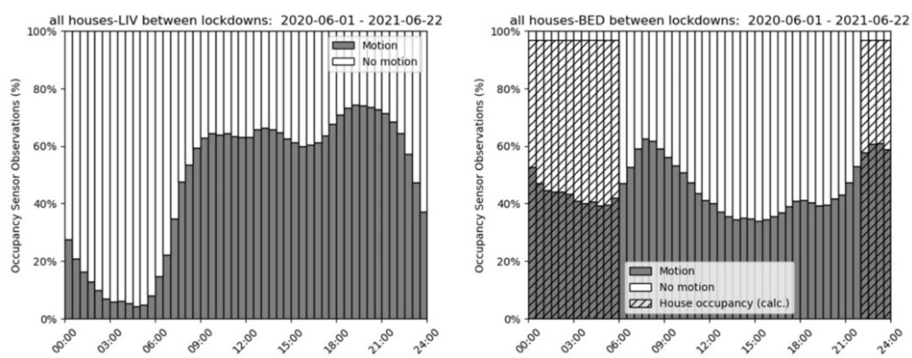
(a) (b)

During Lockdown



(c) (d)

Between Lockdowns



(e) (f)

Figure 24: 24 hour Occupancy Sensor Observations in Living and Bedrooms (data source: Fairwater Living Laboratory)

4. Simulation and Modelling outcomes

5.1. Description of the modelling assumptions

On the basis of the results in Section 4, two major departures from NATHERS modelling assumptions were identified for testing:

- The first relating to thermostat setting for heating at night between midnight and 7am in the bedroom or night time zones
- And the second, relating to the need for testing for comfort in the bedroom zones during the day between 9am and 4pm where no testing is currently done within NATHERS.

Table 11: NATHERS Simulation Run Plan and Settings

Run	Description	Heating Set Points		Cooling Setpoints	
		Bedroom	**Living Room**	**Bedroom**	**Living Room**
Base Case 7 stars Code compliant* for CZ28	Base Case NATHERS thermostat settings unchanged for all zones	7.00-9.00: 18C 9.00-16.00: N/A 16.00-24.00: 18C 24.00-7.00: 15C	7.00-24.00: 20C 24.00-7.00 N/A	7.00-9.00: 24.5C 9.00-16.00: N/A 16.00-24.00: 24.5C 24.00-7.00: 24.5C	7.00-24.00: 24.5C 24.00-7.00 N/A
Run 2	Run 1 + **All bedroom zones** thermostat setpoints set to 18C from midnight-7am	7.00-9.00: 18C 9.00-16.00: N/A 16.00-24.00: 18C **24.00-7.00: 18C**	7.00-24.00: 20C 24.00-7.00 N/A	7.00-9.00: 24.5C 9.00-16.00: N/A 16.00-24.00: 24.5C 24.00-7.00: 24.5C	7.00-24.00: 24.5C 24.00-7.00 N/A
Run 3	Run 2+ **Master Bed room zones** @ 24 hr occupancy; apply daytime thermostat between 9am-4pm	7.00-9.00: 18C **9.00-16.00: 20C** 16.00-24.00: 18C **24.00-7.00: 18C**	7.00-24.00: 20C 24.00-7.00 N/A	7.00-9.00: 24.5C **9.00-16.00: 24.5C** 16.00-24.00: 24.5C 24.00-7.00: 24.5C	7.00-24.00: 24.5C 24.00-7.00 N/A
Run 4	Run 2+ **All bedroom zones** @ 24 hr occupancy, apply daytime thermostat between 9am-4pm	7.00-9.00: 18C **9.00-16.00: 20C** 16.00-24.00: 18C **24.00-7.00: 18C**	7.00-24.00: 20C 24.00-7.00 N/A	7.00-9.00: 24.5C **9.00-16.00: 24.5C** 16.00-24.00: 24.5C 24.00-7.00: 24.5C	7.00-24.00: 24.5C 24.00-7.00 N/A

The Simulation Run Plan and Settings are set out in Table 1.

