Australia's National Science Agency

Data Analysis Report and Comfort Rating Recommendations

Darwin House Comfort Rating Project

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About

This report was delivered as part of the work of the Darwin Living Lab. The Darwin Living Lab was established to foster improvements in the liveability, sustainability and resilience of the city. The Darwin Living Lab is an initiative under the Darwin City Deal and is a 10-year collaboration between CSIRO and the partners of the Darwin City Deal: Australian Government, Northern Territory Government and the City of Darwin. The City Deal was signed by the Prime Minister of Australia, Chief Minister of the Northern Territory and Lord Mayor of the City of Darwin in November 2018.

More information and contacts available at: https://research.csiro.au/darwinlivinglab/

Acknowledgement

We acknowledge the Traditional Owners of the greater Darwin region, the Larrakia people, and recognise their culture, history and connection to this land and water. We pay our respects to their Elders past, present and emerging.

Citation

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Cover Photo: CSIRO, Raised lightweight dwelling in Muirhead, 30 November 2018.

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Acknowledgments

The Darwin House Comfort Rating project is led by CSIRO’s Building Energy team and the Northern Territory Department of Infrastructure, Planning and Logistics (NT DIPL) as part of the Darwin Living Lab. This report is part of that project, providing the evidence to support the development of a comfort rating tool. The work reported here has been undertaken by Queensland University of Technology with the following contributions.

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Executive summary

This report provides the evidence to support the development of a comfort rating tool with 'for information' living room and bedroom comfort ratings for Darwin dwellings. Such a tool could be used to (i) educate Darwin consumers and other stakeholders about good climate sensitive design for hot humid tropics, including methods to optimise comfort when air conditioning is not used; (ii) improve passive comfort outcomes in Darwin residential building design; and (iii) increase stakeholder awareness of the need to design and build climate change resilient residential buildings, to the extent possible, to reduce health risks when air conditioning is not available.

Formulae for determining comfort thresholds (°C) for living rooms and bedrooms in Darwin dwellings were used to calculate comfort thresholds for living and bedroom zones for each month of the year, at 80% and 90% acceptability. Note that the formulae are different for living rooms compared to bedrooms (to account for differences in occupant activity, clothing and metabolic rate). The formulae account for humidity, natural ventilation and the air movement from ceiling fans.

These comfort thresholds were incorporated into a new version of AccuRATE and applied to two sets of dwellings: (i) 1043 dwellings from CSIRO's Australian Housing Data, Darwin dwellings that had a Universal Certificate issued for the years 2020 and 2021; and (ii) simulations of 11 dwellings (5 detached houses (4 plans), 2 duplexes and 2 apartments (each as middle and top floors)). All dwellings were simulated for the four cardinal orientations and 3 design variations). Each variant was modelled using 2016 and 2050 climate files. One of these variants was also optimised (total number of simulation files = 266).

The AHD data set shows that:

- Very few dwellings are designed to include wall or ceiling insulation.
- The majority of Class 1 dwellings have 1 living area (the kitchen/living zone), with under 30% having a second separate living area. Most of these dwellings have 3-4 bedrooms. In contrast, almost all Class 2 dwellings have only 1 living zone, with the majority having 1 or 2 bedrooms. There are relatively few 3 and 4 bedroom apartments.
- Dwellings in Darwin require no or very little heating and lower energy rated dwellings generally had a higher cooling intensity than higher energy rated dwellings.

Analysis of these results was used to recommend the parameters of the proposed comfort rating.

The overarching principles of the comfort rating are:

- Ratings will be based on the kitchen-living zone and the worst bedroom. The worst bedroom is the one with the highest degree (hours) of discomfort.
- Separate comfort ratings will be provided for these two zones.
- Ratings would be based on occupied hours for each zone.
- The main comfort rating for each zone would use total annual degree (hours) of discomfort (DD) for all occupied hours. Additional information provided on a 'Comfort Rating Certificate' would include % of occupied hours where the threshold was exceeded, and maximum hourly DD (i.e. the worst hour).

A look-up table for the recommended comfort rating bands was developed, taking into account the minimum and maximum values revealed in the data, and the midpoint of the comfort rating being representative of the average comfort rating of AHD dwellings in the 5-5.9 energy star rating band.

COMFORT RATING	LIVING ROOM DD	WORST BEDROOM DD
1	15,000	3,600
2	9,000	2,160
3	5,400	1,296
4	3,240	778
5	1,944	467
6	1,166	280
7	700	168
8	420	101
9	252	60
10	151	36

A summary of the report's recommendations and limitations is provided here.

Recommendation 1: The comfort bands for the kitchen/living zone and the worst bedroom should be assigned as per the look-up table (Table 10 and above) for total DD relevant to each zone. Increments of 0.1 could be applied, as currently happens for energy star ratings.

Recommendation 2: Consideration should be given by designers of housing specifically meant for vulnerable populations to use the comfort threshold formulae relating to 90% acceptability. This could apply to demographics known to have higher incidence of chronic disease (e.g. indigenous, elderly, disabled) or known susceptibility to overheating (e.g. very young children, pregnant women, elderly), and to demographics with limited financial resources (e.g. social or private rental housing for lower socio-economic clients).

Recommendation 3: Designs should strive for a comfort band rating of 9 for living zones, equating to approximately 4% of annual occupied hours over the comfort threshold. For bedrooms a minimum comfort rating of 7 is recommended, representing 2.7% of annual occupied hours over the comfort threshold.

Recommendation 4: Designs should consider both current and future weather conditions, as dwellings constructed today are likely to be in operation in 2050. The data analysis suggests that this housing in 2050 could have 30% more annual hours above the comfort threshold compared to current overheating based on the 2016 weather file (at 80% acceptability).

Limitation 1: None of the comfort criteria communicate the distribution of overheating. This is an important issue particularly when zones have a high DD count and exceedance is often above 1°C, because accumulative exposure to overheating can have a different impact on occupants compared to short term exposure.

Limitation 2: The medium and good variants of the simulated designs changed multiple features. It may be helpful for the housing industry to understand the implications of individual changes to design (e.g. increase in insulation only; in glazing only; in ventilation only etc). In addition, parametric modelling is recommended to investigate what combinations of improvements can provide the most benefit.

Limitation 3: Neither the 2016 nor the 2050 weather files utilised in this project take into account heat wave conditions (i.e. both files are based on a Reference Meteorological Year that uses average weather conditions). As such, the building performances simulated do not reflect the full extent of 'discomfort' that might be experienced during sequential or extreme hot days that exceed the average maximum temperature and humidity for each month.

1. Introduction

This report provides the evidence to support the development of a comfort rating tool with 'for information' living room and bedroom comfort ratings for Darwin dwellings. Such a tool could be used to:

- Educate Darwin consumers and other stakeholders about good climate sensitive design for hot humid tropics, including methods to optimise comfort when air conditioning is not used;
- Improve passive comfort outcomes in Darwin residential building design; and
- Increase stakeholder awareness of the need to design and build climate change resilient residential buildings, to the extent possible, to reduce health risks when air conditioning is not available.

The report is structured into three main sections. Section 2 characterises Darwin dwellings, based on data from Universal Certificates (energy rating certificates) issued as part of the building application process in the years 2020 and 2021. It then applies the comfort rating methodology to that data set. Section 3 applies the comfort rating methodology to 8 dwelling plans, showing the impact of design choices on the comfort levels for each of the dwellings. Section 4 summarises the key findings from the previous sections and uses these findings to propose the parameters for a comfort rating tool.

Image 1: Louvres and ceiling fans assist comfort through air movement (Supplied: Wendy Miller)

2. Australian Housing Data

This section contains analysis of data from CSIRO's Australian Housing Data (AHD). This data set consists of all Darwin dwellings (1103) that had a Nationwide House Energy Rating Scheme (NatHERS) Universal Certificate issued in 2020 and 2021. The analysis is based on the data from these Universal Certificates.

2.1 Characterisation of Darwin dwellings

The charts presented in this section have been provided by CSIRO's Michael Ambrose, with commentary by QUT's Wendy Miller. Data was analysed using Tableau (a visual analytics platform).

The distribution of energy ratings for these Class 1 and Class 2 dwellings is shown in Figure 1. Note that there are no Class 2 dwellings under a 5 star energy rating, while there are 60 Class 1 dwellings under 5 stars.

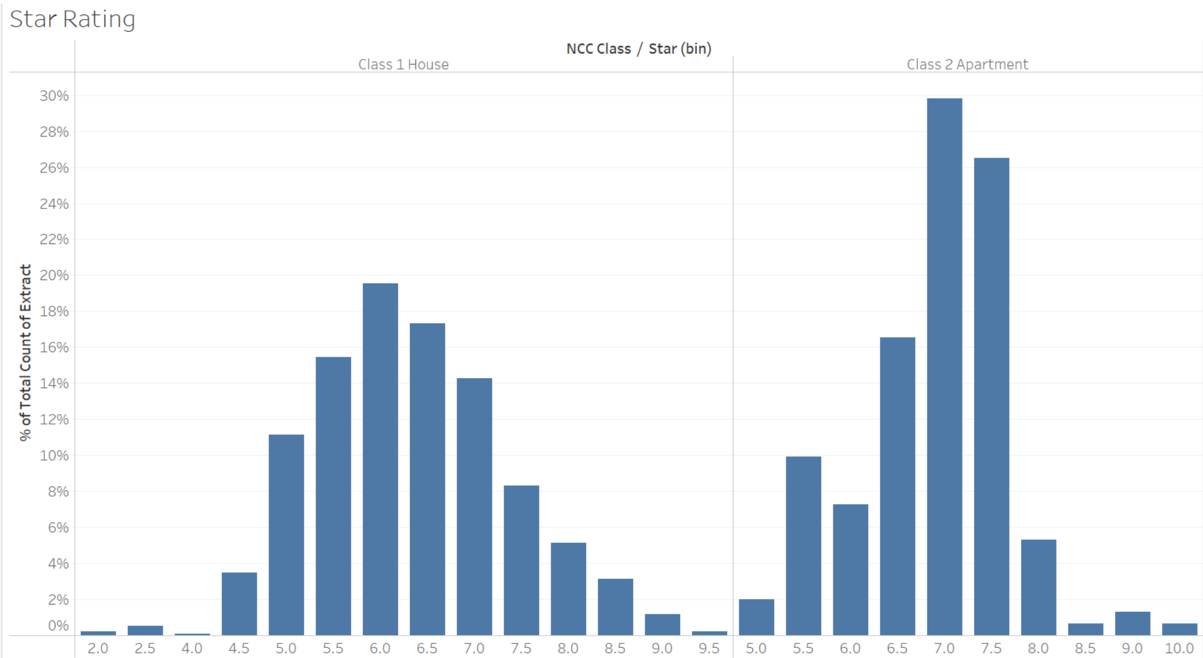


Figure 1 Class 1 and Class 2 energy rating distribution

The scatter plots in Figure 2 and Figure 3 compare the space heating demand (x axis) with the space cooling demand (y axis) for Class 1 and Class 2 dwellings respectively. They confirm that dwellings in Darwin require no or very little heating and that, generally, lower energy rated dwellings had a higher cooling intensity than higher energy rated dwellings. The cooling intensity for Class 1 dwellings is roughly between 200 and 400 MJ.m^2.year, while for Class 2 dwellings the cooling energy intensity is slightly lower, at 190 – 370 MJ.m^2.year.

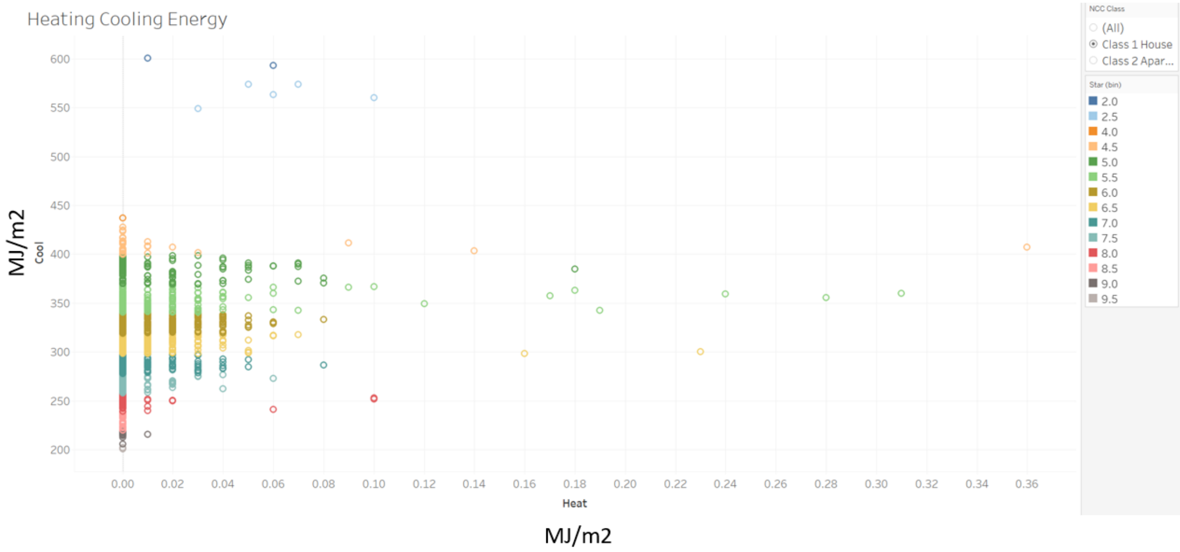


Figure 2 Class 1 space cooling vs space heating intensity

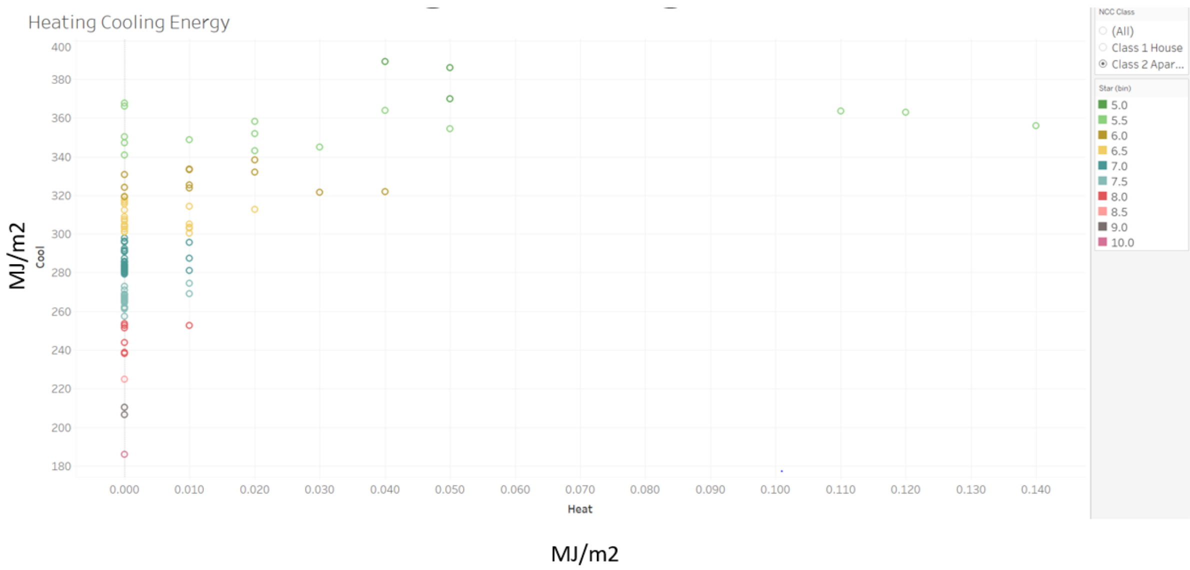


Figure 3 Class 2 space cooling vs space heating intensity

The AHD also confirms that very few dwellings are designed to include wall or ceiling insulation (Figure 4). The reason for this low level of insulation was not examined, although anecdotal evidence gathered by the main author from tropical housing projects in Queensland suggests four possible reasons:

- A belief that housing in the tropics will cool down more quickly if insulation is not present (i.e. bulk insulation traps heat inside the house);
- Low energy efficiency regulations (housing can often achieve 5 stars without insulation);
- Complexities of managing heat and vapour in hot humid conditions; and
- Builders and designers don't pay for the air conditioning of the dwellings they construct (and air conditioning is perceived as the only / main way to achieve thermal comfort).

These possible reasons suggest that there may be limited understanding of heat (and moisture) transfer and a lack of industry and consumer knowledge about products and design solutions that can effectively manage both.

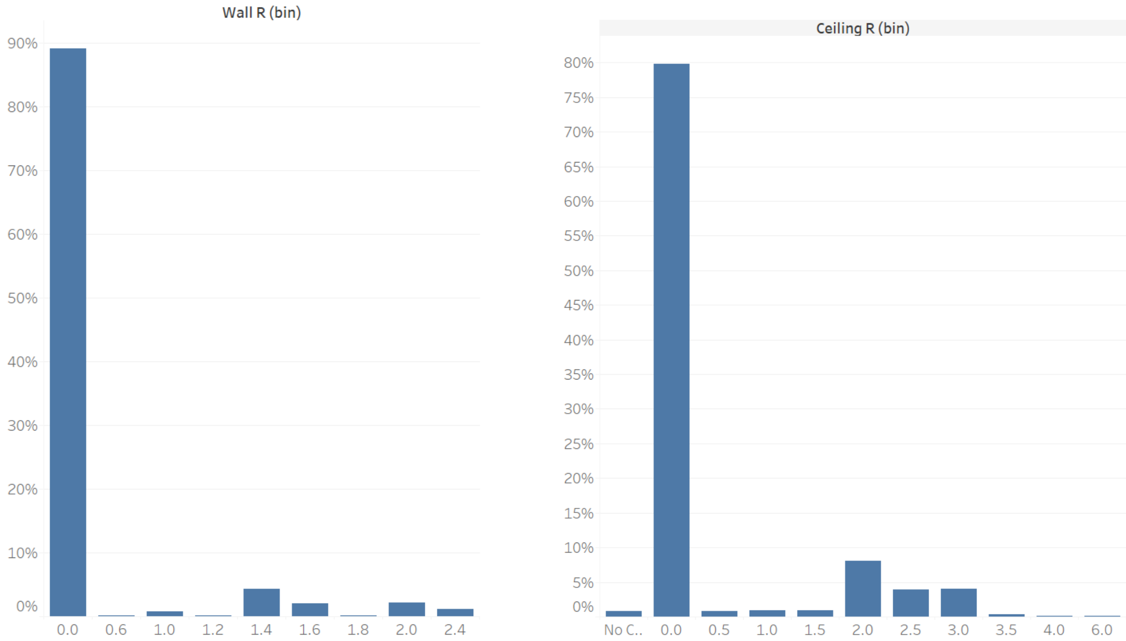


Figure 4 Percentage of dwellings with different R value wall (left) and ceiling (right) insulation

Most Class 1 dwellings have a total floor area of 100 – 180m^2, with a conditioned area of 60 – 120 m^2. Class 2 dwellings were smaller, with a total floor area of 60 – 80m^2, and a conditioned area of 40 – 60m^2. A greater proportion of the floor area of apartments (Class 2) is conditioned, compared with Class 1 dwellings (detached homes, duplexes, terrace homes).

The majority of Class 1 dwellings have 1 living area (a combined kitchen-living zone), with under 30% having a second separate living area. Most of these dwellings have 3-4 bedrooms (Figure 5). In contrast, almost all Class 2 dwellings (Figure 6) have only 1 living zone, with the majority having 1 or 2 bedrooms. There are relatively few 3 and 4 bedroom apartments.

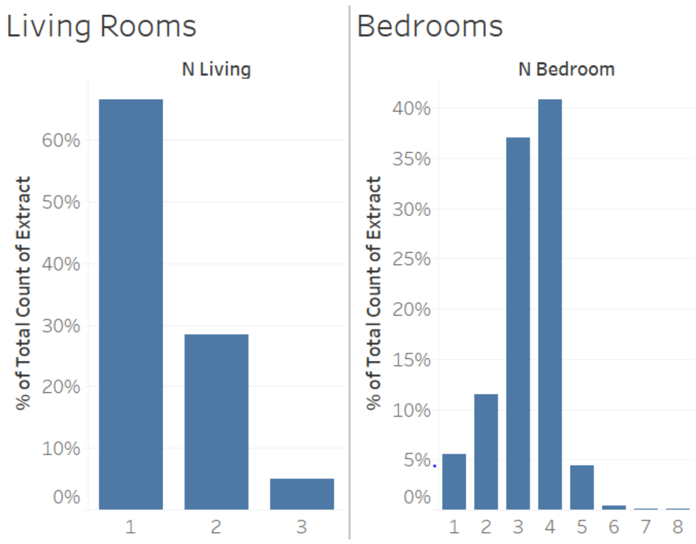


Figure 5 Class 1 Number of living room and bedroom zones

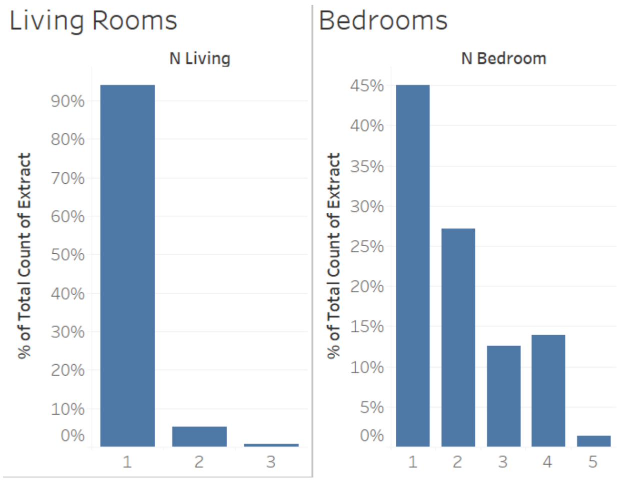


Figure 6 Class 2 Number of living room and bedroom zones

Ninety-five percent of all the dwellings have between 2 and 6 zones. For this reason, further analysis only considered up to 6 zones. Zone 1 is always the kitchen-living zone, as all dwellings are required, in the Universal Certificate, to have this type of zone. Zone 2 may be a living zone or bedroom zone, depending on each individual dwelling. Zones 3-6 were assumed to be bedrooms, as 84% of zone 3 data in the AHD related to bedrooms.

2.2 Darwin dwellings comfort analysis

60 homes from the AHD Darwin data set were excluded from the following analysis because they were below the 5 star energy rating and therefore considered to be non-compliant with the current NT building regulations. The following analysis relates to the remaining 893 class 1 and 150 Class 2 dwellings (n=1043). Data analysis used both Tableau and Excel.

The comfort thresholds for Darwin had been agreed by this project's Technical Reference Group (TRG), based on scientific data. Refer to the overheating assessment methodology for more information[1]. The formulae used to determine the Degree (hours) of Discomfort (DD) are shown in Table 1. Note that the formulae are different for living rooms compared to bedrooms (to account for differences in occupant activity, clothing and metabolic rate). The formulae account for natural ventilation and the air movement from ceiling fans. The application of these formulae to Darwin's climate results in monthly 'comfort thresholds' as shown in Table 2.

Table 1 Formulae used to calculate Degree (hours) of Discomfort (DD)

OPERATION	ROOM	ACCEPTABILITY[2]	DEGREE (HOURS) OF DISCOMFORT (DD)[3]
MIXED MODE (NATURAL VENTILATION + CEILING FANS)	Living Rooms	90%	$ET^* - (0.31 * Toutmm + 20.9) - CEV$
	Living Rooms	80%	$ET^* - (0.31 * Toutmm + 22.6) - CEV$
	Bedrooms	90%	$ET^* - (0.31 * Toutmm + 19.8) - CEV$
	Bedrooms	80%	$ET^* - (0.31 * Toutmm + 21.3) - CEV$

[1] Williamson, T., Damiati, S.A., Soebarto, V. 2022. "Developing a Methodology to Assess Potential Overheating of Houses in Darwin". In P.Izadpanahi and T.Glusac (es.), *Architectural Science and User Experience: How can Design Enhance the Quality of Life: 55th International Conference of the Architectural Science Association 2022*, pp. 1-11.

[2] Refer to section 2.2.3 for a discussion on the meaning and implications of acceptability.

[3] Refer to the Glossary for an explanation of the abbreviations.