Three house plans (Figure 4) were selected to test the implications of the altered thermostat settings and occupancy for bedrooms within the climate zone of interest. Each have four bedrooms and were tested for an east facing orientation for the main bedroom. While House B is a single floor house, House A and C are double storeyed and representative of our study houses, and many western Sydney developments where main living zones are on the ground floor and bedrooms are on the upper floor. To control for other impacts, the street and garage orientation is East facing, making the master suite typically east facing and the main living zone predominantly west. As previously noted all three house models were set up so the Base Case in each house would "just comply to 7 Stars as per NATHERS heating and cooling caps for 2022. In all cases construction included, bulk ceiling insulation (R4.0) and thermally broken double-glazed window (U value 2.5W/K.m2, SHGC 0.39) and construction of external walls were either insulated brick veneer (R2.96) or insulated FC Cladding (R2.91), with a concrete ground floor slab and intermediate floors as Hebel floors for Houses A and C.

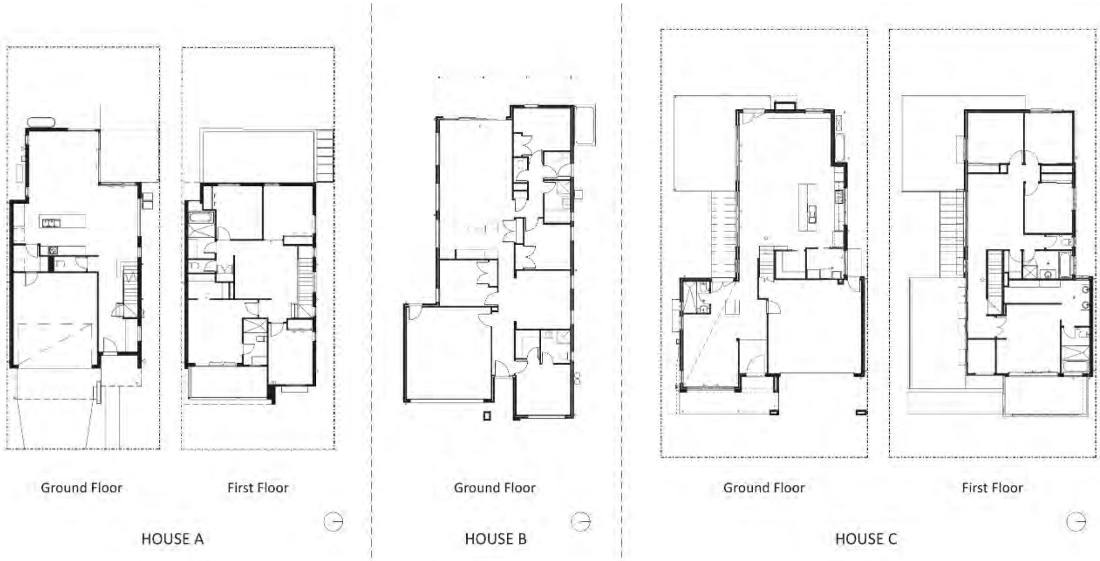


Figure 25: House Layout Plans

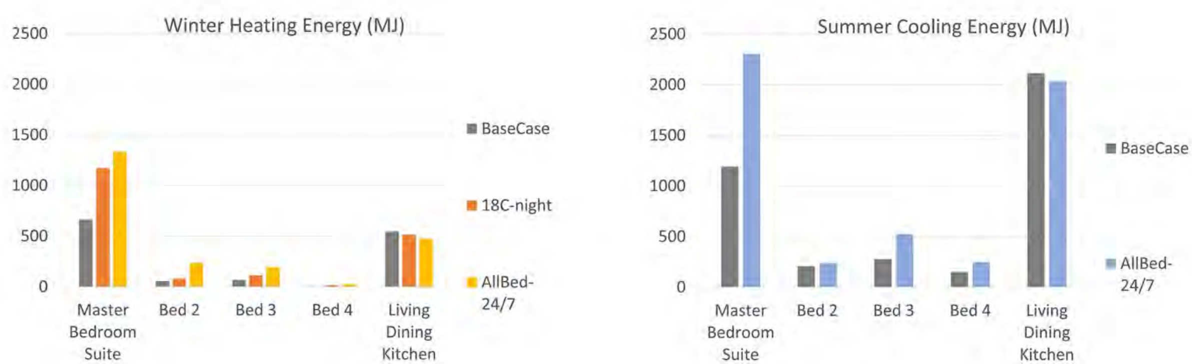
Based on the monitored data, the heating setpoint of 15°C was considered too low. A revised heating setpoint for night time could arguably be set based anywhere from 18 °C which is the lower quartile threshold when AC is off or even 20 °C based on the lower quartile threshold when AC is on. However, from a health perspective and in keeping with WHO guidelines: *"For countries with temperate or colder climates, 18°C has been proposed as a safe and well-balanced indoor temperature to protect the health of general populations during cold seasons"* (WHO, 2018) we have chosen to adopt the 18°C setpoint. Consequently, for subsequent runs, the AccuRate engine input scratch file was edited to adjust the heating set point from 15 to 18°C for midnight to 7am for all bedrooms (Run 2, 3 and 4). When rethinking the bedrooms as daytime spaces between 9-4pm, we then set the heating and cooling setpoints to be 20°C and 24.5°C in line with the other daytime zones under NATHERS. The progressive impact of applying this first to the Master bed and then to All bedrooms is set out for Runs 3 and 4.