Table 2 Monthly comfort thresholds for living and bedroom zones (Effective Temperature °C)

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
LIVING ZONES	90%	29.59	29.54	29.51	29.50	29.21	28.66	28.44	28.71	29.43	29.86	30.02	29.83
	80%	31.29	31.24	31.21	31.20	30.91	30.36	30.14	30.41	31.13	31.56	31.72	31.53
BED-ROOMS	90%	28.49	28.44	28.41	28.40	28.11	27.56	27.34	27.61	28.33	28.76	28.92	28.73
	80%	29.99	29.94	29.91	29.90	29.61	29.06	28.84	29.11	29.83	30.26	30.42	30.23

The following criteria were applied to the comfort analysis:

- AHD dwellings < 5 star energy rating were excluded.
- The remaining 1043 dwellings were simulated using the comfort simulation software.
- The simulations used 2 weather files in NatHERS format to check the sensitivity of existing designs to the current climate and to future climate change.
  - The 2016 reference meteorological year (RMY) weather file is called up by the National Construction Code 2022 and is based on 1990 – 2015 historical data.
  - The 2050 predictive weather file is based on the 2016 RMY file and was developed by CSIRO for non-regulatory building simulation purposes. The specific file used for this project is based on the IPCC's RCP8.5[4] scenario that assumes limited abatement of carbon has occurred[5].
- 80% and 90% acceptability[6] of the comfort thresholds were determined (as per Table 1).
  - ASHRAE 55 recommends 80% for typical applications and 90% when higher thermal comfort is wanted (e.g. very young, elderly, chronic diseases, pregnancy etc).
- Data was analysed by
  - % of total annual hours above the threshold – representing duration of overheating; and
  - Degree (hours) of Discomfort (DD) for occupied hours – representing magnitude and duration of overheating.
- The occupancy and appliance schedules in NatHERS for Universal Certificates were used:
  - Living Zones – 07:00 – 24:00 (17 hours/day; 6210 occupied hours per year);
  - Bed Zones – 16:00 – 09:00 (17 hours/day; 6210 occupied hours per year).

[4] The International Panel on Climate Change (IPCC) developed a number of Representative Concentration Pathway (RCP) climate projections that reflect a range of possible climate futures for the period 2020 - 2100. RCP8.5 assumes that there has been little reduction in greenhouse gas emissions. Greenhouse gas emissions, atmospheric greenhouse gas concentrations and resultant radiative forcing are used to predict future weather.

[5] Ren, Z., Tang, Z., Names, M. 2021. *Predictive weather files for building energy modelling: Using Guide*. CSIRO, Australia.

[6] Refer to section 2.2.3 for more explanation of acceptability percentages.

2.2.1 Class 1 dwellings

Table 3 compares class 1 energy star ratings (in half star bands) with the average % of annual hours overheating, i.e. the % of annual hours when the dwellings in these bands were above the comfort threshold. This figure is derived by combining the overheating % of zone 1 (living/kitchen) and the worst bedroom, resulting in an average overheating %. Because this data did not include specific dwelling plans, some assumptions were made:

- If a dwelling had 5 zones, it was assumed that zones 2-4 were bedrooms, and hence the worst of these was selected.
- If the dwelling had 6 zones, it was assumed that zone 2 was a 2nd living zone, so the worst of zones 3-6 was selected.

It is worth noting that percentages may not give a clear indication of the extent of overheating. For example, 45% of annual hours overheating equates to 167 days, or 4022 hours. 14% equates to 51 days, and 5 % equates to 18 days.

What is not shown in this table is the minimum and maximum overheating % for each of these zones separately. The distribution of overheating hours is also not shown. For example, if 5% of hours are overheating, what is their distribution? Are they consecutive hours or days, or more random? This is an important issue particularly when zones have a high percentage of overheating, because accumulative exposure to overheating can have a different impact on occupants compared to short term exposure.

Table 3 Class 1 energy rating bands and overheating percentage

STAR BANDS	NO. OF DWELLINGS	% OVERHEATING (TOTAL ANNUAL HOURS)[7]		
		Min.	Mean	Max.
5.0 – 5.4	101	8.84	18.02	40.58
5.5 – 5.9	143	8.60	16.51	39.74
6.0 – 6.4	185	7.52	14.78	45.92
6.5 – 6.9	163	7.50	13.62	41.31
7.0 – 7.4	136	5.67	11.97	24.82
7.5 – 7.9	79	5.02	10.64	24.55
8.0 – 8.4	46	4.98	9.31	20.72
8.5 – 8.9	29	6.58	10.07	20.73
9.0 – 9.4	9	5.23	9.23	19.09
9.5 - 10	2	-	7.05	-

[7] The Min. and Max. % overheating figures relate to the lowest and highest values indicated in the dwellings for each star band (i.e. they each relate to a single dwelling). The Mean % overheating figure is the mean of all dwellings in each star band.

When graphed (Figure 7), this data shows a general trend of decreased average annual overheating hours, and decreased range of overheating, as energy star bands rise. This shows that overheating hours are less in 7+ star homes compared to <7 star homes. Note that this data is only looking at the average overheating % (the sum of the living/kitchen zone and the worst bedroom).

It is worth noting that the minimum overheating values (for each star band) are between 3 and 10% of annual hours, but the maximum overheating values for 5 and 6 star dwellings are concerningly high (40-45% of the year). Though much improved with 7-8 star homes, the maximum overheating values are still in the range of approximately 20-25%.

It needs to be highlighted that the min. and max. values are from individual dwellings, showing that, within each half star energy band, individual dwellings can have vastly different overheating potential (based on the criteria used in this project). The difference between the best and worst, within each star band, is less once you get to 7 stars (difference of about 20%); and 8 stars (difference of about 15%).

A scatter plot of this data (Figure 8) shows the concentration of overheating, with a mean generally between 10-20%, and decreasing as star ratings rise.

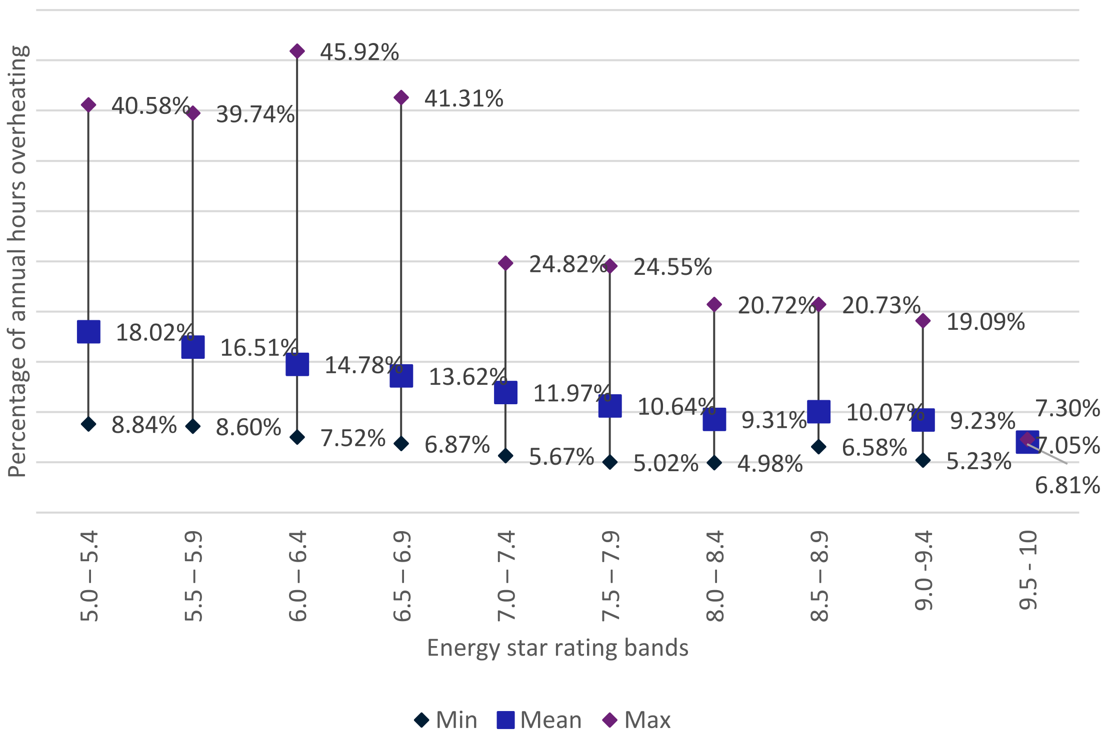


Figure 7 Class 1 Overheating % vs energy star ratings (average of living and worst bedroom)

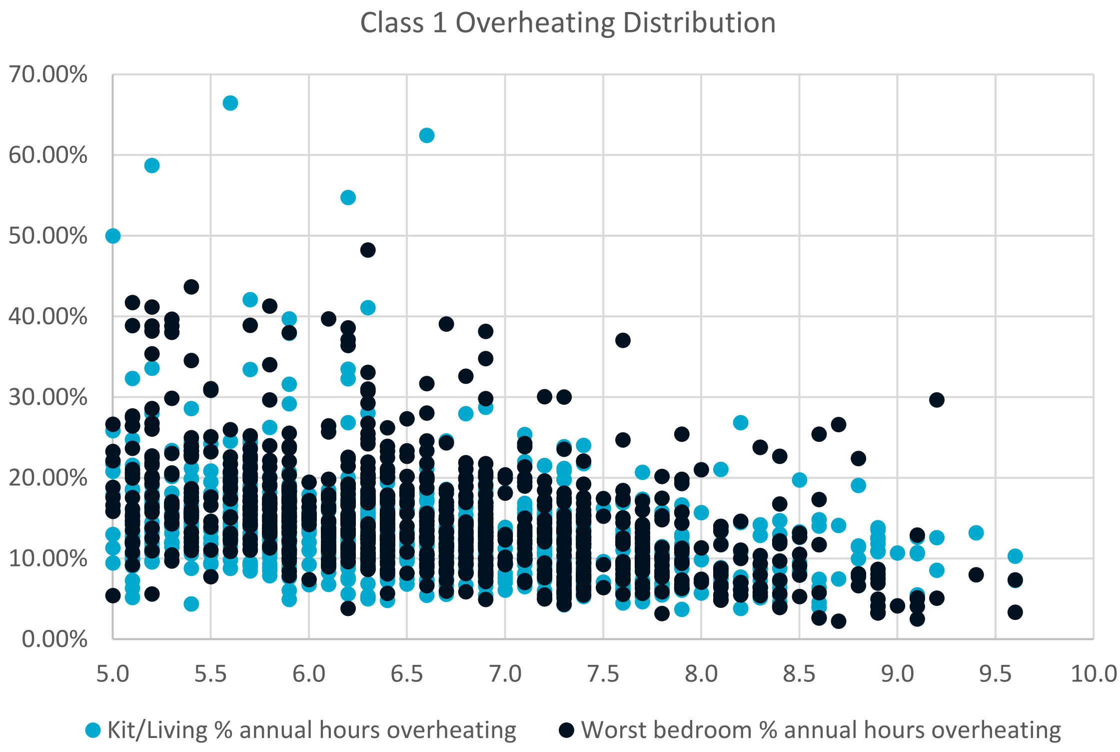


Figure 8 Scatter plot of Class 1 overheating % and energy star rating

Figure 9 separates out the overheating of the living and bedroom zones. It shows the average % of annual hours overheating for each of these zone (red for living zone, and orange of worst bedroom). The green bar is the mean of the two (as shown previously in Table 3). It shows a general trend for the worst bedroom to have more overheating hours than the kitchen/living room, for all star bands up to 8.4. For the higher star bands (keeping in mind the smaller data set), the trend is for discomfort hours to be greater in the living room compared to the worst bedroom. Note that only 3 star bands (8-8.4; 9-9.4 and 9.5-10) achieved an average overheating percentage of less than 10%, and individual room overheating (living room and worst bedroom) of less than 10%. Note also that the difference between the living room and bedroom overheating % is less than 5%.

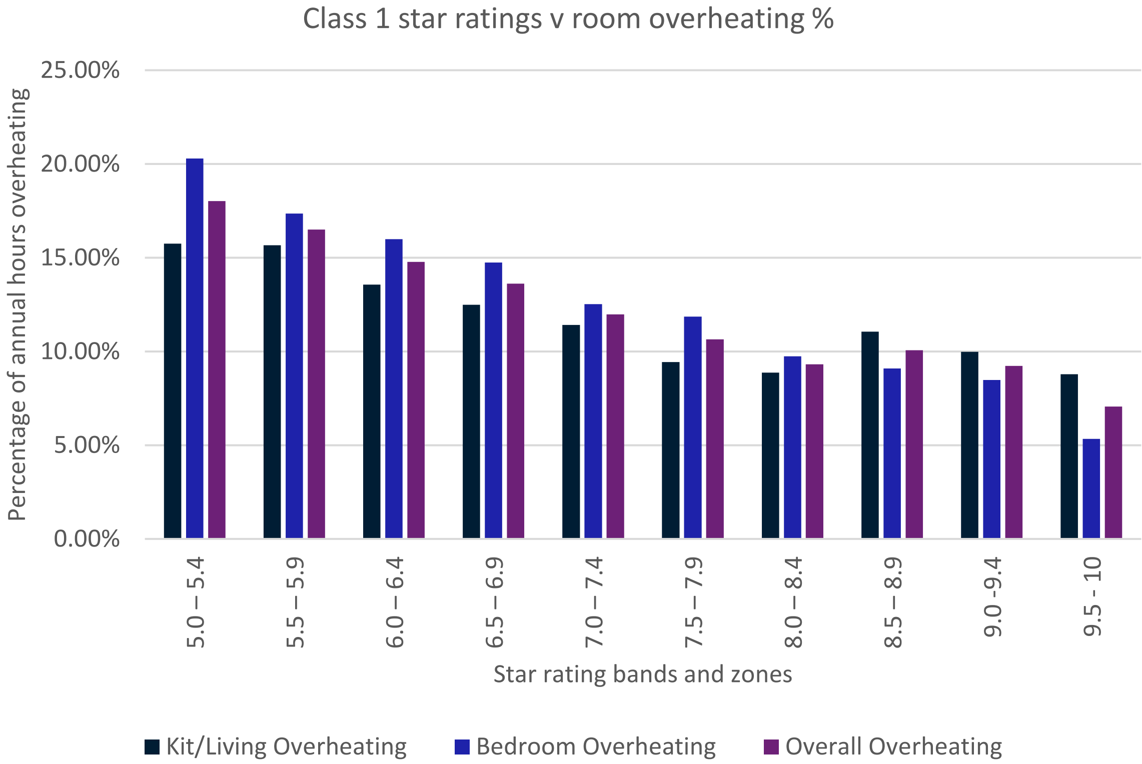


Figure 9 Class 1 star ratings v room overheating %

The 'overheating' analysis only counts the number of hours in a year that the comfort threshold was exceeded. It does not account for the magnitude of the overheating, i.e. by how many degrees did each incident exceed the comfort threshold. The Degree (hours) of Discomfort – DD – is a measure of the magnitude of the overheating. It is a count of the both the hours of exceedance as well as the degree of that exceedance.

DD analysis, as shown in Figure 10, is based on the occupied hours of each zone, rather than total annual hours. It compares the DD for the kitchen/living zone with the DD of the worst bedroom, again presented per half energy star band. Note the general trend for the DD to decrease as the energy star ratings increase. Also note that the DD for bedrooms, across all star bands, is less than the DD for the living zone

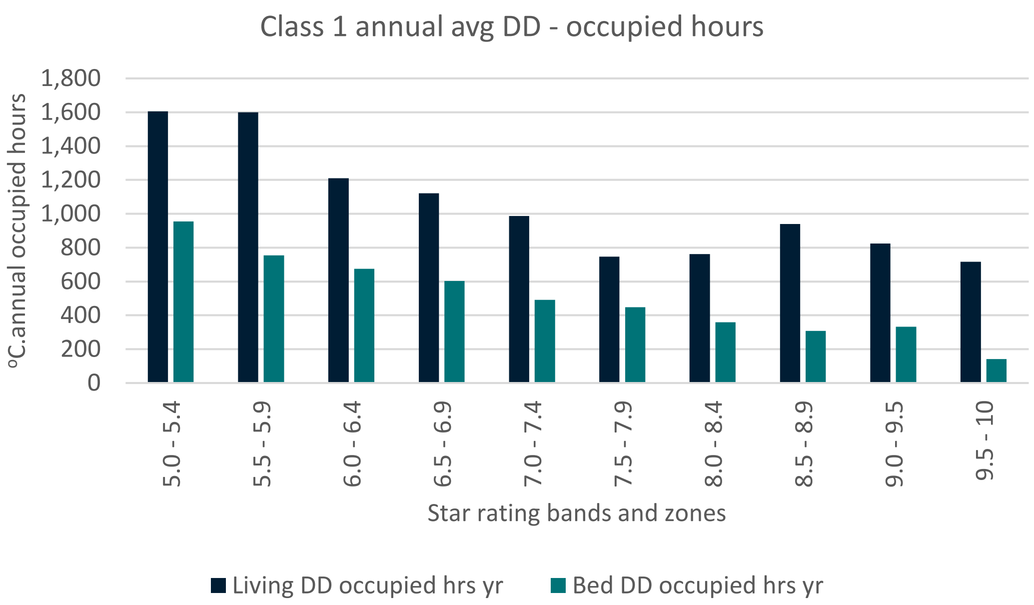


Figure 10 Class 1 average annual DD

The magnitude of overheating can also be examined by looking at the maximum and average DD, for each zone, recording the highest and average hourly figure for occupied hours Figure 11. Again, it is clear that the extent of overheating diminishes as star ratings increase, although even in a 9+ star home, a living room can exceed the comfort threshold by almost 8 degrees. Living rooms exceed the comfort threshold by a greater extent than bedrooms, as would be expected due to the different occupancy times. The average DD for living zones and bed zones, shown in the table, also decreases with increased star ratings.

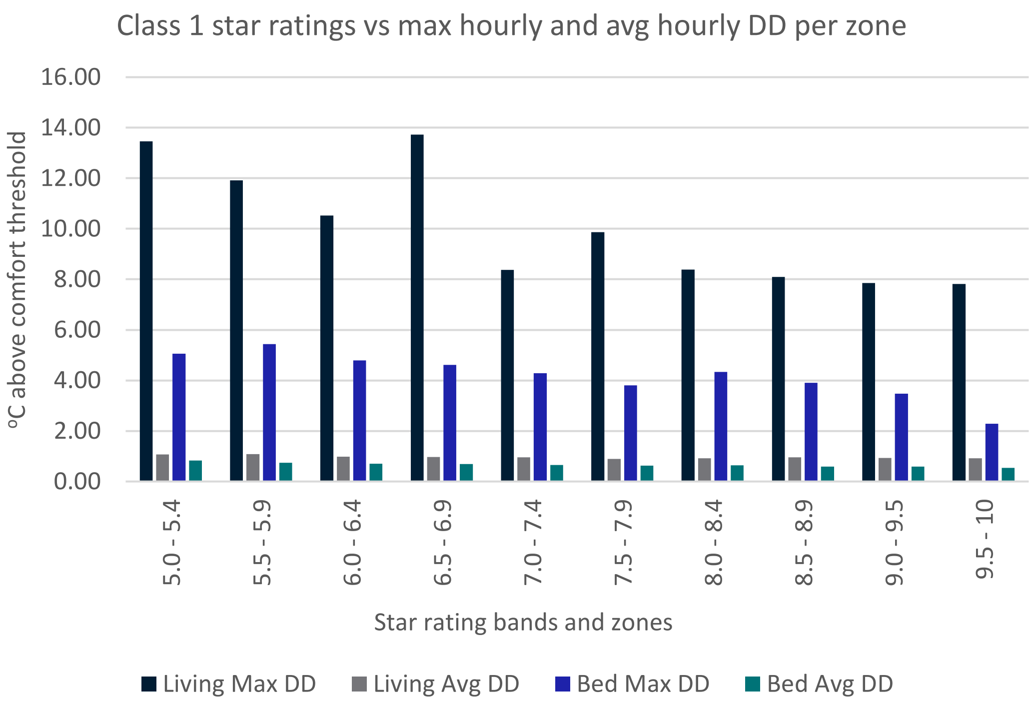


Figure 11 Class 1 maximum and average DD

2.2.2 Class 2 dwellings

The same analysis was applied to the Class 2 data set. Table 4 and Figures 12-14 compare the energy star ratings with the percentage of annual hours overheating.

Table 4 Class 2 energy rating bands and overheating percentage

STAR BANDS	NO. OF DWELLINGS	AVERAGE % OF ANNUAL HOURS OVERHEATING		
		Min.	Mean	Max.
5.0 – 5.4	3	11.82	13.85	15.88
5.5 – 5.9	15	12.09	17.58	26.76
6.0 – 6.4	11	9.12	14.87	22.92
6.5 – 6.9	25	6.10	15.06	21.09
7.0 – 7.4	44	7.59	16.49	24.37
7.5 – 7.9	40	7.09	16.40	19.79
8.0 – 8.4	8	9.59	11.30	13.40
8.5 – 8.9	1	8.98	8.98	8.98
9.0 – 9.4	2	8.64	8.92	9.20
9.5 - 10	1	4.37	4.37	4.37

Keeping in mind there are only 150 dwellings in this data set, when graphed (Figure 12), this data shows several things of importance:

- In general, the average overheating values fall noticeably once apartments have a rating of at least 8 stars;
- In general, the spread between min to max also decreases significantly from 8+ stars;
- Even 6 and 7 star apartments can have quite significant overheating (>15% of the year);
- Apartments in the 5-5.4 star range seem to present an anomaly. This data is from 3 dwellings only. Further investigation is required to understand this anomaly.

Figure 13 shows the distribution of overheating in Class 2 dwellings while Figure 14 allows for one to compare the overheating performance of the living room and worst bedroom, within each energy star band.

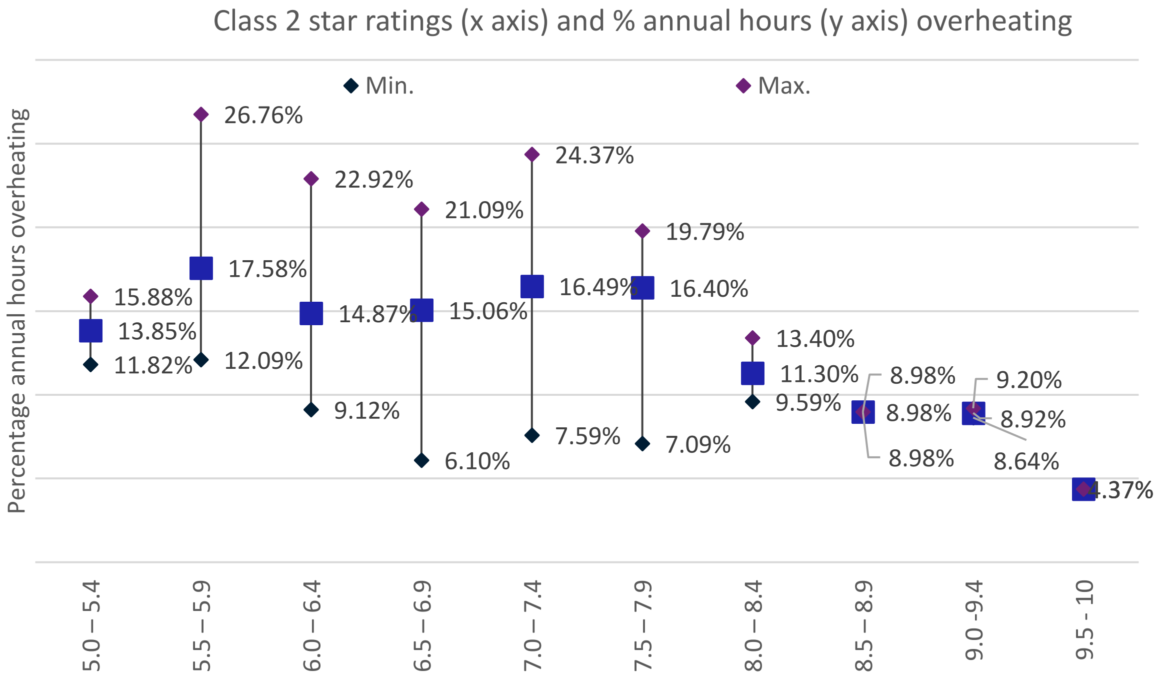


Figure 12 Class 2 energy star ratings vs % annual house overheating

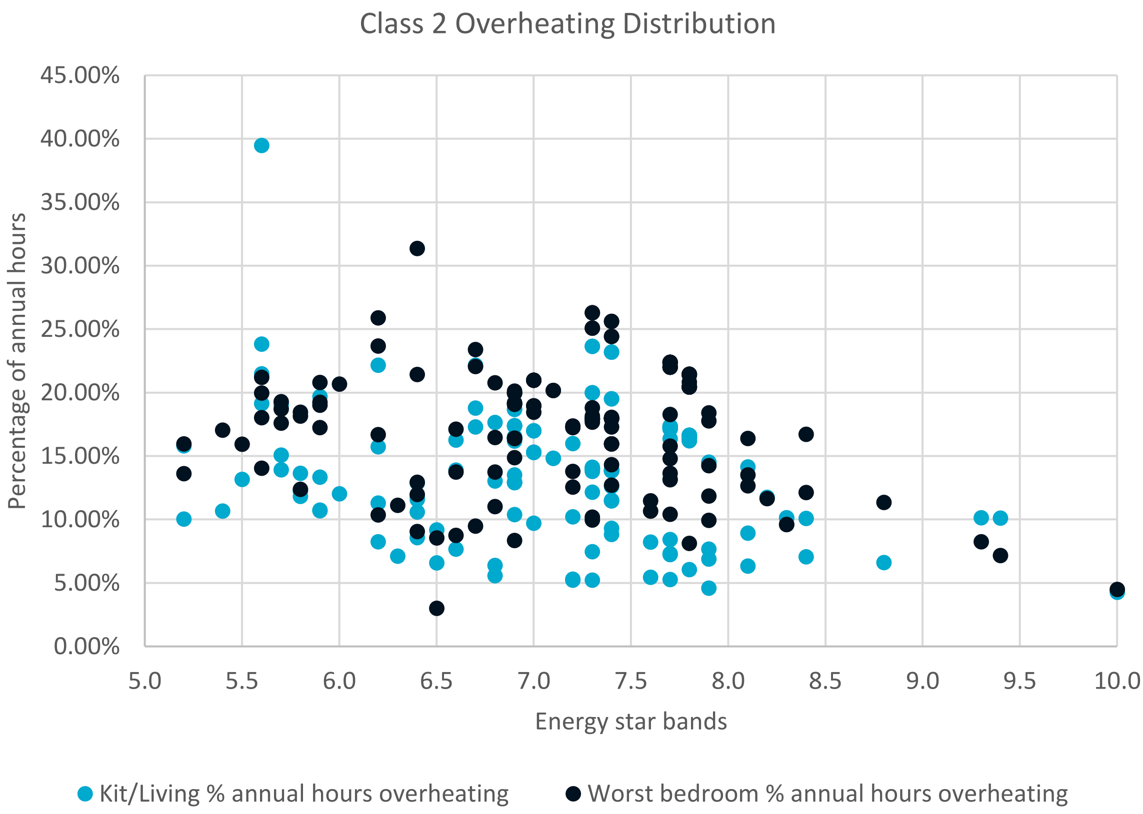


Figure 13 Class 2 overheating distribution

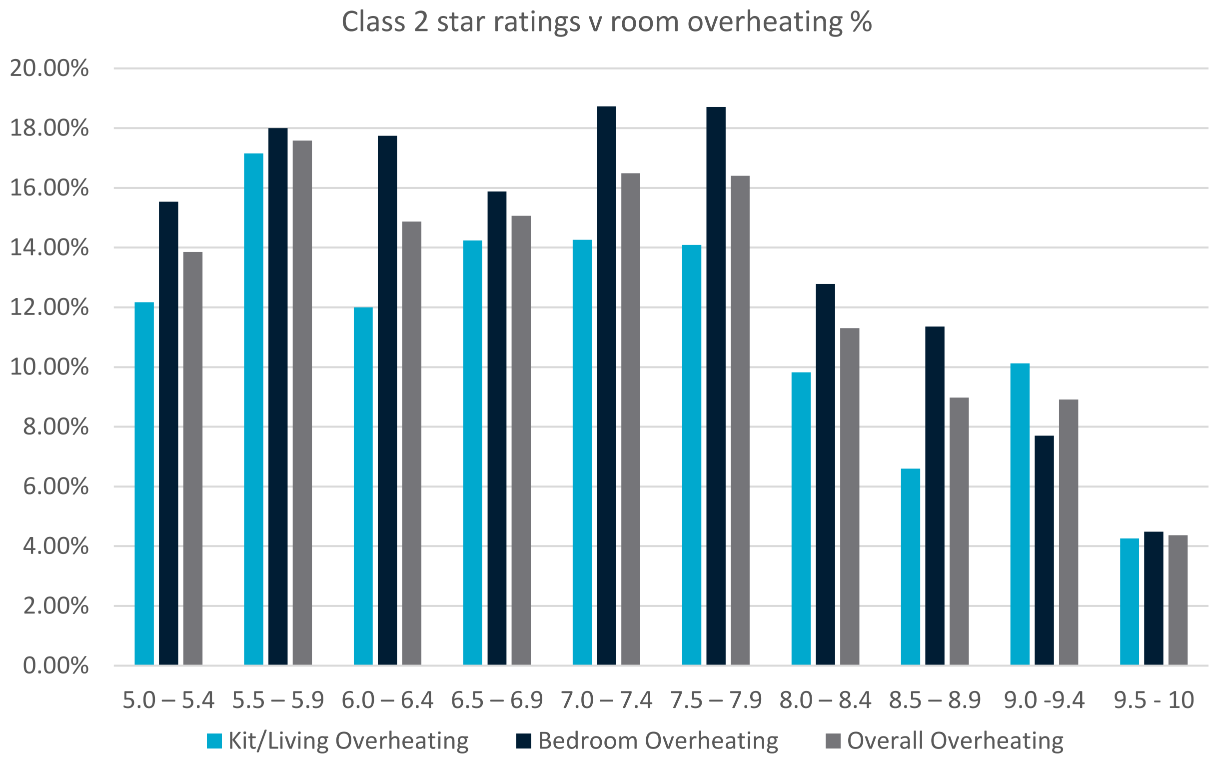


Figure 14 Class 2 living and bedroom overheating comparison

Figures 15 and 16 show the magnitude of the overheating (i.e. DD during occupied hours). The trend seen in Class 1 dwellings is not as clear for Class 2 dwellings (i.e. living room and bedroom DD decreasing as energy star bands increase). This may be because of the much smaller sample size. Units also often only have 1 or 2 external walls and therefore the living room and worst bedroom performance can be dictated by the orientation of that particular unit (e.g. a NW unit is likely to perform much worse than a N or S facing unit).

Similar to Class 1 dwellings, Class 2 living rooms have a max DD higher than that of the worst bedroom, regardless of energy star rating.

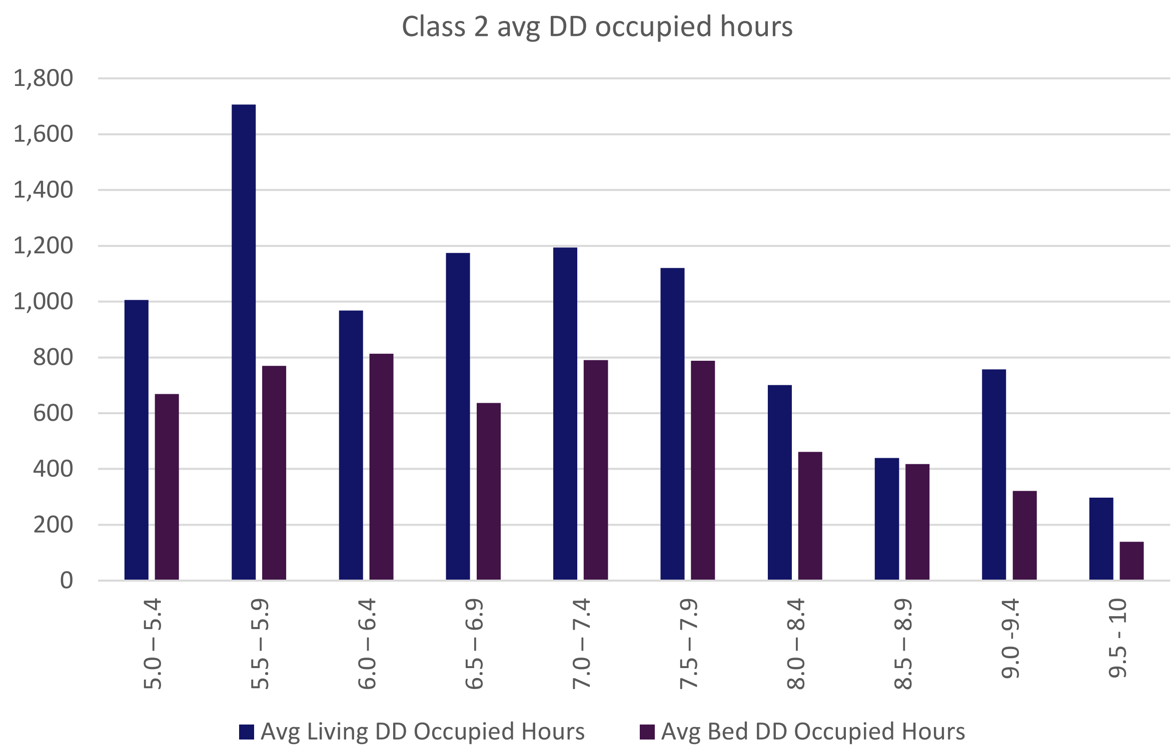


Figure 15 Class 2 average DD occupied hours

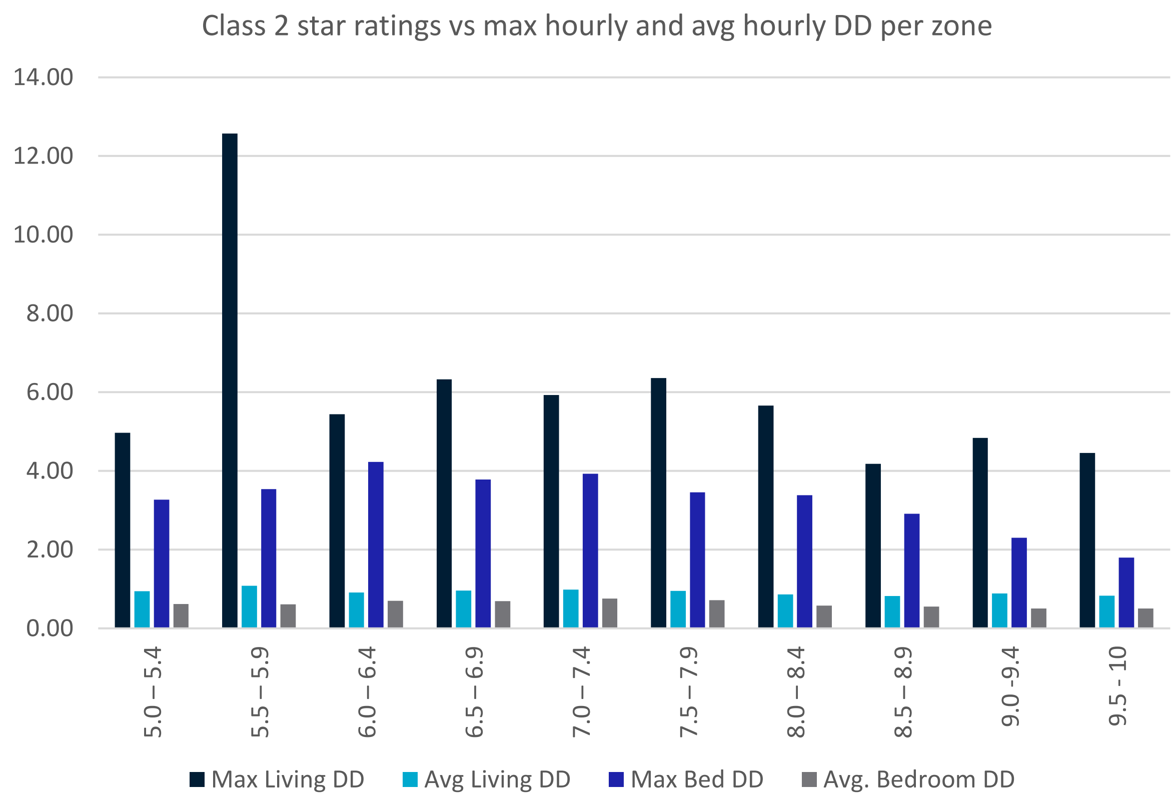


Figure 16 Class 2 Max and Average hourly DD

2.2.3 Implications of acceptability selection and climate file

So how does 80% acceptability compare with 90% acceptability? And what is the impact of the changing climate? To understand 'acceptability', it is helpful to remember that thermal comfort is based on a combination of environmental conditions (air temperature, thermal radiation, humidity, airspeed) and personal attributes (physical activity and clothing insulation). Thermal discomfort, at a population or large cohort level, can be quantified by an index called Predicted Percentage of Dissatisfied (PPD), i.e. the predicted percentage of a population of occupants who would find particular conditions too hot nor too cold. The 80% and 90% acceptability are the inverse of this. 80% acceptability is used to refer to conditions that 80% of people (healthy adults) would find acceptable (not too hot or too cold); 90% acceptability refers to conditions that would be acceptable to 90% of the population or cohort. The PPD (and inverse acceptability percentages) are used in international standards such as ASHRAE 55 (USA) and TM59 (UK). The PPD index relates to populations and should not be considered as indicative of acceptability for specific occupants in a single dwelling.

Figure 17 shows the differences in overheating percentages between 80 and 90% acceptability, and between 2016 and 2050 climate files. The graph is based on the mean overheating percentage for each of the zones from all of the AHD Darwin dwellings (1043 Class 1 and Class 2 dwellings).

When looking only at the 80% acceptability pairs of bars, it can be seen that the 2050 climate scenario (dark blue bars) would result in about 30% more annual hours above the comfort threshold compared to the current (2016) weather model overheating (light blue bars).

Compared to the 80% acceptability, the 90% acceptability 2016 bars (light blue) show a three- to four-fold increase in annual hours above the comfort threshold. There is a smaller difference (less than two-fold) between 2016 and 2050 (compared to 80% acceptability).

The 90% acceptability results and 2050 results have not been analysed per star rating. This chart however does point out that homes where a higher level of comfort is required (e.g. very young, elderly, those with temperature sensitive chronic illnesses) should not rely on 80% acceptability criteria to provide acceptable temperatures to those occupants. It also shows that consideration should be given now to the expected increase in overheating by 2050 (within the lifespan of dwellings constructed now).

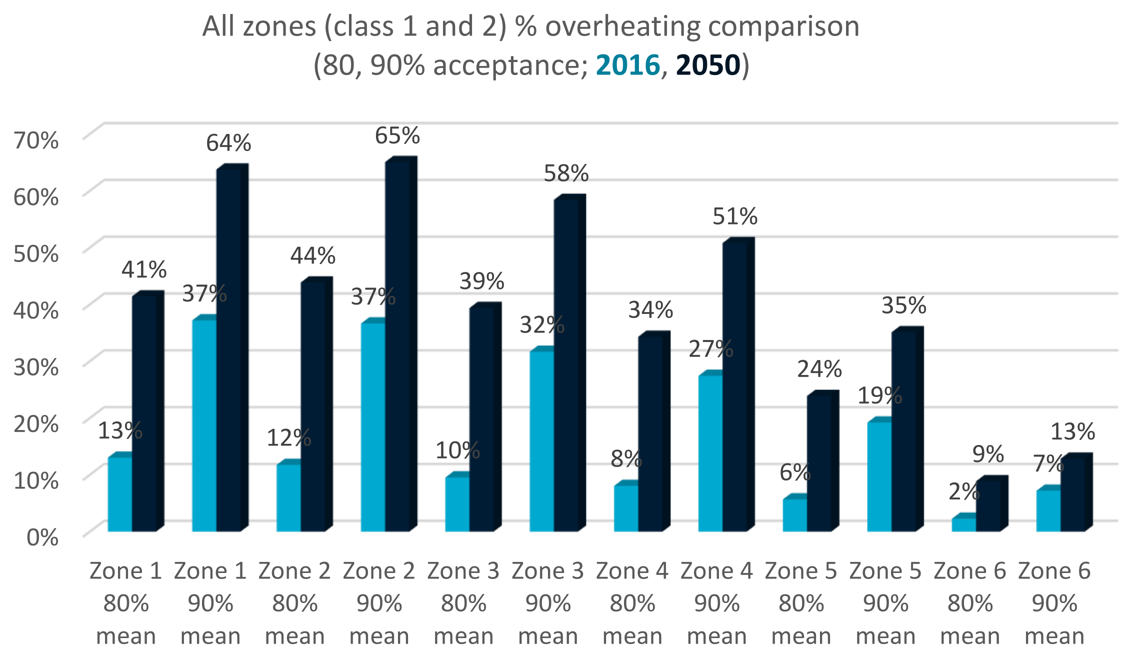


Figure 17 Comparison of 80 and 90% acceptability in current and future climate

Figure 18 shows the expected impact of the 2050 climate on the DD (occupied hours annually) for class 1 dwellings, correlated to energy star bands. Living rooms, at all star bands, have higher DD than bedrooms. The DD decreases with higher energy ratings but is expected to increase significantly by 2050. Bedrooms in 8+ star dwellings have a lower DD than those in lower star ratings, but again a significant increase is expected by 2050.

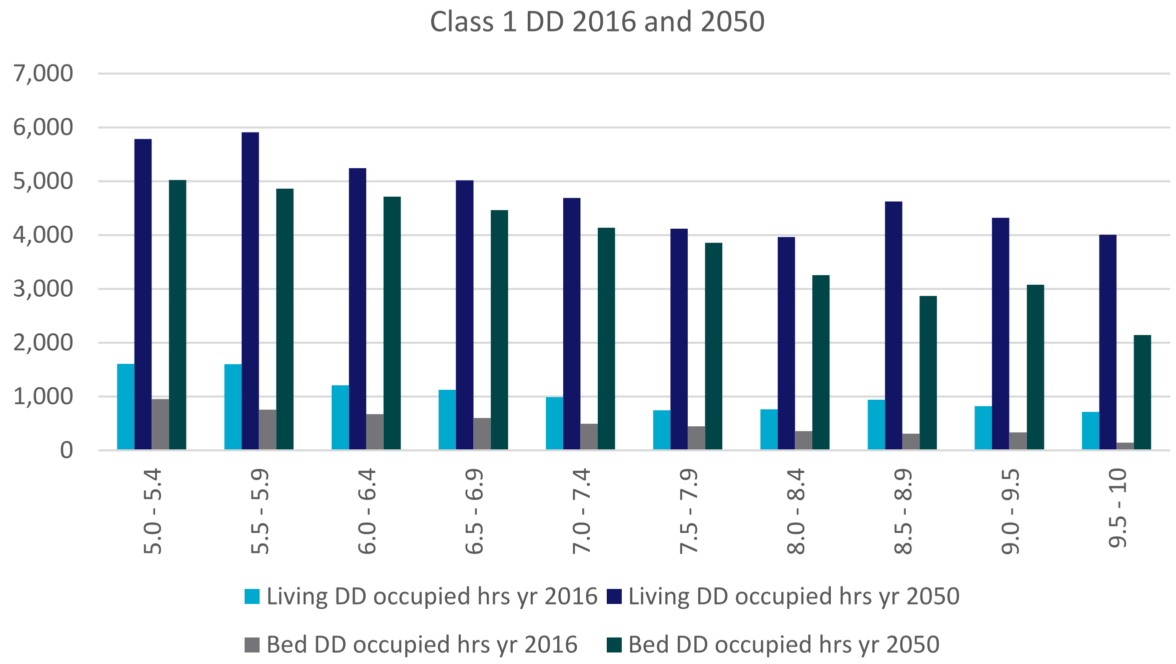


Figure 18 Comparison of acceptability and future climate on DD

These results would seem to indicate that the current energy ratings (up to 10 stars) are not sufficient to ensure minimal DD in a future climate scenario. But, alternatively, aiming for 8.5+ star ratings now will have benefits now (in reduced overheating % and reduced DD in the 2016 climate) as well as advantages in the future. If higher energy rated buildings are not regulated for future climate, then consideration needs to be given to how comfort will be achieved. This means consideration of the cooling equipment, the energy required to power it, the timing of energy use (and impact on the grid), and the affordability of that energy.

3. Building simulations

3.1 Building typologies and simulation parameters

A range of building typologies that could be found in the Darwin housing market were selected by members of the TRG for modelling and simulation. This included 4 detached houses, 2 duplexes, and 2 apartments. Models of these buildings were developed based on the provided plans. A summary of the building types and their key characteristics is shown in Table 5.

Table 5 House model key characteristics

HOUSE ID	BUILDING TYPE	LIVING AND BED ZONES	MAIN MATERIALS
DLLH01	Raised light weight home; large proportion of understorey enclosed	2 living zones, 4 bedrooms	Ground level blockwork where enclosed; uninsulated intermediate floor; upper level steel frame with metal cladding; metal roof
DLLH02	Raised light weight home; little enclosure of understorey	2 living zones, 3 bedrooms	Ground level blockwork where enclosed; uninsulated intermediate floor; upper level steel frame with fibre cement cladding; metal roof
DLLH03	Slab-on-ground single storey home	1 living zone, 5 bedrooms	Modelled as steel frame with fibre cement cladding; and as concrete block (external walls and most internal walls; walls between bedrooms and walk-in-robes and WC are steel framed); metal roof
DLLH04	Slab-on-ground 2 storey home	3 living zones, 4 bedrooms	Concrete block (external and internal walls); suspended concrete intermediate floor; some cavity panel (steel frame) upper floor walls (between bedroom/WIR and WC); metal roof)
DLLD01	Slab-on-ground 2 storey duplex / terrace house	1 living zone, 3 bedrooms	Concrete block walls throughout; suspended concrete intermediate floor; metal roof
DLLD02	Slab-on-ground 2 storey duplex / terrace house	1 living zone, 2 bedrooms	Concrete block wall throughout; suspended concrete intermediate floor; metal roof
DLLA01	Corner apartment, modelled as top floor and intermediate floor	1 living zone, 2 bedrooms	Concrete block walls throughout; suspended concrete floor (and ceiling for mid floor apartment); steel frame metal roof for top floor
DLLA02	Single-sided apartment, modelled as top floor and intermediate floor	1 living zone, 2 bedrooms	Concrete block walls throughout; suspended concrete floor (and ceiling for mid floor apartment); steel frame metal roof for top floor

The software used for the simulations was a version of AccuRATE (AccuRATE Homes V1.0.3.22) that was modified specifically for this project to incorporate the formulae shown previously in Table 1. Each dwelling was modelled in four cardinal orientations, with orientation determined by the location of the main entry (i.e. the 'front door'). Each of these orientations was modelled with 'bad', 'medium' and 'good' variants as selected by the TRG and summarised in **Error! Not a valid bookmark self-reference.**. The variants relate to changes in insulation, ventilation, solar absorptance (SA) and shading. The variants were selected to test the impact of different approaches, regardless of constructability. The default values (as indicated in AccuRATE) for solar absorption and glazing were used.

Table 6 Building variants applied to models

BUILDING ELEMENT	'BAD' VARIANT	'MEDIUM' VARIANT	'GOOD' VARIANT
EXTERNAL WALLS	Foil wrap applied to steel frame Dark colour	R2.0 bulk insulation in wall cavity (framed buildings only) Medium colour	R2.7 bulk insulation (in cavity or on outside of blockwork) Light colour
INTERNAL WALLS	No insulation	No insulation	R1 insulation in framed walls
PARTY WALLS	No insulation	No insulation	R1.5 bulk insulation on both sides (acoustic separation)
FLOOR	No insulation	No insulation	No insulation
CEILING	No insulation	No insulation	R2.5 bulk insulation
ROOF	Foil (reflective) Dark colour Unventilated	Foil (reflective) Medium colour Ventilated	R1.5 reflective blanket (reflective roof space) Light colour Unventilated
SHADING	No shade	0.9m eaves all orientations, all plans (unless larger eave or verandah indicated on plans)	Houses and duplexes: 2.5m eaves on ground floor, 1.2m eaves on 2nd storey Apartments: 2.5m eaves
GLAZING	Aluminium frame Single glazed clear	Aluminium frame Single glazed clear	Aluminium frame Single glazed low e tint (U5.6, SHGC 0.41)
VENTILATION (WINDOWS AND FANS)	20% openings 1400mm fans	45% openings 1400mm fans	90% openings 1400mm fans

NOTE: some House 2 variances are described in section 3.2.2.

Each of these models was simulated for both the 2016 weather file (NCC 2022) and CSIRO's 2050 future weather file (based on RCP8.5 – no abatement). The same appliance schedules and building operation parameters required by NatHERS for energy ratings were used. Occupant behaviour was assumed to be unchanged from 2016 to 2050 (i.e. no adaptation behaviours in response to a warming climate).

Data analysis was undertaken utilising both Tableau and Excel.