5.2. Results

Table 12: Annual Heating and Cooling Energy and Star Rating for Study Houses

	HOUSE A *Total Area 234 m², Conditioned Area 161m²*							***HOUSE B*** *Total Area 201 m², Conditioned Area 128m²*							***HOUSE C*** *Total Area 302 m², Conditioned Area 210m²*						
	Heating Energy MJ/m2-yr		*Cooling Energy MJ/m2-yr*		*Total Energy MJ/m2-yr*		*Stars*	*Heating Energy MJ/m2-yr*		*Cooling Energy MJ/m2-yr*		*Total Energy MJ/m2-yr*		*Stars*	*Heating Energy MJ/m2-yr*		*Cooling Energy MJ/m2-yr*		*Total Energy MJ/m2-yr*		*Stars*
Base Case	**21.1**		**36.5**		**57.6**		7	**43.2**		**23.8**		**66.9**		*7*	**24.7**		38.4		**63.1**		*7*
Run 2	**24.3**	*15%*	**36.6**	*0%*	**60.8**	*6%*	6.8	**48.1**	*11%*	**23.8**	*0%*	**71.8**	*7%*	*6.8*	**29.8**	*20%*	**38.5**	*0%*	**68.2**	*8%*	*6.7*
Run 3	**24.9**	*18%*	**42.8**	*17%*	**67.7**	*18%*	6.4	**49.2**	*14%*	**25.6**	*8%*	**74.8**	*12%*	*6.6*	**30.8**	*25%*	**41.4**	*8%*	**72.2**	*14%*	*6.5*
Run 4	**25.8**	23%	**44.9**	23%	**70.7**	23%	6.2	**53.1**	23%	**26.8**	13%	**79.9**	19%	*6.4*	**31.9**	29%	**47.5**	24%	**79.4**	26%	*6.1*

% change shown above refers to the increase in energy with respect to the Base Case set at the updated compliance level of 7 stars.



(a) (b)

Figure 26: HOUSE A – Step Change in Seasonal Heating and Cooling Energy with reference to its 7-star BaseCase. (Source: Authors)

(a) (b)

Figure 27: HOUSE B – Step Change in Seasonal Heating and Cooling Energy with reference to its 7-star BaseCase. (Source: Authors)

(a) (b)

Figure 28: HOUSE C – Step Change in Seasonal Heating and Cooling Energy with reference to its 7-star BaseCase. (Source: Authors)

When considering the performance of the homes in annual terms, Table 2 shows that changing the night time thermostat results in a 6%-8% increase with respect to the base case, and when combined with the consideration of day time use of bedrooms, this increases to 19-26%.