3.2 Simulation Results

Each of the dwellings, in all variations, was modelled to determine the energy star rating, the total degree hours of discomfort (DD) and the maximum hourly degree of discomfort (i.e. the extent of the 'worst hour'). These results are presented in the following sections per dwelling, enabling an understanding of the impact of each dwelling's design and variants on occupant comfort. For this section, variants of each design have been stipulated by B, M or G (referring to bad, medium and good variations shown in Table 6), and by orientation (N, S, E, W). All analysis in this section is based on the 2016 RMY weather file (the TMY for the period 1990 – 2015) and on 80% acceptability, and on the relevant occupied hours of the kitchen/living zone and the worst bedroom.

A summary of these results and those from the AHD data set, is provided in section 4, providing the evidence on which the comfort rating recommendations are made.

3.2.1 House 1 (DLLH01)

House 1 is a raised light weight home (Figure 19) where a large proportion of the understorey has been enclosed (concrete block) to provide a 4th bedroom or a secondary or independent living space with a combined be/living room zone, kitchen and bathroom/laundry. The upper storey consists of a kitchen/living zone and 3 bedrooms.

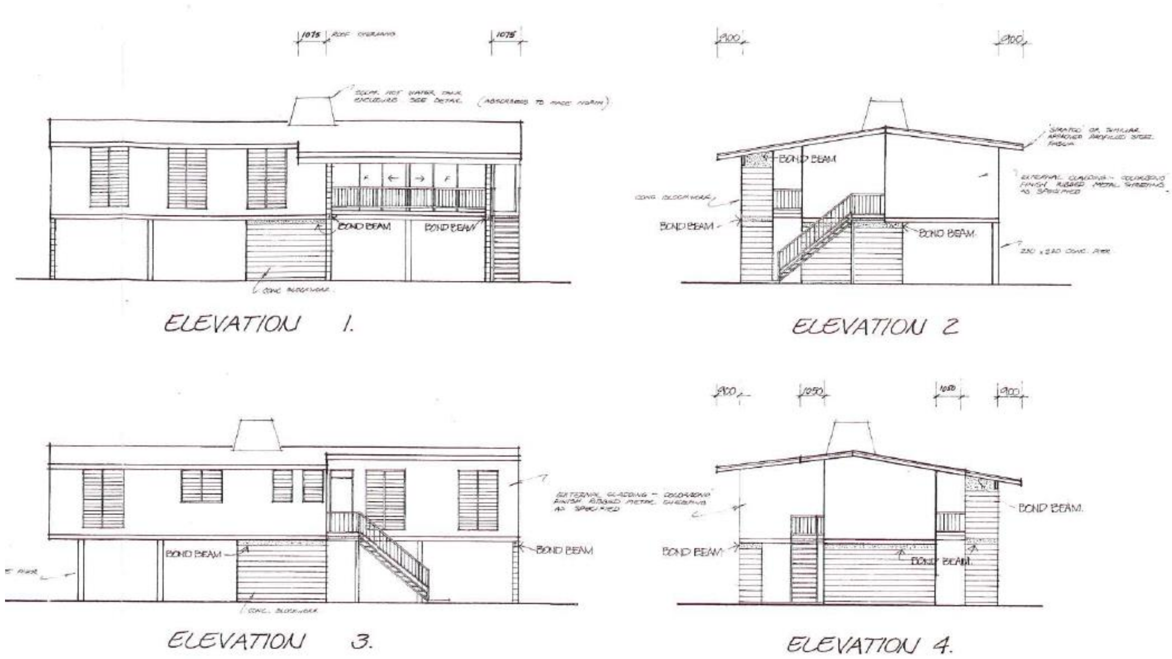


Figure 19 DLLH01 elevations

The energy ratings of the 16 variants of this design are shown in Figure 20. The 'bad' variants of this design do not achieve any star rating, and the medium variants also fail to meet current minimum Northern Territory performance standards (5 stars). The 'good' variants, however, result in homes above 7 stars, showing that reasonably good performance (of energy rating) is possible with slight changes to materials and design.

The two variants highlighted in the graph are the ones used for analysis of the comfort implications. Figure 21 shows the impact of an improvement of 3 stars – from 4.9 to 7.9. The total DD (left hand graph) reduces in both the kitchen/living zone and the worst bedroom, with a greater reduction in the bedroom. The maximum hourly DD (right hand graph) shows the worst or hottest hour for the two zones. It is the °C above the comfort threshold. The good variant results in a reduced max DD in both zones.

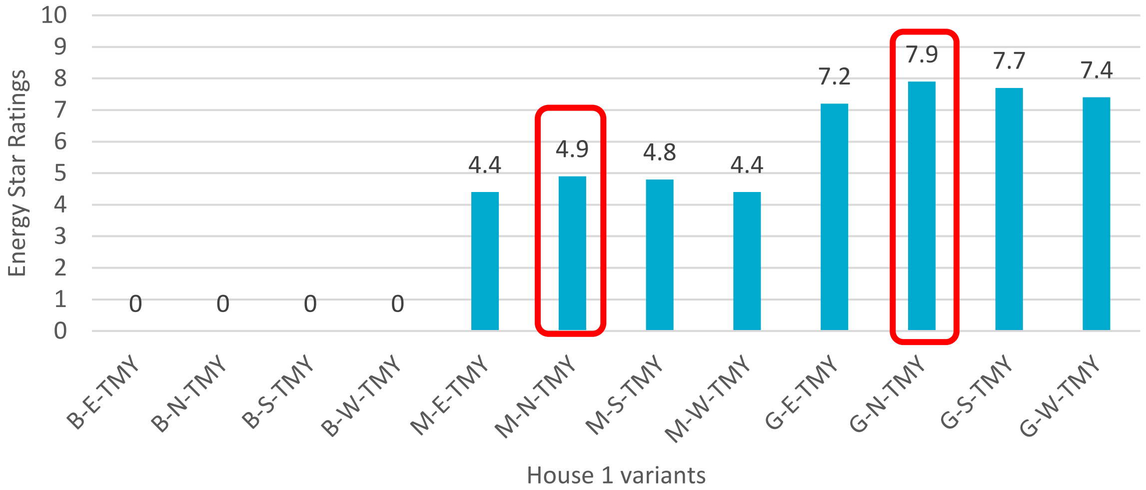
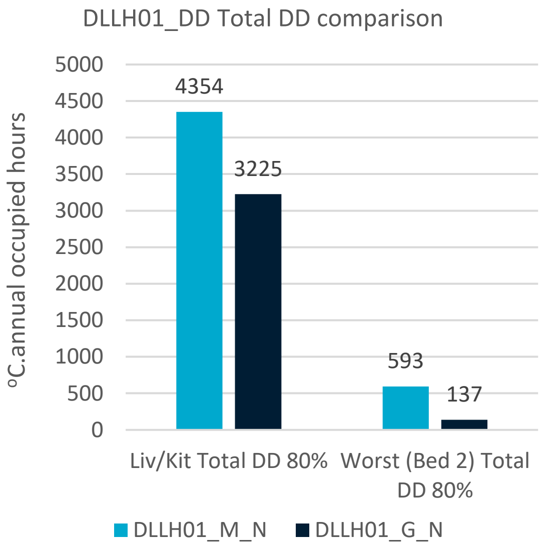


Figure 20 DLLH01 Energy Ratings



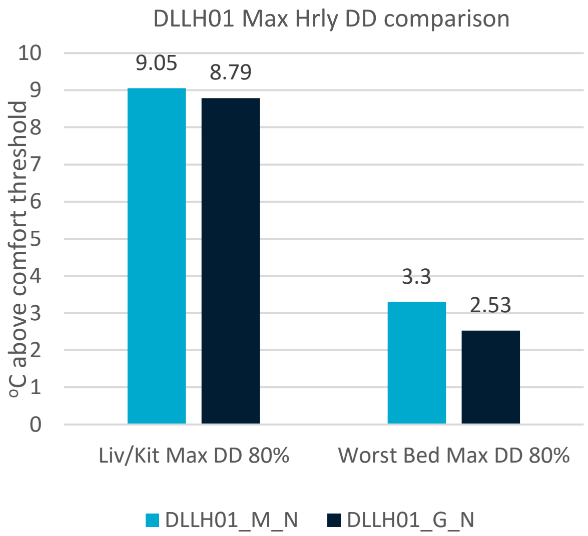


Figure 21 DLLH01 Comfort performance_ Total DD and Max Hrly DD

3.2.2 House 2 (DLLH02)

House 2 (Figure 22) is similar to House 1, but with two important design differences. First, the roof has been modelled as flat (i.e. a skillion or cathedral roof), and a smaller proportion of the understorey has been enclosed with concrete block (resulting in the intermediate uninsulated floor being more exposed to the ambient conditions).

Figure 22 DLLH02 image

This particular design, as modelled, does not perform well from an energy rating perspective. It is a 'lemon' for both the 'bad' and 'medium' design options. It barely makes 5 stars, even under the 'good' option. To achieve 5 stars, the 'good' option (shown in

The software used for the simulations was a version of AccuRATE (AccuRATE Homes V1.0.3.22) that was modified specifically for this project to incorporate the formulae shown previously in Table 1. Each dwelling was modelled in four cardinal orientations, with orientation determined by the location of the main entry (i.e. the 'front door'). Each of these orientations was modelled with 'bad', 'medium' and 'good' variants as selected by the TRG and summarised in **Error! Not a valid bookmark self-reference.**. The variants relate to changes in insulation, ventilation, solar absorptance (SA) and shading. The variants were selected to test the impact of different approaches, regardless of constructability. The default values (as indicated in AccuRATE) for solar absorption and glazing were used.

Table 6) had to be further modified to increase the shading of the upper storey to 2.5m and include R2 insulation in internal stud walls. The design was not optimised to determine if a higher energy rating (and better comfort levels) can be achieved. For example, a gable roof may improve performance, as may higher levels of insulation, and insulating the intermediate floor.

The comfort performance compared the east and northern orientations of the 'good' variant, representing 4.6 and 5.2 stars respectively (Figure 23). The DD performance (Figure 24 left) shows that the eastern orientation provides for a better kitchen/living zone, but only a slightly better worst bedroom. The max DD (Figure 24 right) however, shows that the kitchen/living zone in the eastern orientation has a higher 'worst hour', compared to the northern orientation.

These charts demonstrate the impact of orientation on comfort, and the challenge of deciding on comfort parameters. Both total DD and max DD will impact on occupants.

Image 2 Darwin home similar to DLLH02

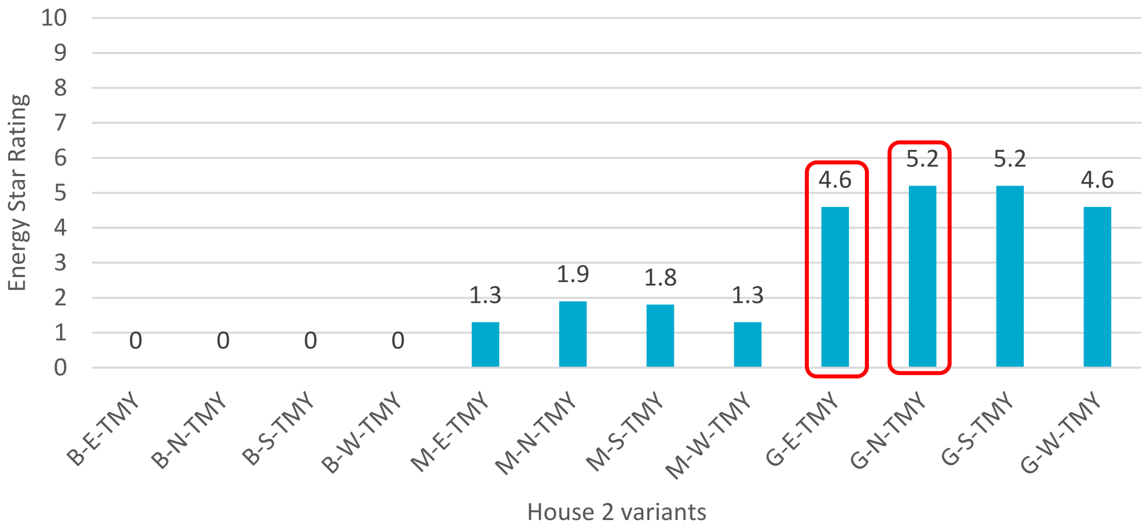


Figure 23 DLLH02 Energy Ratings

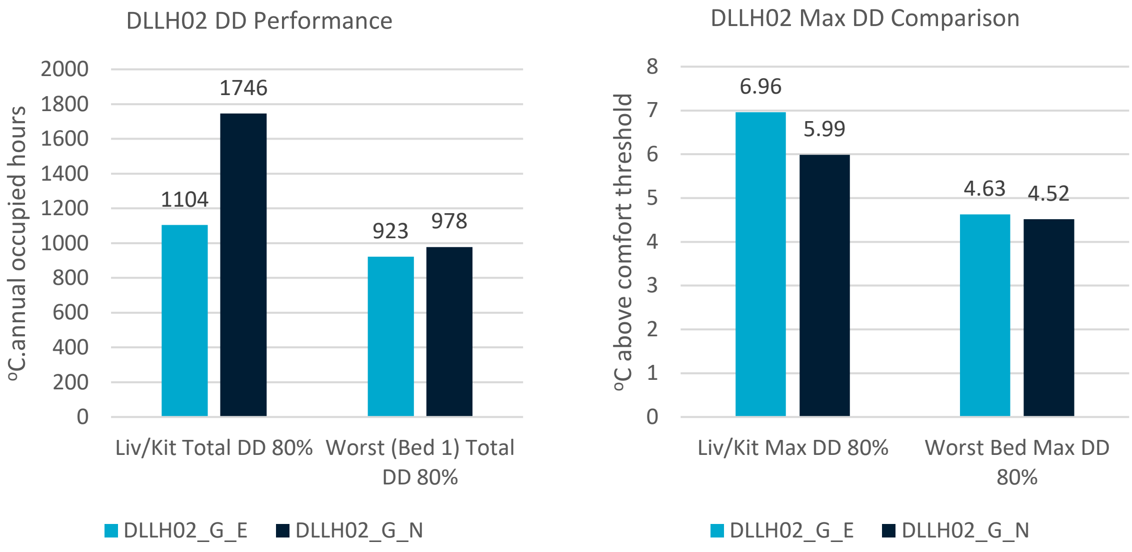


Figure 24 DLLH02 Comfort performance_Total DD and Max Hrly DD

3.2.3 House 3 (DLLH03)

House 3 (Figure 25) is a single storey slab-on-ground 5 bedroom home with 1 living room. It has been modelled in two variations: concrete block (BLK) construction (all external and internal walls) and steel frame (SF) construction (all external and internal walls) with fibre cement external cladding.

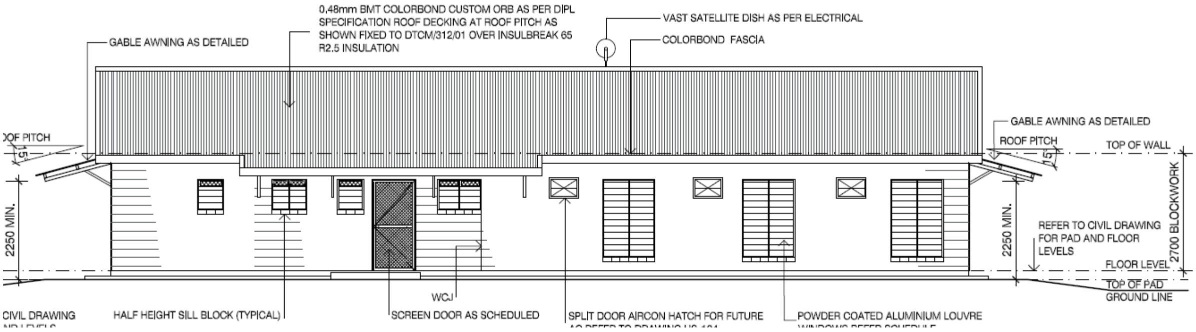


Figure 25 DLLH03 elevation

The energy ratings (Figure 26 and Figure 27) show that the 'bad' variant of this home (no shading or bulk insulation, only 20% openable windows, dark colour) is a lemon in both block and steel frame construction. The medium variant sees a difference between block work and steel frame performance because the steel framed house has R2 wall insulation whilst the blockwork house does not have any insulation. This results in the steel frame version achieving approximately 1 star rating higher than the uninsulated blockwork house. All other design features are the same.

Both construction types perform well in the good variant, with the blockwork version slightly outperforming the steel framed version in terms of energy star rating.

NOTE: The Gopt_E_TMY seen in Figure 26 refers to an optimisation of the eastern orientation of the blockwork house. The optimisation strategy and results for this dwelling design are discussed in detail in Section 3.3.

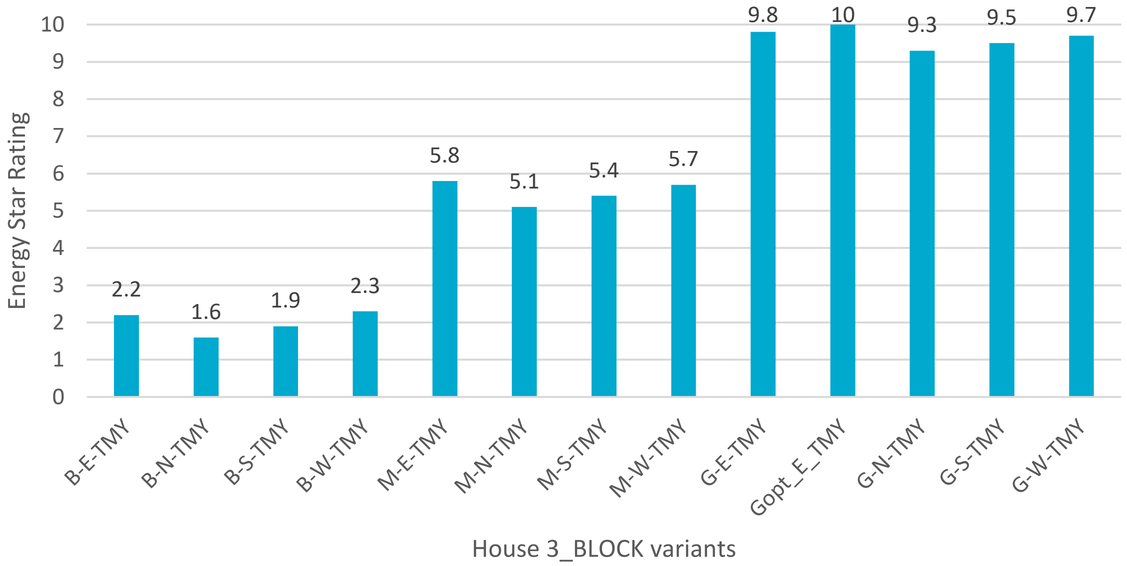


Figure 26 DLLH03 BLOCK Energy Ratings

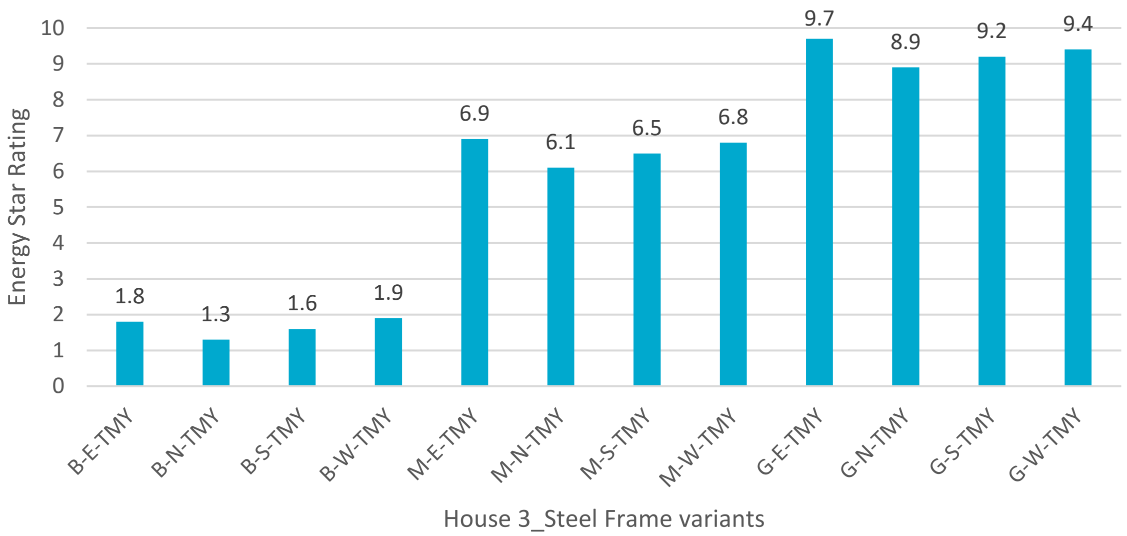


Figure 27 DLLH03 SF Energy Ratings

Figure 28 allows comparison of the total DD for each room in the eastern orientation of the medium and good variants of both the block and steel frame versions. First, if you look at the columns of the same colour, you can see that the worst bedroom is not the same for each variant (i.e. not always bed 1).

Second, the DD varies quite a bit between bedrooms, so one could argue that knowing the DD for each room may be useful for designers (to improve all rooms) and for occupants (perhaps in deciding allocation of each room for a particular family member or activity).

Third, the good variation, of both the BLK and SF options, significantly drop the total DD for all rooms. Lastly, the concrete block variations (the first two columns in each set) provide a slightly lower DD, in all rooms, compared to the steel frame variations.

The differences between the concrete block and steel frame options are slightly more pronounced when you look at the max DD (Figure 29), particularly in bedrooms (although this difference is less than 1 degree). The concrete block good variations have a lower max DD in all rooms.

It should be reiterated, however, that both construction types perform very well when the good design options are implemented (additional shading, insulation, ventilation openings and lower solar absorptance materials).

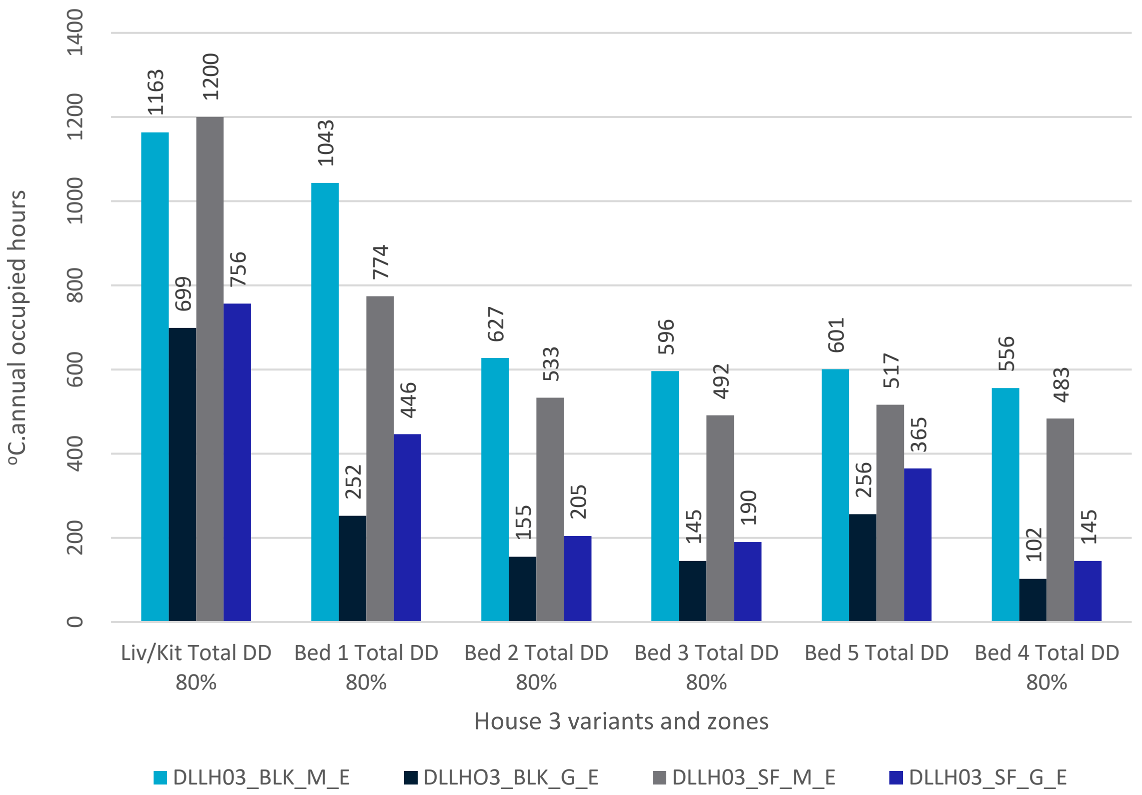


Figure 28 DLLH03 Comfort performance_Total DD per zone

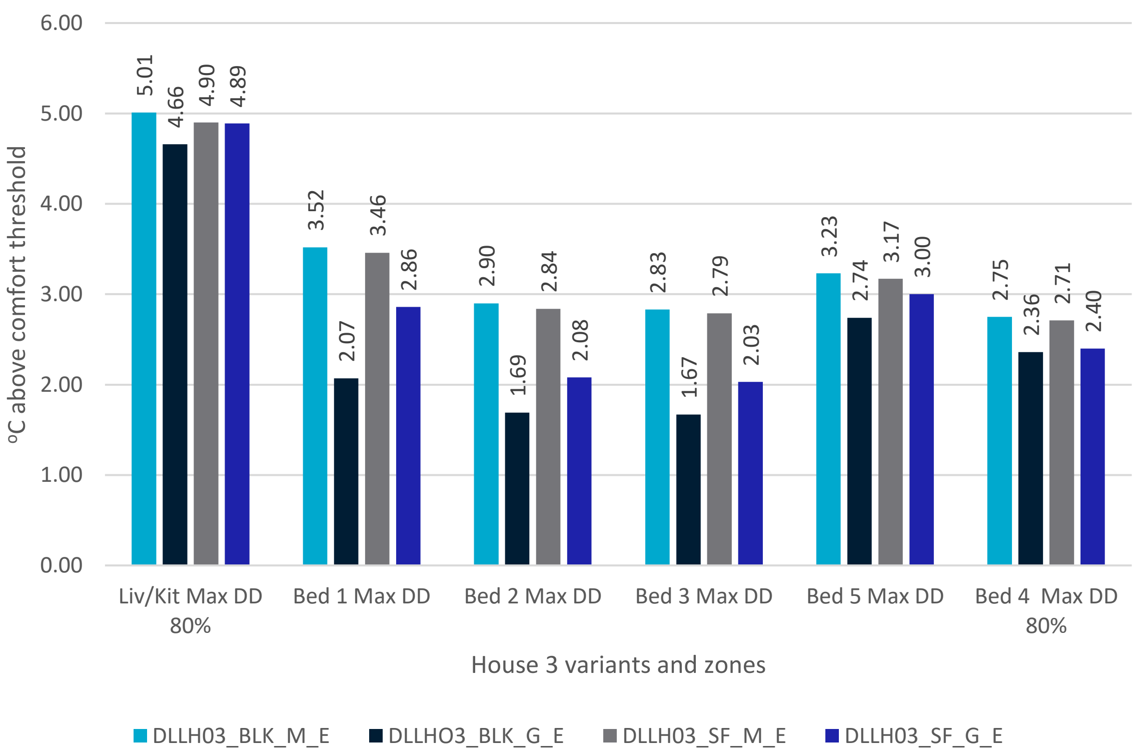


Figure 29 DLLH03 Comfort performance_Max Hrly DD per zone

3.2.4 House 4 (DLLH04)

House 4 (Figure 30) is a 2 storey slab-on-ground 4 bedroom home with 3 living zones. The living zones and enclosed garage are on the ground floor, with the bedrooms on the upper floor. The master bedroom leads out to a balcony, hence there is a large area of glazing in this room. The house has been modelled as all concrete block walls (internal and external) with the exception of walls between bedrooms and walk-in-robes/toilets. The house has a metal roof.

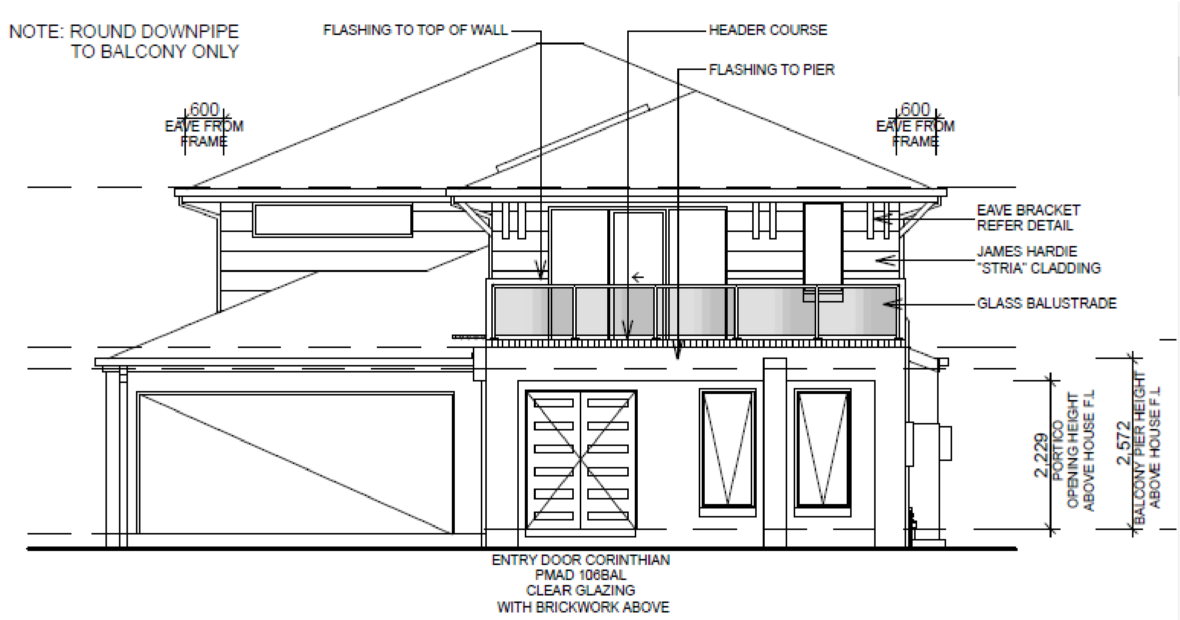


Figure 30 DLLH04 elevation

As seen in Figure 31, the 'bad' and 'medium' variants result in homes under 5 stars. The 'good' variant achieves over 8.5 stars regardless of orientation. This suggests that, for this design, having 2.5m ground floor eaves and 1.2m upper floor eaves provide a good level of shading for all rooms.

Figure 32 and Figure 33 show the comfort performance of east orientation of the medium and good variants (the worst and best of all of the medium and good variations).

Note the significant decrease in total DD (Figure 32) when the good design variants are implemented: a minimum 30% reduction in living zones and even greater reductions in all bedrooms.

In contrast to the reduction in total DD, note that the max DD (Figure 33) is not always reduced by the better design variant. For this design, the good design variant makes little difference to the max DD in the main living/kitchen zone and in bedrooms 2-4. It is reduced for the two secondary living zones but increased for the main bedroom.

This again highlights the need to consider comfort parameters and the need to include both total DD and max DD in some way.

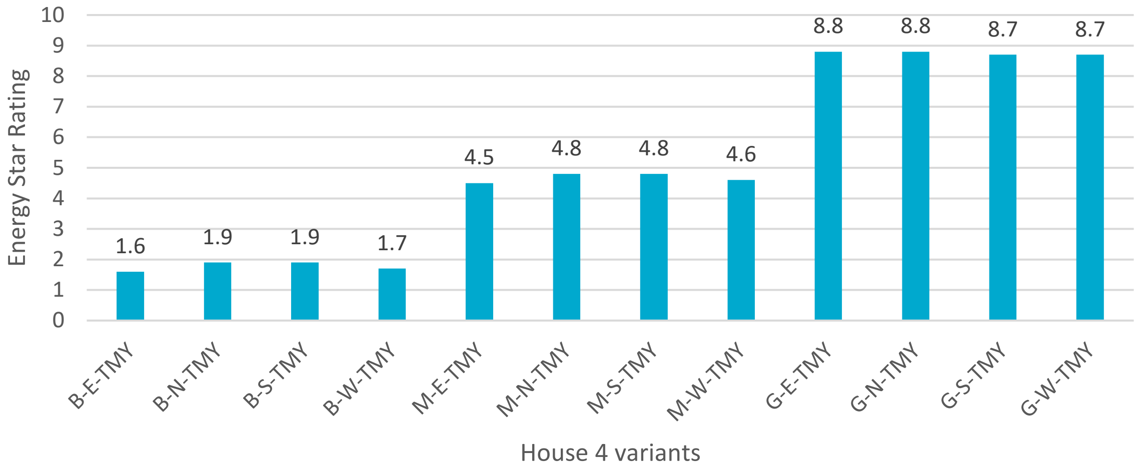


Figure 31 DLLH04 energy ratings

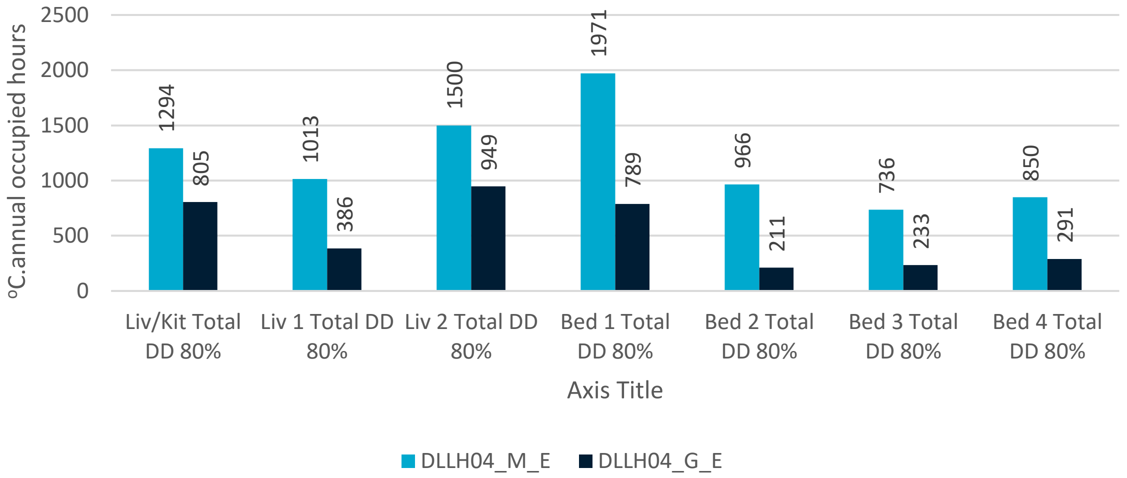


Figure 32 DLLH04 comfort performance_Total DD per zone

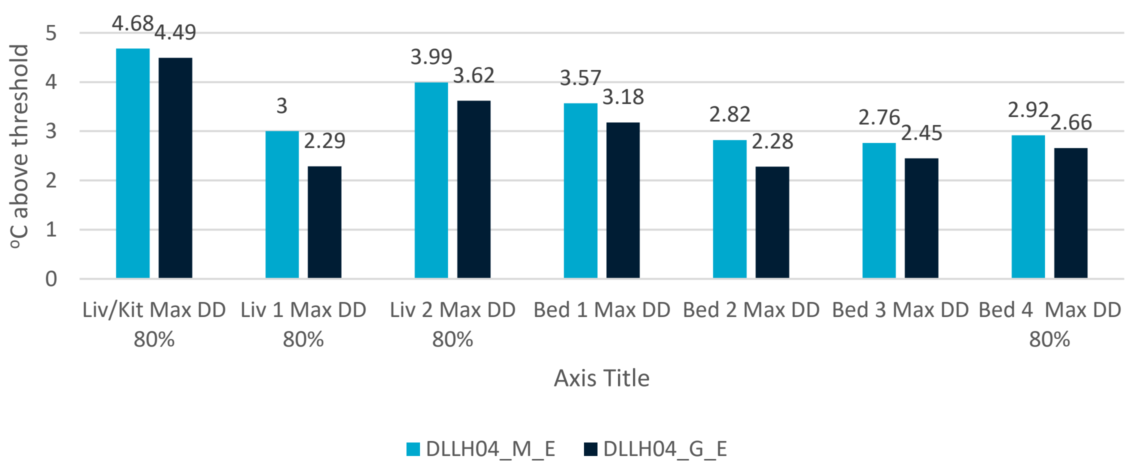


Figure 33 DLLH04 comfort performance_Max DD per zone

3.2.5 Duplex 1 (DLLD01)

Duplex 1 (Figure 34) is a 2 storey duplex or terrace house with 1 kitchen/living zone downstairs and 3 bedrooms upstairs. Similar to DLLH04, the master bedroom has a balcony, hence a large area of glazing for this room. The carport is at the rear of the building (i.e. not impacting on the living spaces). The duplex has been modelled as concrete block walls (external and most internal), with suspended concrete intermediate floor and steel roof.

Figure 34 DLLD01 elevation

Figure 35 shows that three orientations of the medium design variants result in just compliant dwellings, but that the good design variants add approximately 3 stars.

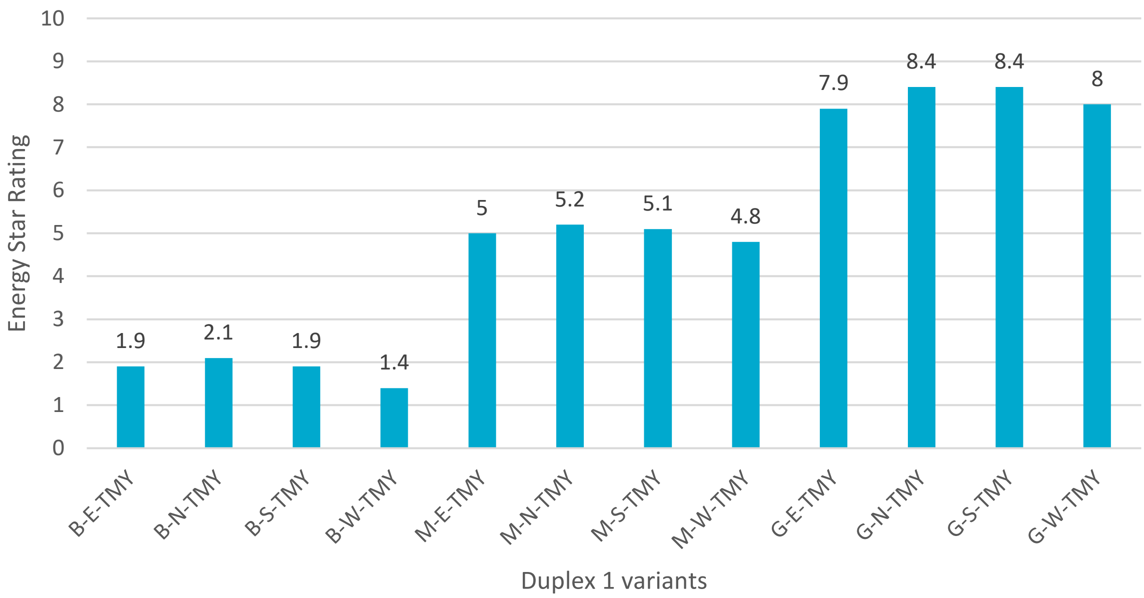


Figure 35 DLLD01 energy ratings

The eastern orientations were selected for comparison. As with all previous designs seen so far, increasing the star rating of this design decreases the total DD (Figure 36). The maximum DD (Figure 37) is also decreased in this design by 0.5 degrees in the living room, and 0.6 degrees in the worst bedroom.

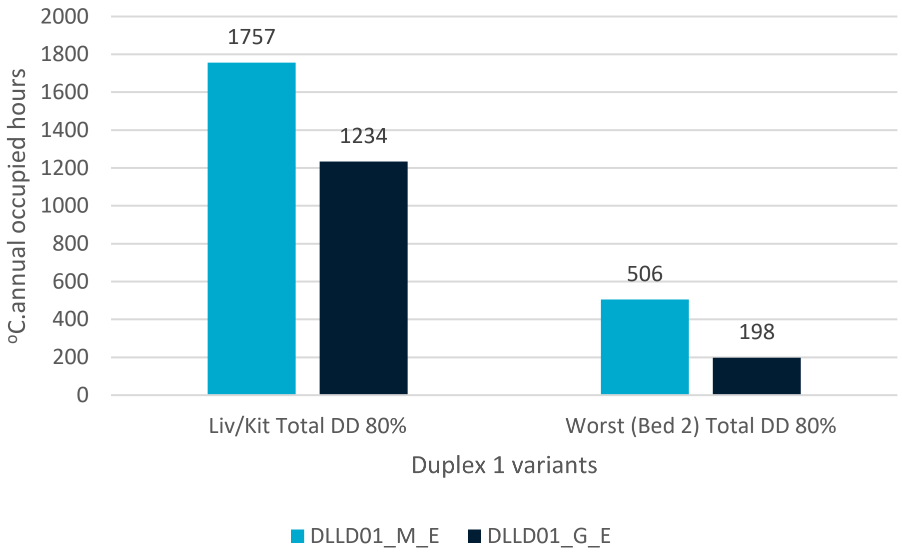


Figure 36 DLLD01 comfort performance_Total DD

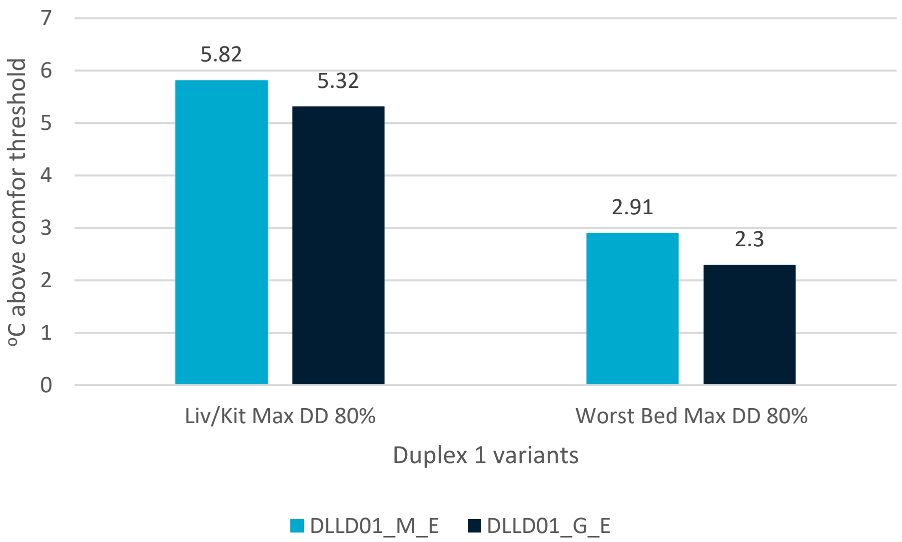


Figure 37 DLLD01 comfort performance_Max Hrly DD

3.2.6 Duplex 2 (DLLD02)

Duplex 2 (Figure 38) is similar to the previous duplex. It is 2 storeys, with living room downstairs and 2 bedrooms upstairs, and a carport attached to the side. It has also been modelled as concrete block construction with suspended concrete intermediate floor and metal roof.

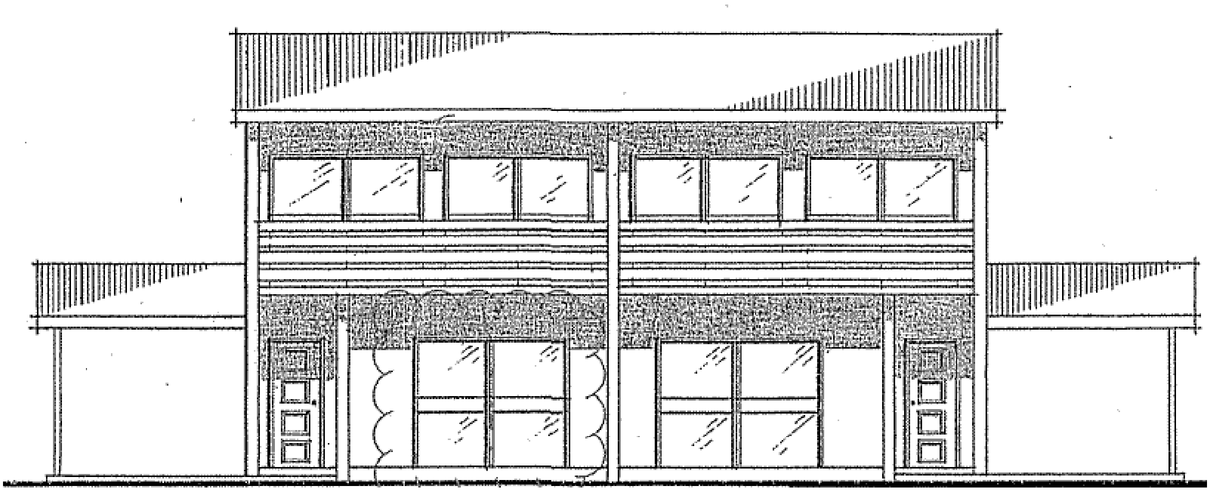


Figure 38 DLLD02 elevation

Note how, for this design, there is little difference between N and S orientations; and for E and W orientations in the medium variants, and no difference in the good variants (Figure 39) (orientation relative to the front door). Because the living room is on the same orientation as the front door, and has large glass windows, E and W orientations will be hotter than if the building was rotated 90 degrees (i.e. N or S orientation). The poorer performance at the E and W orientations could be somewhat mitigated by some vertical external shading or performance glazing (high SHGC). This has not been modelled.

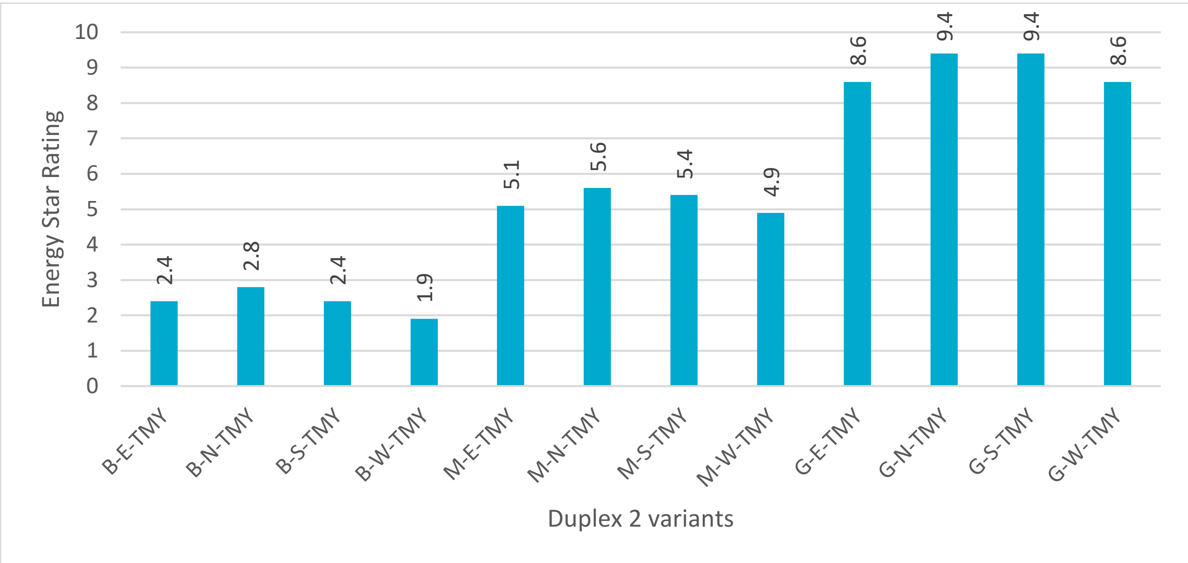


Figure 39 DLLD02 energy rating

For this dwelling design, the comfort performance is compared between the worst variation (medium, west orientation) and the best variation (good, north orientation). Selecting the best and worst allows for seeing the comfort impact of variations – raising this duplex from 4.9 stars to 9.4 stars.

Figure 40 shows the reductions possible in total DD, with the greatest benefit, in terms of percentage reduction, to the two bedrooms.