When considering just the three winter months, in comparison to their base case, the heating energy in winter across bedrooms in the three houses increased by 75% in House A, 100% in House C and 130% in House–B – roughly double on average when setpoint changed from 15-18C. See Figure 5, Figure 6, and Figure 7. During the same period, the combined effect of set point at night and bedrooms occupied during the day is at least double to over three times the heating energy of the base case in the three homes studied (126% in House A, 148% in House C and 291% in House B.

Considering the bedrooms to be occupied over the day in summer also has a significant effect, with the increase at individual bedroom level anywhere between 30% and 100% of the base case and an average increase of 40% across the three houses.

5. Discussion and Conclusion

The results for occupant practices in the monitored homes reveal that some settings within NATHERS are out of touch with observed and prevailing practices and could be compromising the intended thermal performance of houses.

Heating set points: The results for monitored temperatures clearly show that the adopted heating setpoints are higher than the NATHERS heating setpoint of 15°C overnight, and once heating is deployed, space temperatures are maintained around 20C. As such the present NATHERS assumption is not reflective of user practices. While it is true that people do adapt to colder temperatures with the benefit of quilts and sweaters and other adaptive practices, the focus of this paper is on ensuring mandatory stringencies to ensure building fabric performance is not compromised especially once heating is deployed. Moreover, we argue that the fabric must be tested for comfort against at least the minimum health guideline of 18°C for night time and agree that NATHERS daytime heating setpoint continue to be 20°C.

The impact and significance of changing the thermostat from 15 to 18°C at night is best understood at the seasonal level for Winter. Given that unconstrained energy estimates in NATHERS are a proxy for thermal discomfort, the doubling of heating energy in the Bedroom zones across the Winter season shows the scale of increased discomfort if the 18°C yardstick was applied to assess night-time performance of code compliant homes under the new NCC. When considered in terms of annual energy, the energy impact of changing the set point from 15 to 18°C seems small (roughly 6-8% as seen in Table 1). However, given health risks previously discussed and the race to lower energy consumption in homes, this is not an energy penalty that can be ignored, but rather one that should be combated with improved building design and thermal performance.

Daytime comfort in bedrooms: Bedrooms may be envisaged as places for sleeping in an idealised world. However, increased pressure on rents, adult children staying at home, requirements and choices for multiple family members working from home, requirements such as caring for children or invalids in bedrooms would suggest that bedrooms are increasingly used as multi-functional spaces (Dincer et al, 2023). As reinforced through our occupancy results, bedrooms must no longer be considered simply as the "night-time" zone envisaged in NATHERS, wherein the heating/cooling energy requirements are not tested between 9am and 4pm.

As shown in our modelling results, the building fabric in the three homes that would be assessed to be code compliant would in fact, incur additional energy penalty when bedrooms are considered to be occupied in the daytime. This indicates that the treatment of bedrooms merely as night-time zones, means the rating tool is ignoring the daytime discomfort both in winter and in summer in the bedrooms and overlooking the need for an improved building fabric that would be required to combat this.

Study limitations: We acknowledge our findings in this paper depict implications for just one climate zone and further research will be required to ascertain the impact under different climate zones, house types and future weather scenarios. Further work is envisaged in this respect. Nonetheless our analysis for Western Sydney climate is noteworthy as it is one of the regions that is experiencing exponential development in the country. (Morrison and Van den Nouwelant, 2020)

The question of night-time heating set point may be perceived as less important in the context of warming temperatures. However, further to the prevalence of cold in Australian homes and health imperative previously discussed (Barlow et al, 2023 and WHO, 2018), it should also be noted that predictions for climate change continue to acknowledge cold snaps with risks from cold being greater for people with health and economic vulnerabilities (Baker et al, 2020). Moreover, the concern for warming temperatures in future summer only reinforces the need to pay careful attention to the bedroom zones in the interest of ensuring all spaces in homes remain resilient to a changing climate.