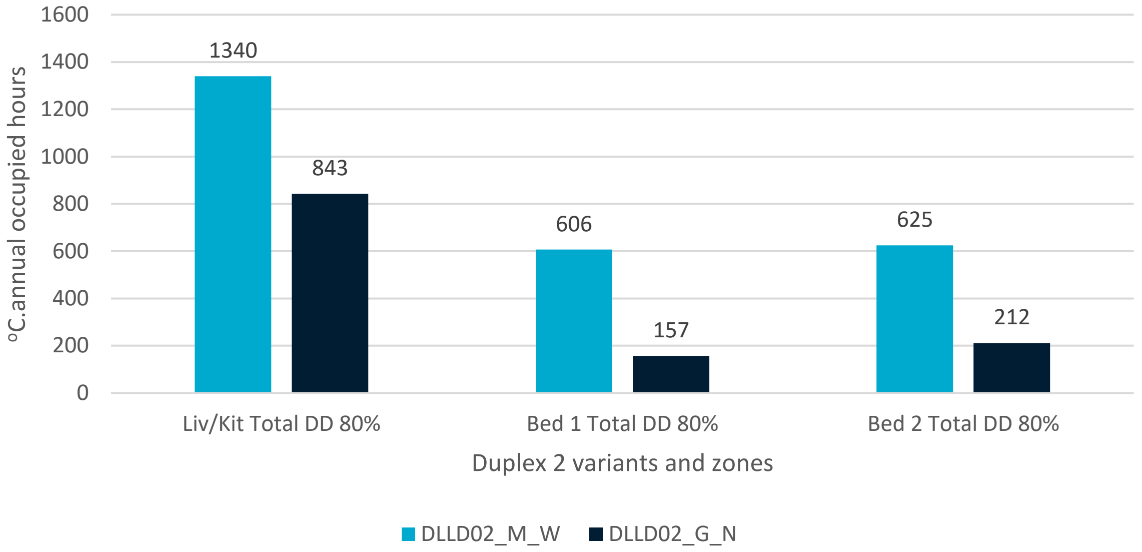


Figure 40 DLLD02 comfort performance_Total DD

Figure 41, however, shows that the good variant actually has a slightly higher max DD in the living zone (likely due to the change in orientation which would put this zone on the north-west corner).

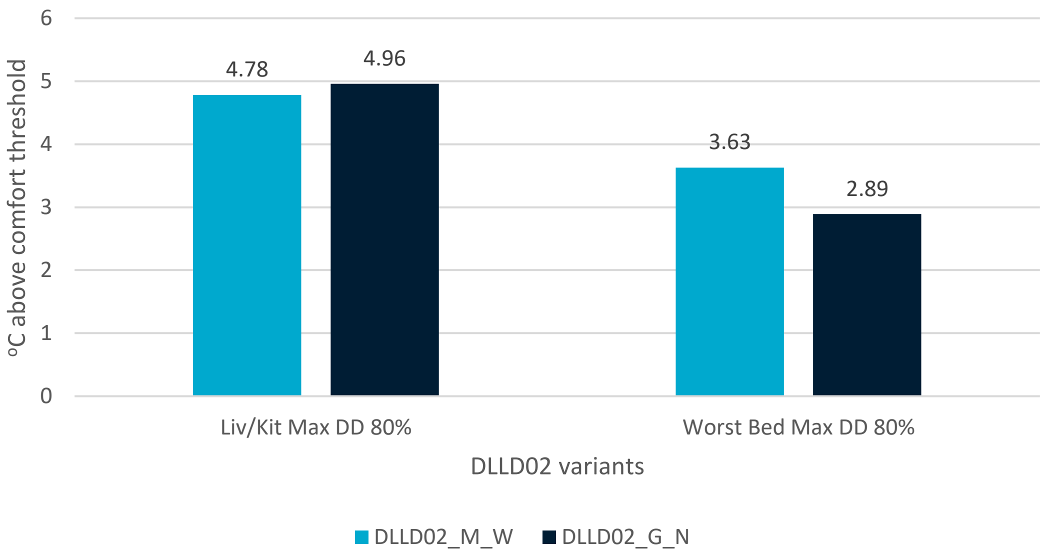


Figure 41 DLLD02 comfort performance_Max Hrly DD

This comparison highlights the importance the selection of materials and strategies that take into account the orientation of the different rooms within a dwelling. Using vertical shading to address specific room challenges has not been modelled.

3.2.7 Apartment 1 (DLLA01)

DLLA01 (Figure 42) is a two bedroom corner apartment. It has been modelled as both a top floor (TF) apartment and mid floor (MF) apartment. All walls are concrete block.

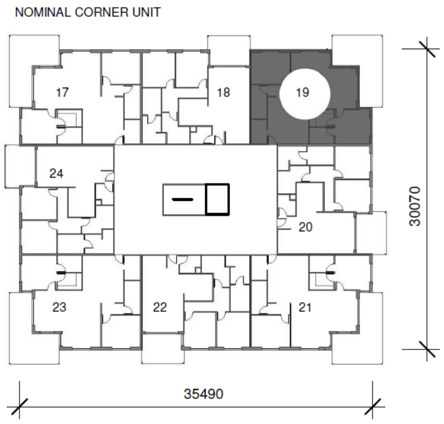


Figure 42 DLLA01 corner apartment

The energy ratings are shown in Figure 43 and Figure 44. Note how the top floor apartment underperform compared to the mid floor apartment for both the bad and medium design options. This is likely because of the additional heat that comes through the ceiling/roof of the top floor. It is only with the additional shading and insulation of the 'good' variants that the top floor unit closely match or slightly outperform the mid-floor unit with the same options.

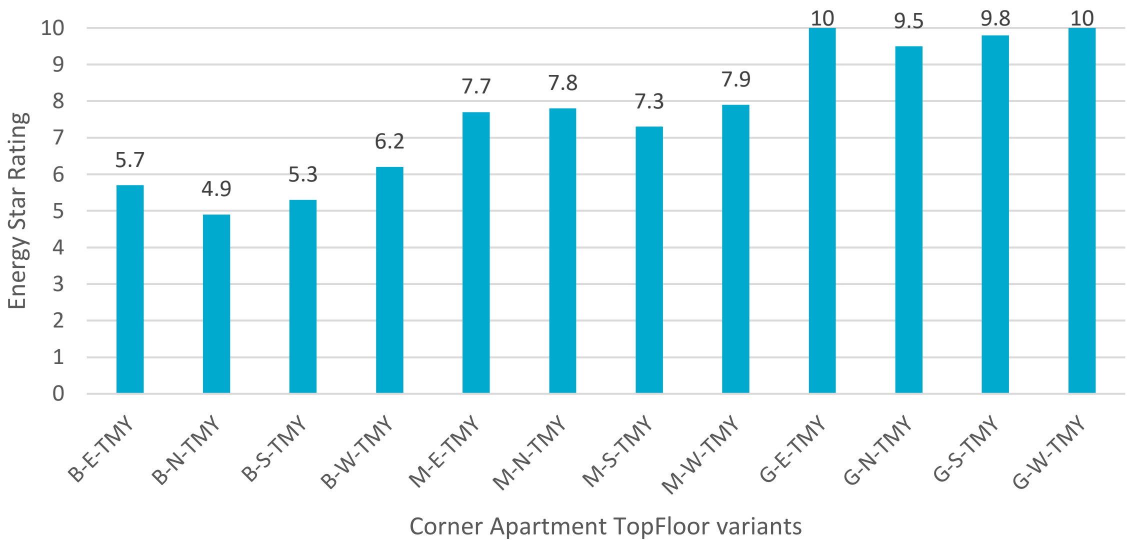


Figure 43 DLLA01 Top Floor energy ratings

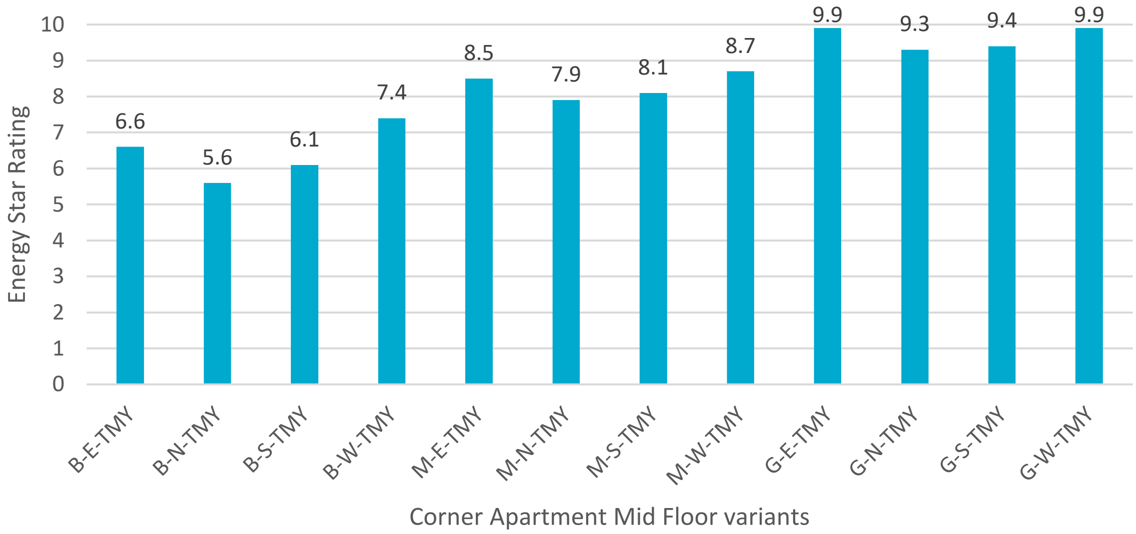


Figure 44 DLLA01 Mid Floor energy ratings

Figure 45 shows the comfort performance for 3 versions of this corner apartment, all on a middle floor (i.e. not exposed to the ground or the sky). The three versions are ‘bad’, ‘medium’ and ‘good’ as previously explained; all are facing east, representing the best star rating of each of the variations modelled. The graph on the right shows that the max DD actually increases with the medium and good variants (0.1 – 0.5 degrees). In contrast, the graph on the left shows strong decreases in total DD. The largest reduction in total DD happens between the bad and medium variant, resulting from lower solar absorptance of the walls and increased ventilation (window openings). Further reductions in total DD are achieved with the good variant (insulation, solar absorptance, window openings and glazing type). The impact of each of these changes individually was not modelled. Doing so could provide feedback to industry as to the most effective strategies or combination of strategies for improving comfort with the least financial impact on the building cost.

This analysis shows that, for this design, the main benefit of the medium and good variants are in the reduction in total DD, rather than the max DD.

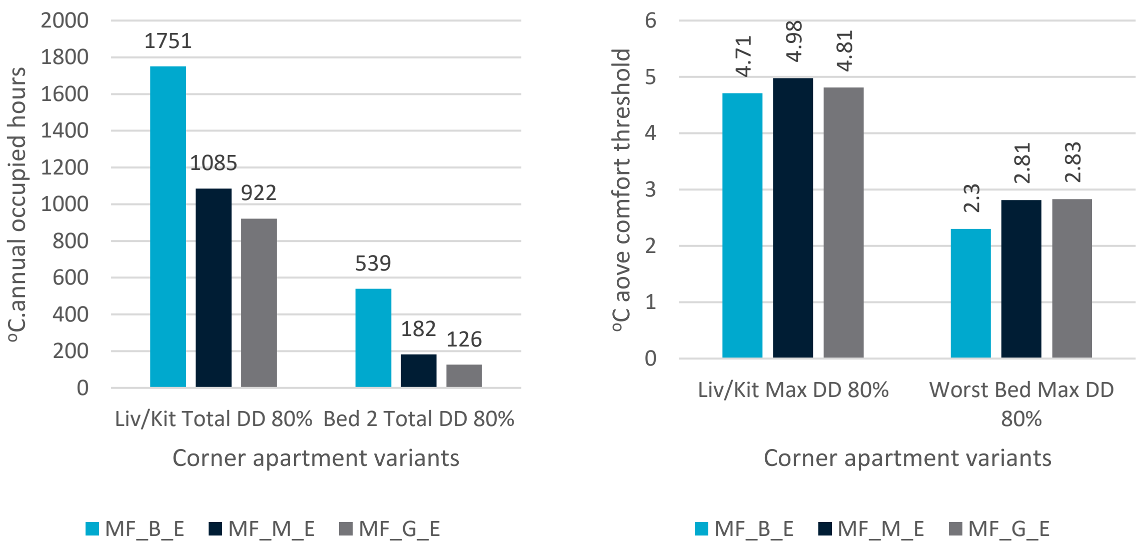


Figure 45 DLLA01 Comfort Performance_Total DD (left) and Max Hrly DD (right)

Similar differences are seen in DD for the top floor corner apartment: big reductions in total DD between the different variants (Figure 46), but minor differences or slight increases in max DD (Figure 47).

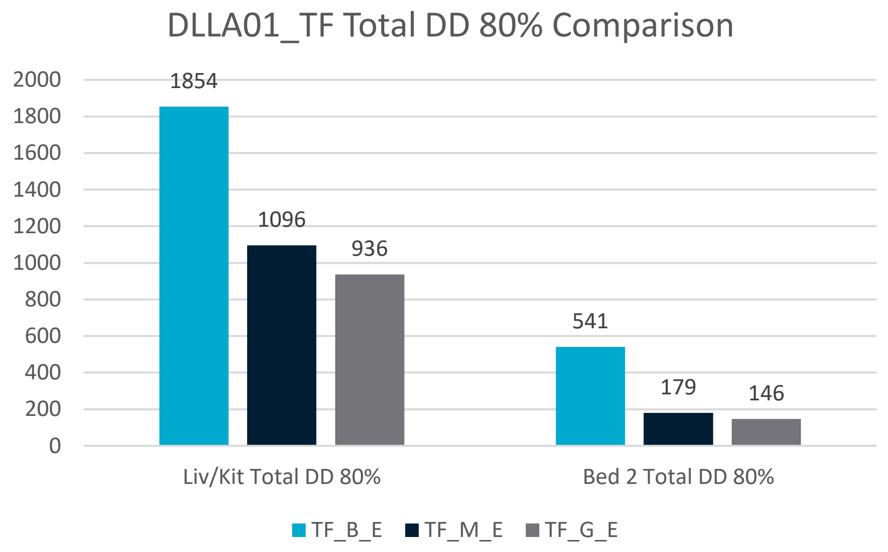


Figure 46 DLLA01 Top Floor comfort performance_Total DD

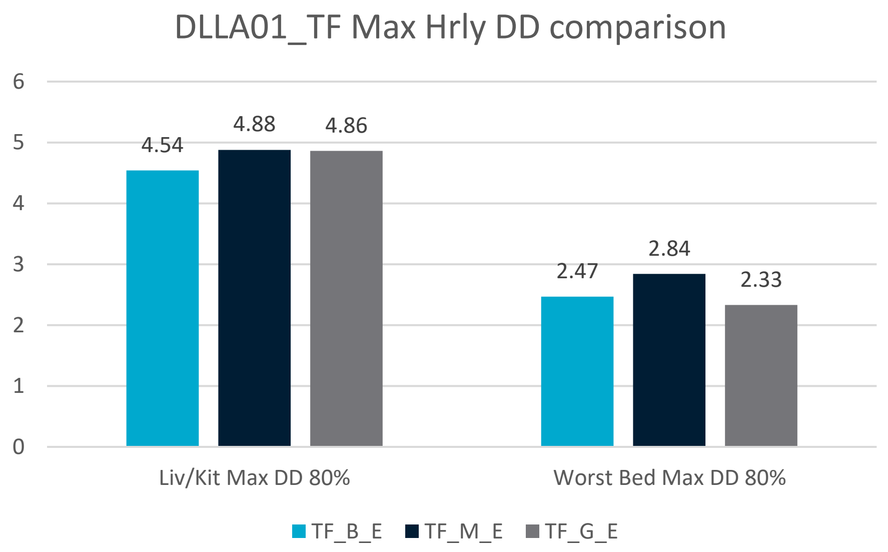


Figure 47 DLLA01 Mid Floor comfort performance_Max Hrly DD

3.2.8 Apartment 2 (DLLA02)

Apartment 2 (Figure 48) is a single sided 'middle' apartment, with only 1 external wall. It has 1 living zone and 2 bedrooms. This type of apartment is renowned, world-wide, for being difficult to achieve natural ventilation.

Figure 48 DLLA02 Single-sided apartment

Similar to the corner unit, the top floor version of this unit (Figure 49) performs worse than its middle floor version(Figure 50) until the good variants are incorporated.

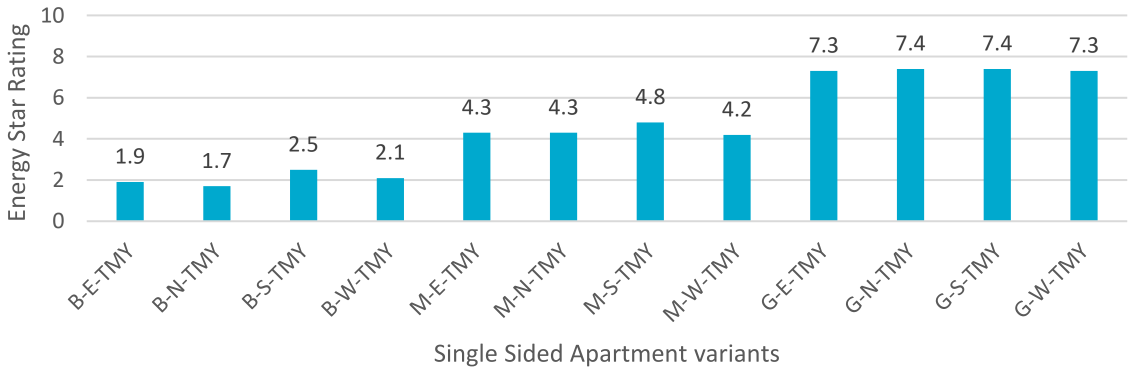


Figure 49 DLLA02 Top Floor energy ratings

Figure 50 DLLA02 Mid Floor energy ratings

In addition, this unit, similar to many units with single sided ventilation, performs quite poorly under 'bad' and 'medium' design options, regardless of orientation. It is only with increased insulation, shading and window openings that the units can perform moderately well. Even the 'good' design options that work with other dwelling designs to bring them over 8 stars, don't work as well for this type of apartment.

The medium and good variants in a southern orientation were selected for comparison. Similar to the corner apartment, the biggest difference between the variants with regards to comfort performance is in the reduction in total DD (Figure 51). An energy star performance increase of 2 stars (5.4 – 7.4 stars) results in reduced total DD in the living/kitchen zone of over ¼, and in the bedrooms of around ½. The performance of top floor and mid floor variants does not differ much in total DD (for this orientation and the medium and good variants).

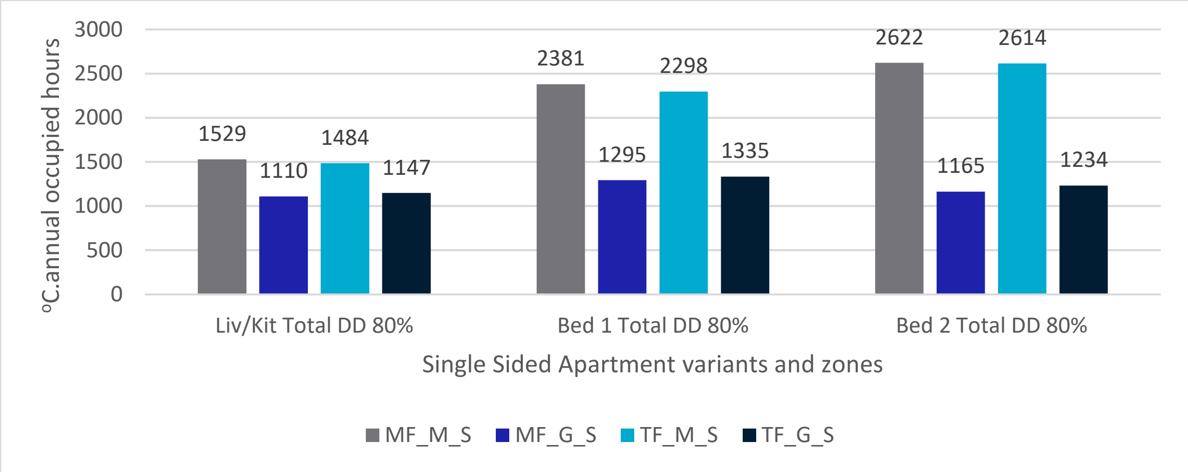


Figure 51 DLLA02 comfort performance_Total DD

Top floor and mid floor apartments have almost identical max DD (Figure 52) in the medium variation, but the top floor good variant shows a slightly higher max DD in the good variant (compared to the mid floor). The drop in max DD between medium and good variants (for both top and middle floor options) is because the 'worst bedroom' is not the same for between medium and good variants (so it is not a direct comparison).

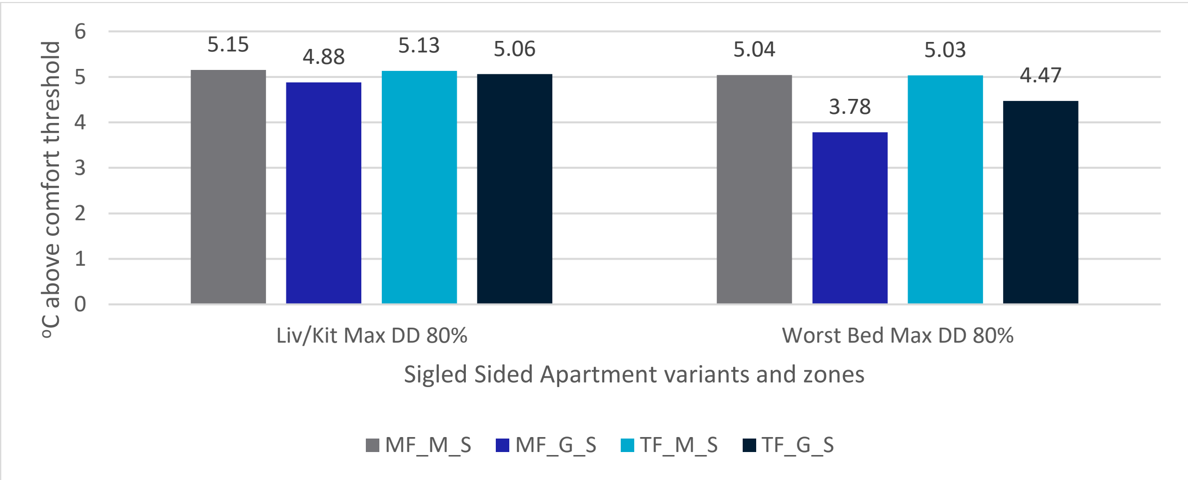


Figure 52 DLLA02 comfort performance_Max Hrly DD

3.3 Optimisation methodology and results

To gain an indication of what the upper limits of a comfort rating might be, it was necessary to see whether total DD could be reduced even further than the good design variants indicated. DLLH03 was selected for the optimisation modelling.

Table 7 shows the three changes made to the good east variant. Each of these changes is feasible with current building products. No other variants were modelled. A more comprehensive optimisation would undertake parametric analysis of the 'best' product available for each of the building elements.

Table 7 DLLH03 Optimisation changes

ELEMENT	GOOD VARIANT	OPTIMISED VARIANT
EXTERNAL WALLS	Reflective foil (inside, facing out)	No change
	R2.7 bulk insulation (outside)	No change
	Light colour	No change
INTERNAL WALLS	R1 insulation in framed walls	No change
FLOOR	No insulation	No change
CEILING	R2.5 bulk insulation	**R4 bulk insulation**
ROOF	R1.5 reflective blanket (downward)	No change
	Light colour (SA 0.3)	**Colour SA 0.2**
	Unventilated	No change
SHADING	2.5m eaves	No change
GLAZING	Aluminium frame	No change
	Single glazed low e tint (U5.6, SHGC 0.41)	**SG low e tint (U 4.9, SHGC 0.31)**
VENTILATION	90% openings	No change
	1400mm fans	No change

Figure 53 shows that optimisation has resulted in a 10 star house, with a reduction in cooling energy intensity (compared to the non-optimised G-E). Note that 190MJ/m^2 is the 'cut off' point for 10 stars: this optimised dwelling achieves 169.1MJ/m^2.

Figure 54 compares the total DD for each zone, revealing a reduction in DD in the living zone and each bedroom. The reduction in the worst bedroom (Bed 5) is particularly significant. At this orientation, bed 5 is in the north-west corner, with window openings on the northern and western walls. Further optimisation, for this house design, could consider the installation of vertical shading on bedroom windows that face east and west in particular (which will vary, depending on the orientation of the house).

Optimisation has had very minor impact on the max DD (**Error! Reference source not found.**) in the living/kitchen zone (NE orientation) and bed 4 (N), with a slightly higher impact on other bedrooms (up to half a degree).

This optimisation approach only changed three characteristics: bulk insulation in the ceiling, the solar absorptance of the roof, and the glazing. The disadvantage of this approach was that it does not allow for disaggregation of the contribution from each of these changes individually. Another disadvantage is that this particular combination of strategies may not be the best combination for achieving optimised results. Parametric modelling, where a wider range of parameters can be considered in multiple combinations, would enable the ‘best’ combinations to be determined to meet particular outcomes (e.g. the highest possible comfort rating, or the highest rating within particular price constraints).

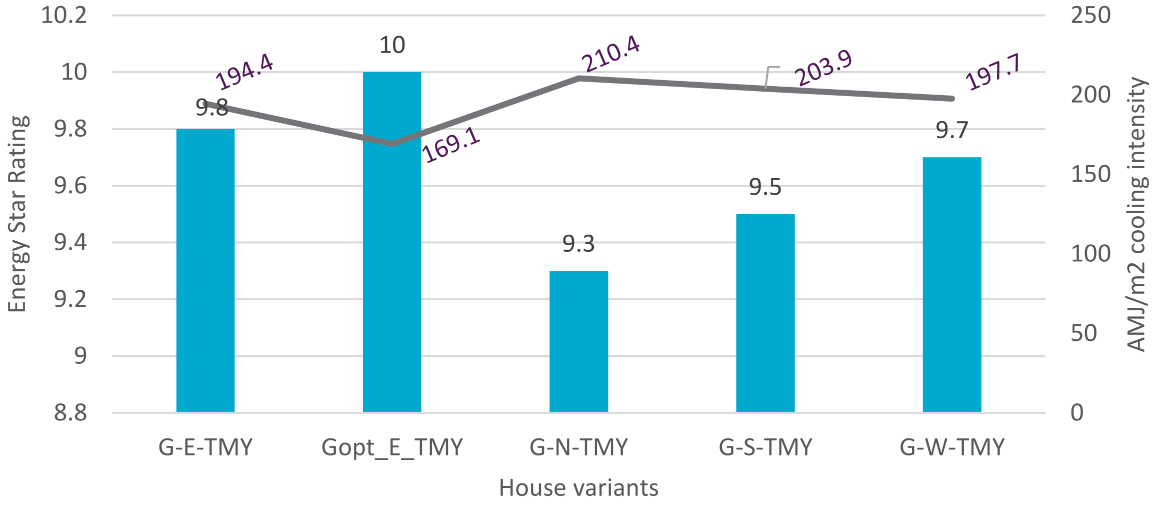


Figure 53 DLLH03 Block optimisation energy ratings and cooling intensity comparison

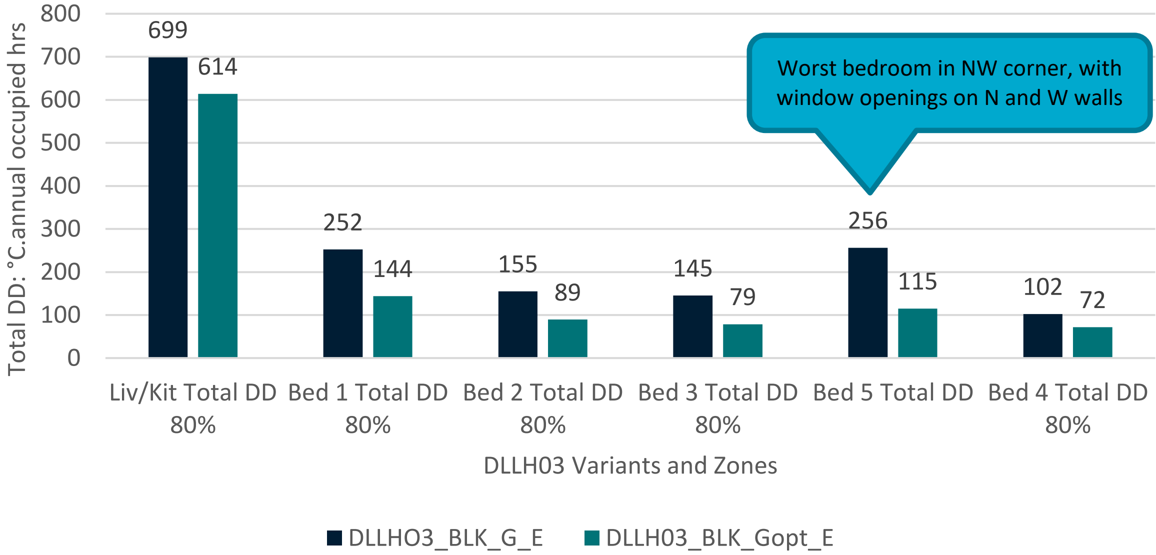


Figure 54 DLLH03 Block optimisation impact on DD

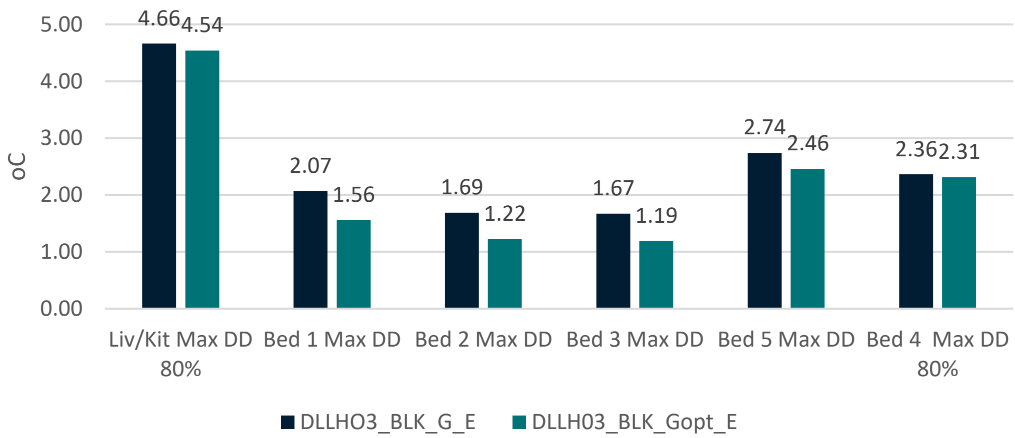


Figure 55 DLLH03 Optimisation impact on max hourly DD

4. Comfort Rating Recommendations

4.1 Analysis summary

Both data sets (AHD and QUT simulations) were examined to identify the lowest and highest DD from all data (excluding simulated dwellings <5 stars). A summary of the highest and lowest DD values is provided in Table 8, differentiating AHD data and QUT simulation data (all simulations). The highlighted figures are the highest/lowest figures from the complete set of data and could be used to provide the outer boundaries of the comfort rating. Interestingly it shows that the lowest figures are achieved in some of the existing dwellings (dwellings in the AHD set) – demonstrating that these figures can be achieved by industry (at least at design stage).

Table 8 Summary of DD data all sources

CRITERIA	AHD	QUT SIMULATION (OPTIMISED VARIATION IN BRACKETS)
LOWEST DD KIT/LIVING ZONE	**233**	699 (614)
HIGHEST DD KIT/LIVING ZONE	**17,611**	4,230
LOWEST DD BEDROOM	**5**	66
HIGHEST DD BEDROOM	3,185	**3,678**
LOWEST MAX DD KIT/LIVING ZONE	**2.58**	4.07
HIGHEST MAX DD KIT/LIVING ZONE	**13.73**	8.79
LOWEST MAX DD BEDROOM	**0.60**	1.61 (**1.19**)
HIGHEST MAX DD BEDROOM	5.44	**7.33**

4.1.1 Should comfort be based on overheating or DD?

Initially the TRG considered whether comfort should be based on an overheating criteria (e.g. percentage of occupied hours over the threshold) or on Degree (hours) of Discomfort (DD). Figure 56 compares the DD (occupied hours) with an overheating count (i.e. a count of the occupied hours where the comfort threshold is exceeded) for DLLH03. The left-hand chart shows the correlation for the kitchen/living zone for five design variants (the four good variants and the optimised variant) shown previously in Section 3.3. The right-hand chart shows the correlation for the bedrooms (5 bedrooms, each with 5 variants). Figure 57 presents the same bedroom data in a different way.

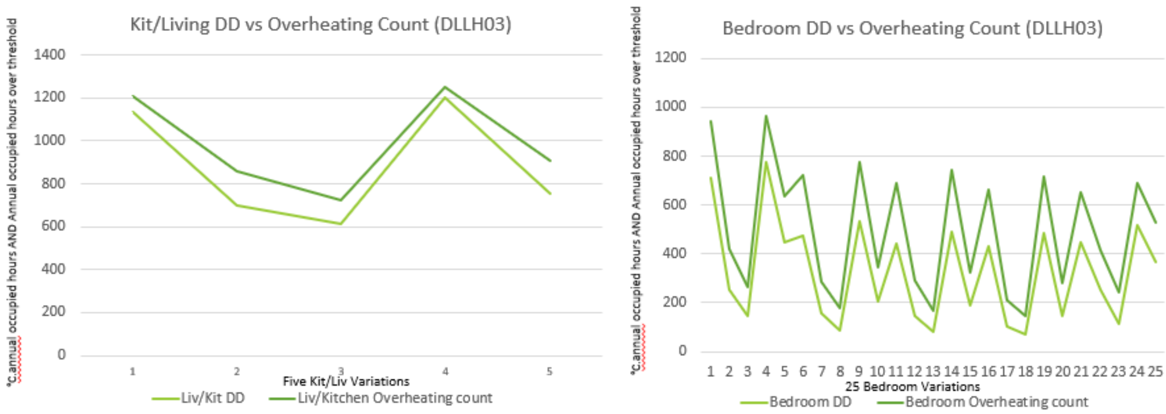


Figure 56 Correlation between DD and overheating count DLLH03

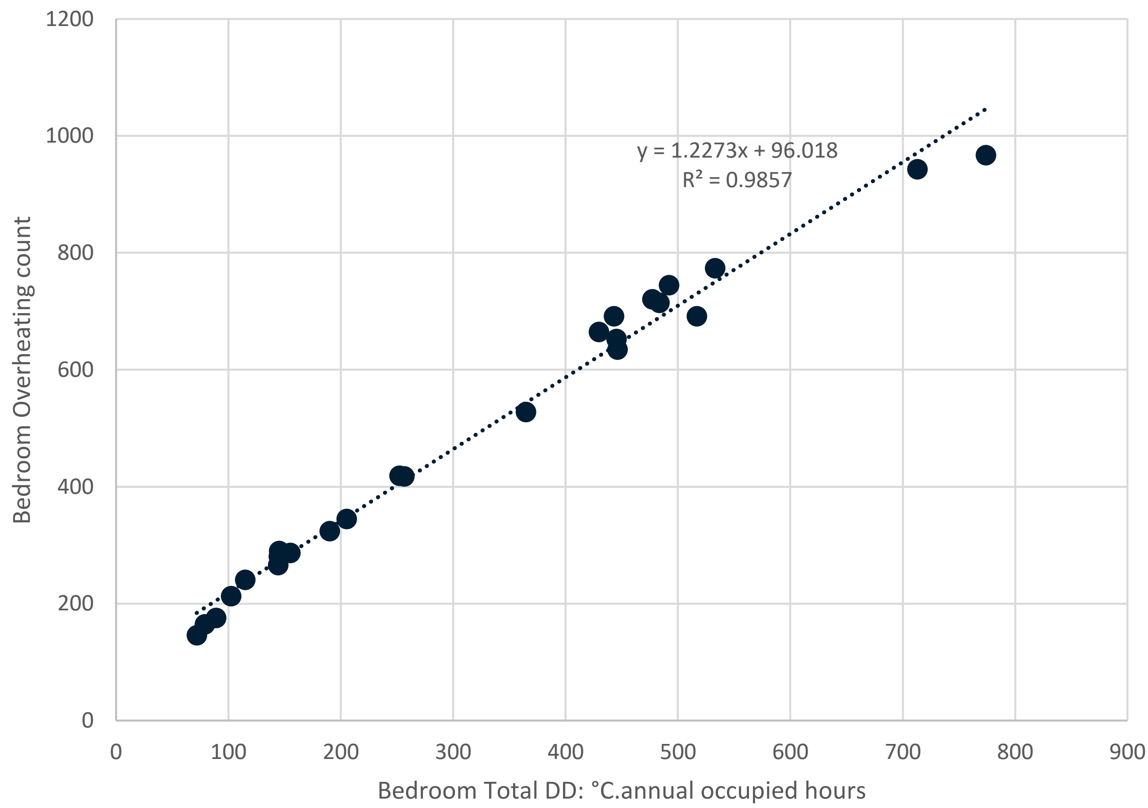


Figure 57 Correlation between bedroom DD and overheating hours DLLH03

The same approach was used to compare overheating hours with DD for all zones for all simulations presented in section 3 (Figure 58). It shows a high correlation between DD and overheating count, with a few outliers.

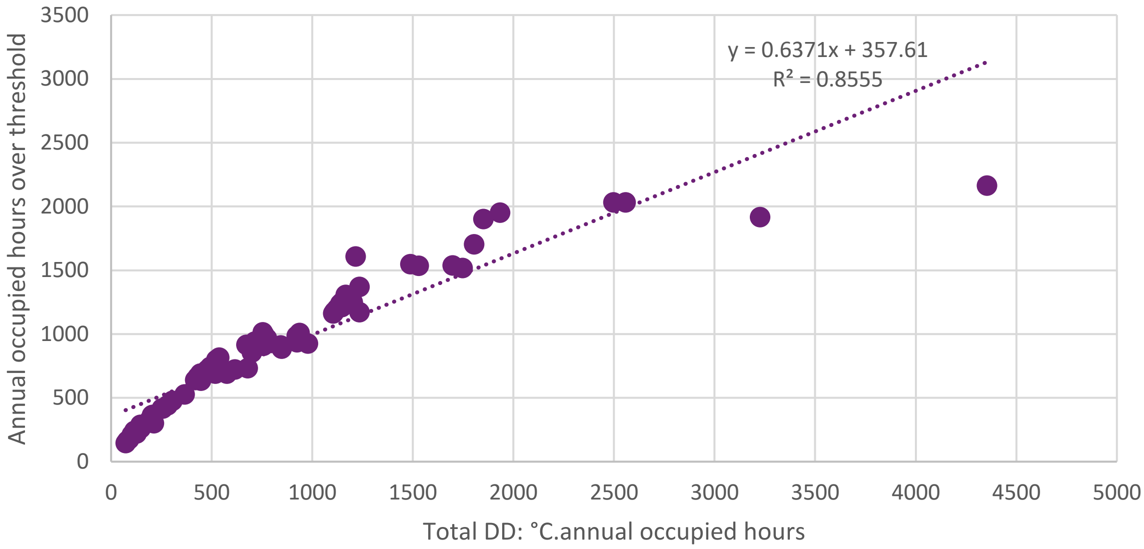


Figure 58 All zones DD vs overheating count

4.1.2 Should comfort be based on total DD or Max DD?

The AHD data (class 1 and class 2 dwellings) kitchen/living zone was used to examine if there was any correlation between total DD and max DD (Figure 59). Total DD (y axis) is in descending order, shown in aqua. The max DD (z axis) is in blue. The graph seems to indicate that living rooms with extremely high DD (e.g. above 9,500) have very high max DD that was not shown generally in dwellings with a lower DD. However, lower total DD does not necessarily mean lower max DD. There is a lot of variation, with a scattering of dwellings having a max DD between 6 and 10. The overall trend, however, is for lower max DD, and less extremes, with lower total DD.

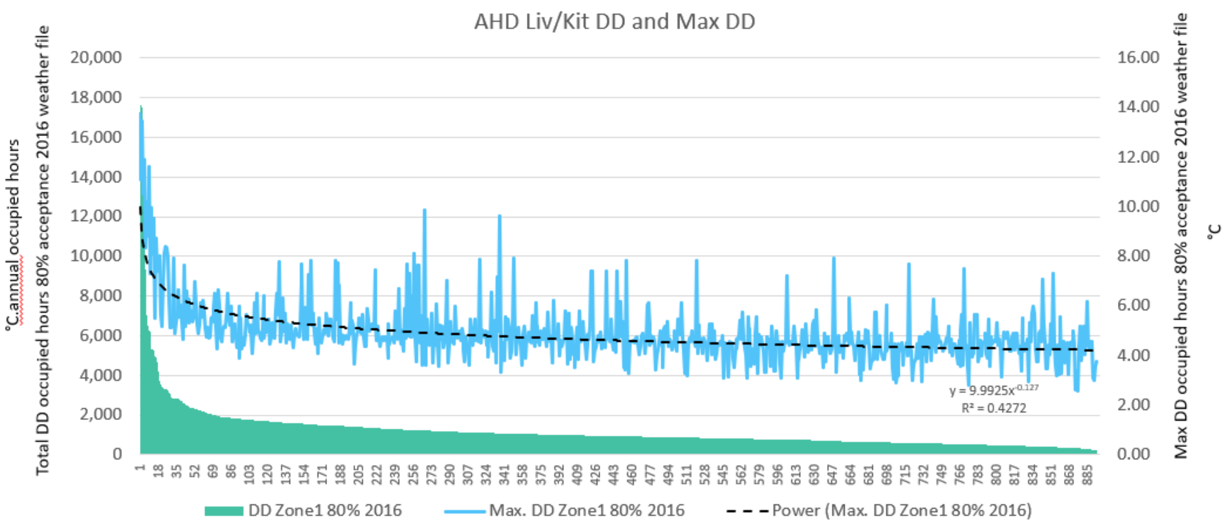


Figure 59 AHD Kit/Living zone DD and max hourly DD

The same data is presented as a scatter graph in Figure 60, with max DD in the y axis, and total DD in the x axis (in thousands). It shows, for this data set, that max DD is generally clustered between 3 and 6 when the total DD is less than 2000.

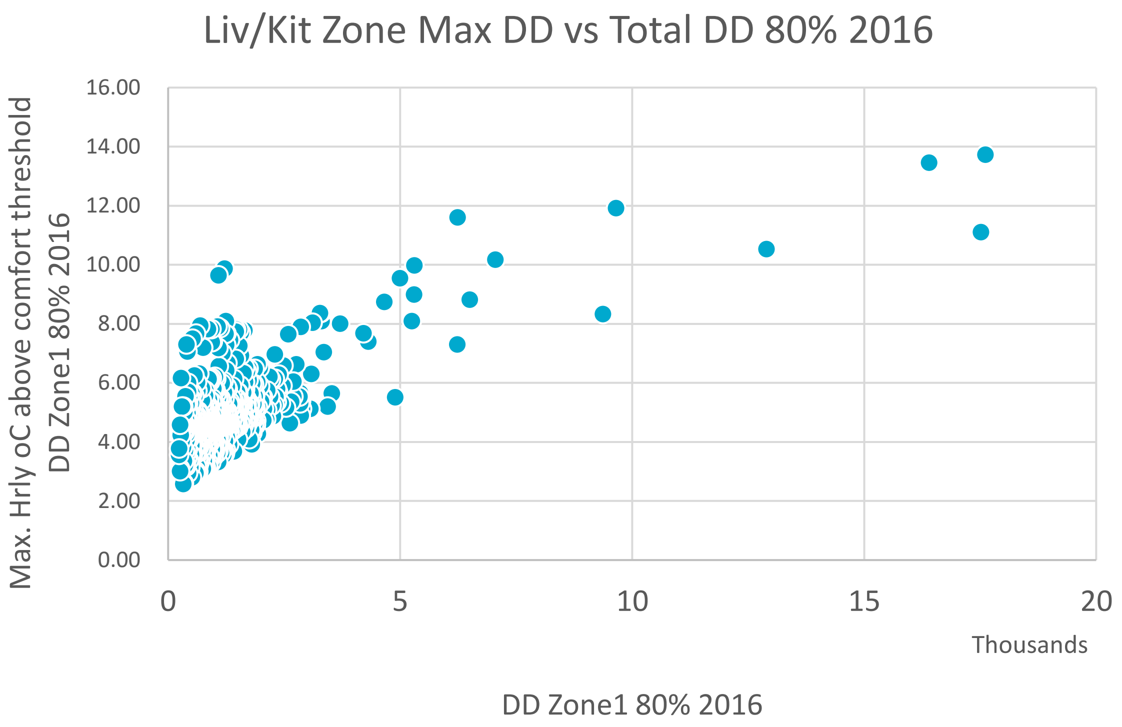


Figure 60 Scatter plot of total DD vs max DD (AHD data)

4.2 Comfort rating parameters and sensitivity analysis

The data presented in the previous sections was reviewed and discussed by the TRG on November 29th, 2022. From that discussion, the five broad parameters of a comfort rating were decided (Table 9).

Table 9 Comfort rating parameters and reasoning

COMFORT RATING PARAMETER	REASONING
1. THE COMFORT RATINGS SHOULD BE BASED ON THE KITCHEN-LIVING ZONE AND THE WORST BEDROOM (NOT THE WORST LIVING ZONE AND THE WORST BEDROOM)	1. The majority of Darwin dwellings have only 1 living zone (the kitchen/living zone) and this is presumed to be the most utilised living space in most dwellings
2. THE WORST BEDROOM WAS DEFINED AS THE BEDROOM WITH THE HIGHEST TOTAL DD IN OCCUPIED HOURS (NOT THE HIGHEST OVERHEATING HOURS OR HIGHEST MAX DD)	2. The worst bedroom (rather than the main bedroom) was voted by Darwin Living Lab Symposium attendees in August 2022 as the most suitable. Identification of the worst room also provides a target for designers to improve that room.
3. SEPARATE COMFORT RATINGS WOULD BE PROVIDED FOR THESE TWO ZONES	3. A single 'comfort rating' will hide the often quite large gap between comfort in the main living zone and in the worst bedroom
4. RATINGS FOR EACH OF THE TWO ZONES WOULD BE BASED ON OCCUPIED HOURS (USING NATHERS OCCUPANCY SCHEDULE)	4. Occupied hours provides consistency with NatHERS. Both DD and overheating can be calculated on occupied hours rather than annual hours.
5. THE MAIN COMFORT RATING WOULD BE TOTAL DEGREE (HOURS) OF DISCOMFORT (DD) FOR THE OCCUPIED HOURS OF EACH ZONE, WITH CONSIDERATION FOR INCLUDING THE MAX HOURLY DD ON THE CERTIFICATE.	5. Total DD (separate for the 2 zones) provides a reasonable overall sense of the extent to which those zones will exceed the comfort threshold. Indicating the max DD (the 'worst hour') on the certificate may provide further impetus to improve the design.

Based on the highest and lowest values of the combined data sets (shown previously in Table 8), the boundaries for the comfort ratings for the two zones were proposed (Table 10). The values for comfort ratings 1 and 10 are loosely based on a rounding down of the highest and lowest values from the combined data set. The value of band 1 was adjusted slightly to ensure that band 5 was roughly equivalent to the average DD of living zones of 5 – 5.9 star dwellings in the AHD (2160) and that band 10 was set to be slightly lower than the lowest DD in the data set (233). A constant multiplier of 0.6 for comfort bandwidths was found to provide the best fit for DD in both the living zone and bedroom. Similar to NatHERS energy ratings, this means that the absolute comfort rating bandwidths become smaller as ratings increase.

Max hourly DD values were initially proposed – stepping down in 1°C intervals (from 10°C) for the kitchen/living zone, and 0.5°C intervals (from 5°C) in the bedroom. This was discussed by the TRG and considered to be too complex to implement. Max DD was considered an important communication tool however, so an alternative solution was agreed: to simply include on the comfort certificate the max DD (the 'worst hour') for that specific design.

Table 10 Proposed comfort rating bands (look-up table)

COMFORT RATING	LIVING DD	BED DD
1	**15,000**	**3,600**
2	9,000	2,160
3	5,400	1,296
4	3,240	778
5	**1,944**	467
6	1,166	280
7	700	168
8	420	101
9	252	60
10	**151**	**36**

The proposed comfort bands are graphed in Figure 61. Note that the slope of this curve does not match the slope of the curve for the energy star rating bands (Figure 62). The range of comfort figures (0 - 16000) compared to the range of energy figures (0 - 900MJ/m^2) are too disparate to enable the same 'line of best fit' to be applied.