As a further caveat, we note that our present analysis remains unquestioning of air-tightness in the houses. While the NCC implies an infiltration rate of 10ach, previously published research (Ambrose and Syme, 2015) of blower door tests in Australian homes suggest infiltration could be as high as 30 ach. If indeed efforts are not taken to ensure infiltration matches modelled assumptions then our results particularly for heating would be under predicted, and the building fabric would need to work harder to compensate for infiltration losses.

Although our monitored data already suggests a tolerance of temperatures around 25-26°C in summer, the cooling setpoint of 24.5°C prescribed under NATHERS has been retained in the present analysis. From the perspective of future warming climates, we acknowledge that the 24.5 cooling setpoint would be expected to increase based on the adaptive model of comfort. However, we anticipate using the current setpoint within present day weather files ensures a more stringent building fabric, that could then be expected to remain resilient in a warming climate.

Implications for the Rating System: Assuming the current energy budget under NCC 2022, our findings show that a home in western Sydney that is assessed to be compliant under current settings would drop by nearly a full star band with an accompanying energy penalty of up to 26% per annum from the combined effect of night time heating setpoint and day time use of bedrooms

Our findings point to an underestimation of energy use which has the potential to compromise the thermal performance and specifications of the building envelope. We call for an update to NATHERS settings to ensure bedroom thermal comfort and fabric performance is not overlooked **and we would recommend bedrooms be assessed with a night time heating set point of 18°C instead of 15°C and also stress the need to test for comfort in bedrooms during the day.**

The urgency for reduction in CO_2 emissions from this sector means that it is imperative that current energy budget must not be diluted. Given the star bands are based on a particular energy budget per climate that seeks to steer the housing stock towards its decarbonisation strategy, we also take the view that these budgets cannot be increased when testing for comfort. In other words, in the face of increased energy predictions from revised settings, we argue **further improvements to the building fabric are needed to maintain the overall thermal efficiency into the future.**

Additionally, with a view to sufficiency, and as discussed elsewhere (see Thomas 2022b), rating tools and policy must protect adaptive and sustainable practices through requiring homes with effective natural ventilation that include adaptive opportunities such as secure openable windows, ceiling fans as well as encourage indoor–outdoor living opportunities to acclimatise occupants to a wider range of temperatures and support occupant education and engagement towards such practices.

Considerations for existing homes: While our discussion up to this point have been in relation to the rating scheme for newly built homes, the findings are also relevant to existing homes. Firstly, it is worth noting the vulnerability of the building fabric will apply to a greater extent to homes that were deemed compliant even at 5-star level (2006 onwards) and 6-star level (since 2010 depending on jurisdictions) and until new provisions come into effect. We also suggest that as NATHERS turns its attention to existing homes, the system carefully consider the manner in which occupants use their homes is correctly reflected, especially as the tool is expected to inform retrofitting decisions. For instance, our past experience has shown that it has been possible to comply with 5 and 6- star requirements with single glazed windows in a western Sydney climate. Recognizing the energy penalty and consequences to bedroom discomfort could become the impetus to consideration of double glazing and other improvements to the building fabric from a thermal comfort point of view well before offsetting energy used with solar panels when retrofitting homes in these climates.

In conclusion: While NATHERS is designed to benchmark thermal performance and is not in itself a predictor of actual energy use, it is only useful as a rating system if it delivers the CO2 emission reductions we need towards Australia's low energy trajectory. Settings within NATHERS must therefore be reflective of user practices especially as they establish policy settings for building envelope stringencies. The reality suggests that in contemporary households the design and comfort in all spaces especially bedrooms must be taken more seriously than is currently acknowledged in the tool. Our study points to an underestimation of energy use has the potential to compromise the thermal performance and specifications of the building envelope by the equivalent of a one star under NATHERS. Our findings call for changes to regulatory settings that ensures bedrooms be tested for comfort more stringently as outlined above, and that the necessary improvements to the building fabric to account for these changes are mandated.

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