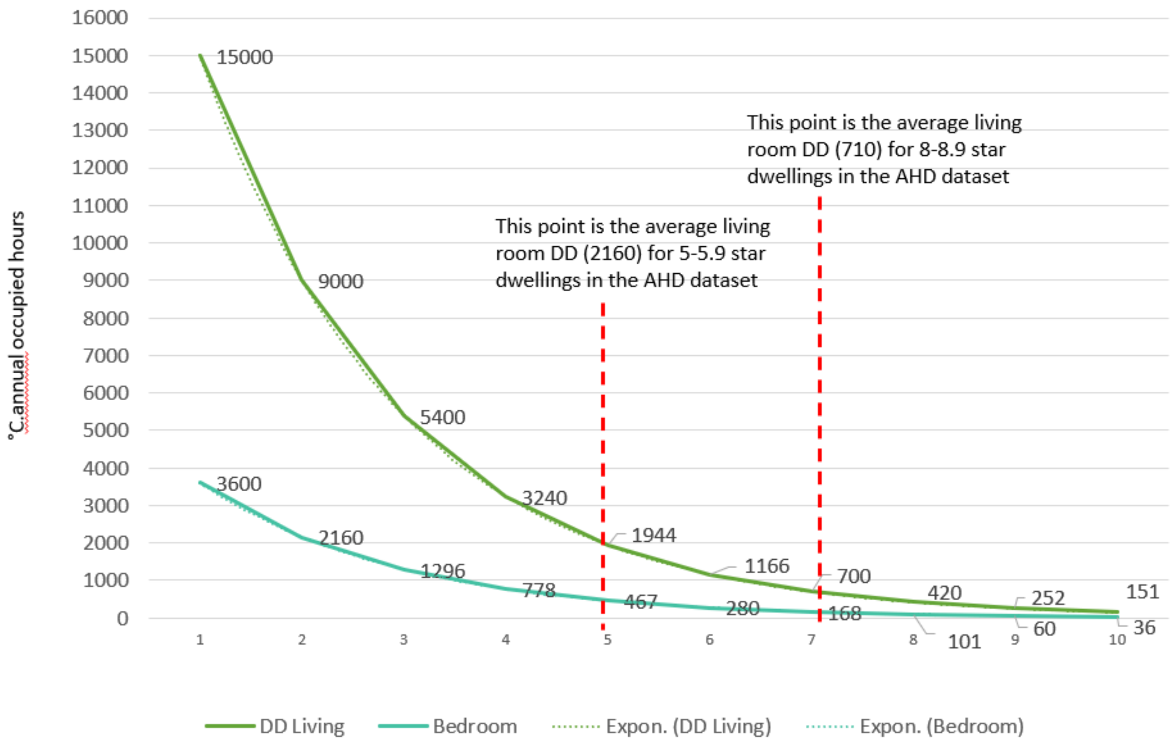


Figure 61 Proposed comfort bands - DD occupied hours annum

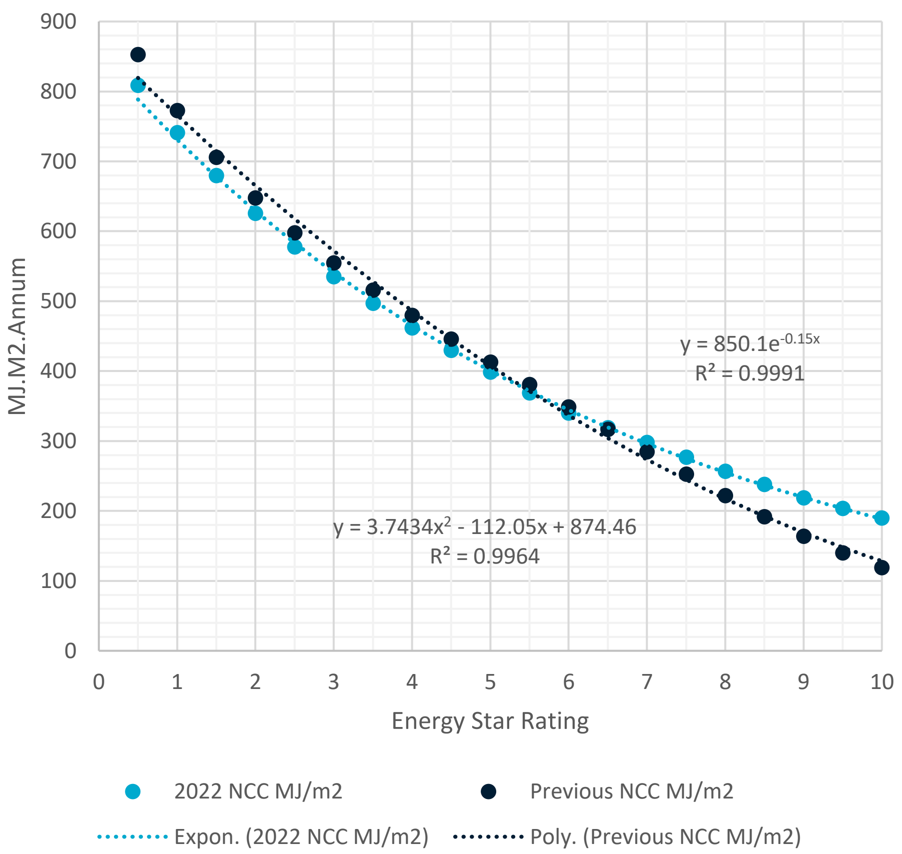


Figure 62 Darwin Energy Star Rating curves: line of best fit

The proposed comfort ratings were applied to the simulation results presented in section 3, as shown in

Table 11. The comfort ratings were assigned based on the look-up-table. An alternative approach would be to assign comfort ratings in 0.1 increments, as currently occurs with the energy star ratings.

Table 11 Simulated results by DD, energy rating and comfort rating

DWELLING ID	LIV/KIT DD	COMFORT RATING	BEDROOM DD	COMFORT RATING	ENERGY RATING
DLLH01_M_N	4354	3	593	4	4.4
DLLH01_G_N	3225	4	137	7	7.9
DLLH02_G_N	1746	5	978	3	5.2
DLLD01_M_E	1757	5	506	4	5
DLLA02_MF_M_S	1529	5	2622	1	5.4
DLLA02_TF_M_S	1484	5	2614	1	4.8
DLLD02_M_W	1340	5	625	4	4.9
DLLD01_G_E	1234	5	198	6	7.9
DLLH04_M_E	1294	5	1971	2	4.5
DLLH03_SF_M_E	1200	5	774	4	6.9
DLLA01_TF_M_E	1096	6	189	6	7.7
DLLA02_MF_G_S	1110	6	1295	3	7.4
DLLA02_TF_G_S	1147	6	1335	2	7.4
DLLH03_BLK_M_E	1163	6	1043	3	5.8
DLLA01_MF_M_E	1085	6	182	6	8.5
DLLH02_G_E	1104	6	923	3	4.6
DLLA01_TF_G_E	936	6	146	7	10
DLLA01_MF_G_E	922	6	126	7	9.9
DLLH04_G_E	805	6	789	3	8.8
DLLD02_G_N	843	6	212	6	9.4
DLLH03_SF_G_E	756	6	446	5	9.7
DLLH03_BLK_G_E	699	7	256	6	9.8
DLLH03_BLK_GOPT_E	614	7	144	7	10

This data was then used to investigate the relationship between energy ratings and DD (Figure 63), and between energy ratings and comfort ratings (Figure 64).

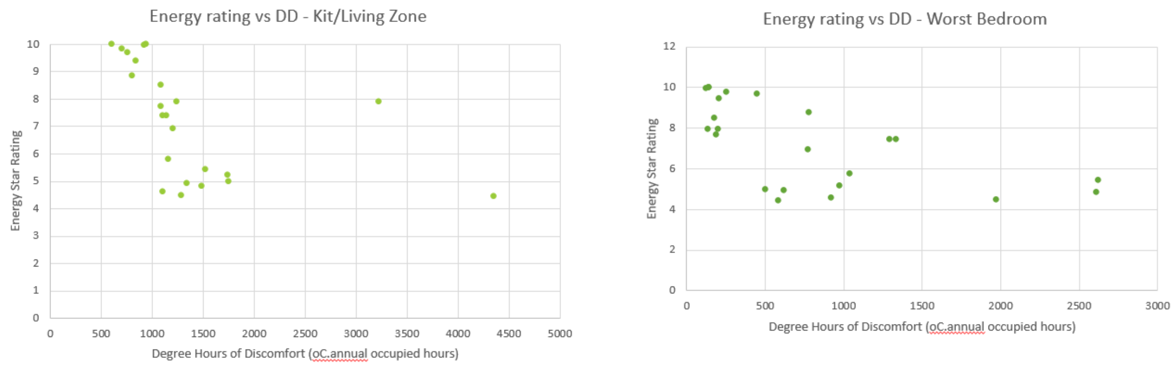


Figure 63 Relationship between energy ratings and DD (simulation data set)

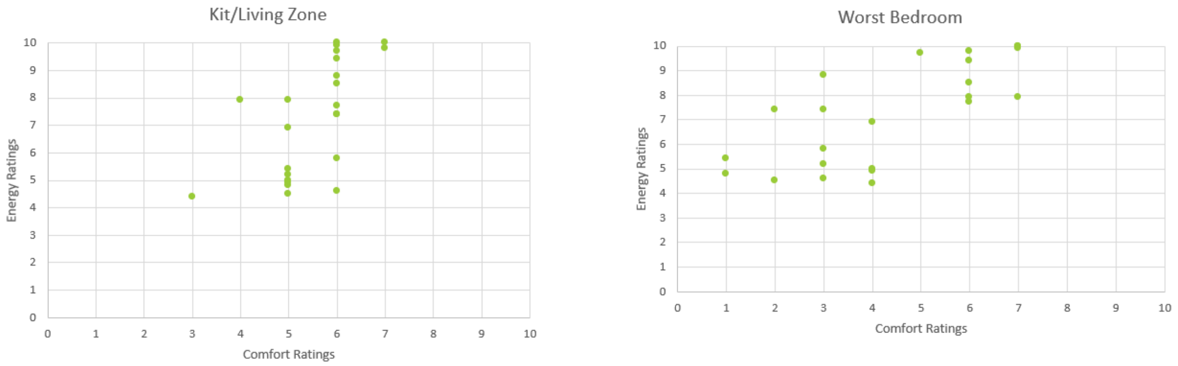


Figure 64 Relationship between energy ratings and comfort ratings (simulation data set)

The same approach was applied to class 1 data from the AHD (**Error! Reference source not found.**) and Class 2 AHD data (**Error! Reference source not found.**).

The data in **Error! Reference source not found.** shows that the majority of class 1 AHD kitchen/living areas achieve a comfort rating of 4-7, with a few achieving comfort ratings of 8 and 9. The correlation between the energy star rating and the comfort rating is significant but weak, for example some 5 and 6 star homes are achieving living zone comfort ratings of 7 and above. Conversely, no dwellings of 7 stars or above had a comfort rating for the living room below 3. This significant but weak correlation between energy star ratings and comfort ratings is also apparent in the Class 1 worst bedroom (**Error! Reference source not found.**), Class 2 results (**Error! Reference source not found.**) and QUT simulation results (Figure 64).

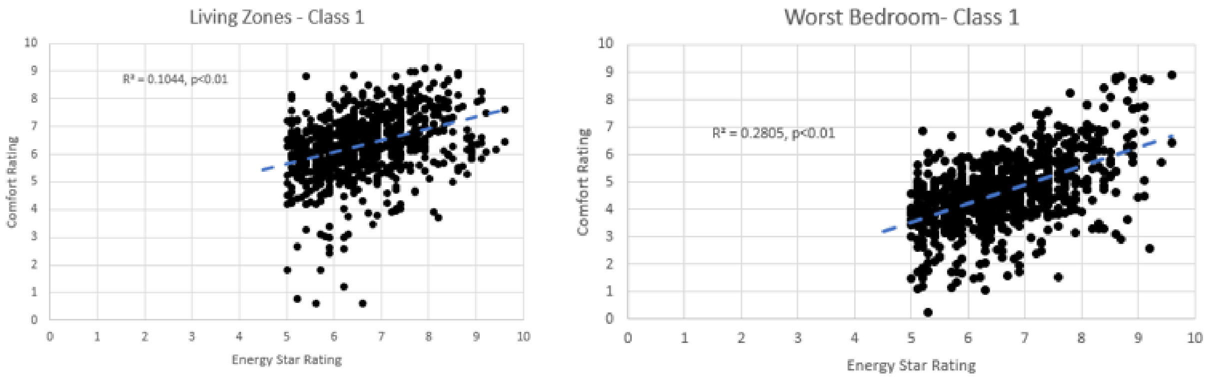


Figure 65 Relationship between energy ratings and comfort ratings (AHD Class 1 dwellings) – comfort and energy ratings in 0.1 increments

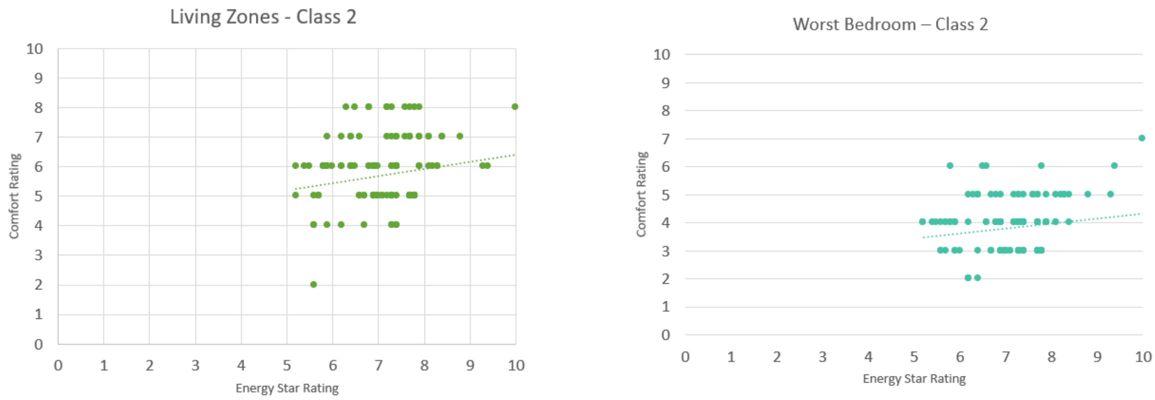


Figure 66 Relationship between energy ratings and comfort ratings (AHD Class 2 dwellings) – comfort ratings as whole integers, energy ratings in 0.1 increments

Figure 68 compares the energy rating of each AHD class 1 dwelling with the total DD (occupied hours) of the kitchen/living zone for each dwelling.

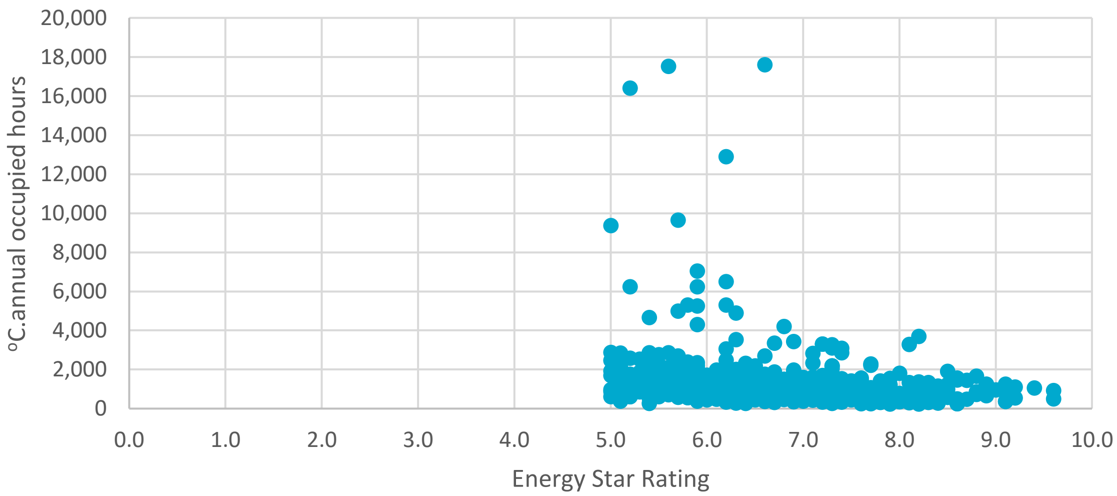


Figure 67 AHD Class 1 Kit/Living DD vs energy star rating

Figure 68 compares the energy rating of each class 1 dwelling with the total DD (occupied hours) of the worst bedroom for each dwelling. Some of the comfort bands have been overlaid on the graph. It shows that the majority of the dwellings achieve a bedroom comfort rating of 4-6.

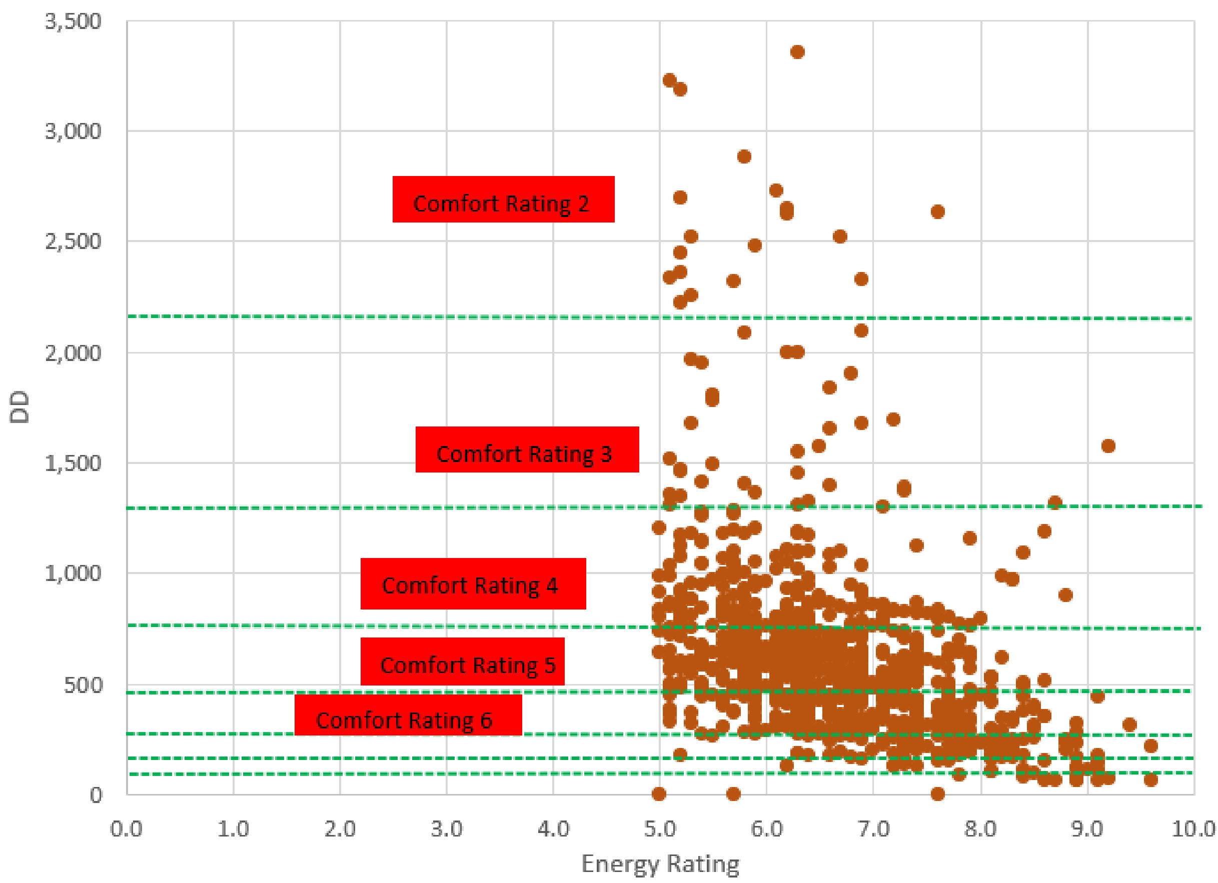


Figure 68 DD and Energy Rating of AHD Class 1 Worst Bedrooms

For further sensitivity analysis, the kitchen/living zone data from AHD Class 1 dwellings was used to investigate whether the ranking of total DD changed with the different climate files (2016 and 2050).

Figure 69 shows the rank order comparison of DD results between the 2016 and 2050 climates. While DD is always worse in 2050, the relative ranking between designs doesn't change enough to significantly change the comfort ranking. This is indicated by a high Spearman rank correlation coefficient ρ=0.958.

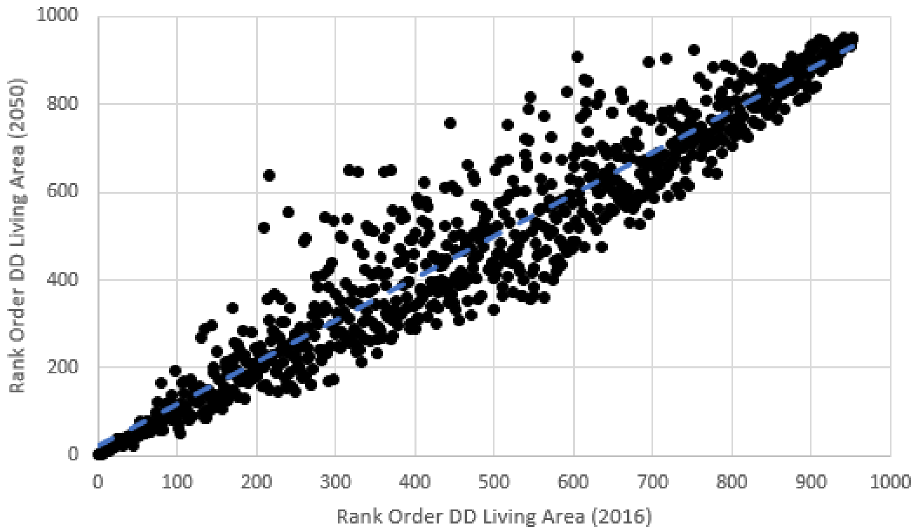


Figure 69 AHD Class 1 DD rank order of houses (living zones) for 2016 and 2050 climate

A comparison of the results showed that only 13 dwellings kept the same ranking, with 85% of dwellings changing ranking (up or down) between 1 and 100 places. These changes in ranking did not generally result in a change in comfort rating (i.e. ratings based on whole integer bands), unless the initial rating was close to the bottom threshold of a comfort band (in which case the rating may have moved down 1). This seems to indicate that while DD is always worse in 2050, the relatively ranking between designs doesn't change significantly enough to change the comfort ranking.

The comfort rating bands were then applied to the kitchen/living zone of all class 1 dwellings, for both the 2016 and 2050 data results. The 2016 results, shown in light blue in Figure 70, have a fairly standard Bell curve distribution. The 2050 results, shown in dark blue, reveal that no dwellings will rate above the comfort rating of 4, with the majority achieving a whole integer rating of 2 or 3. Note that there are some dwellings that fail to achieve a comfort rating (shown as band 0).

The sensitivity analysis confirms that the proposed comfort rating bands (Table 10 and Figure 61) can be applied to Darwin dwellings to provide more insight into the performance of the dwellings. The information in this report will10pm – 7am be utilised by CSIRO to amend AccuRATE.

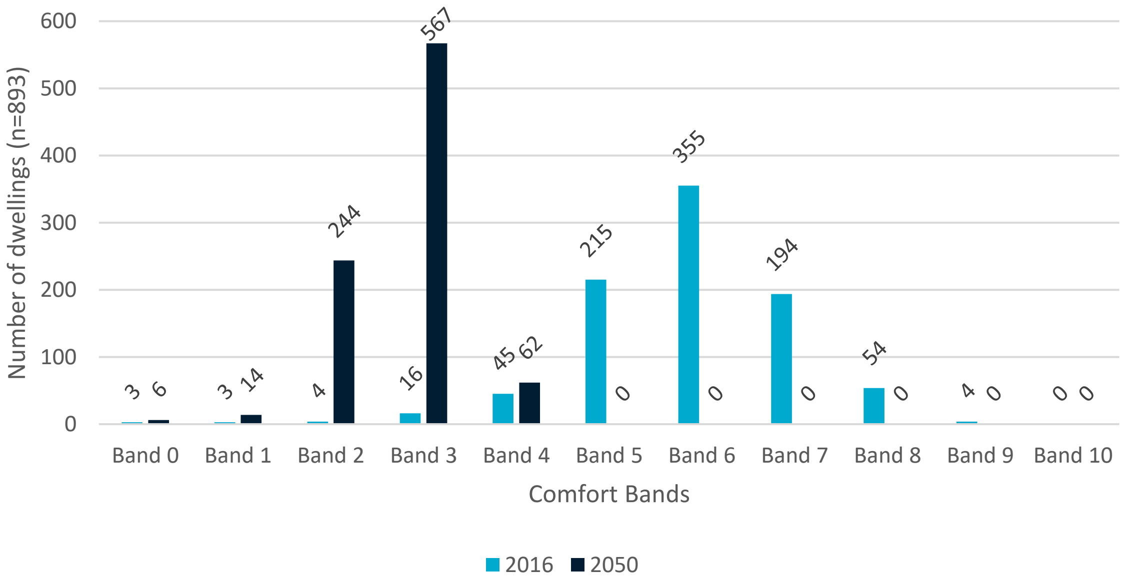


Figure 70 Comparison of 2016 and 2050 comfort ratings (AHD Class 1 Kit/Liv zone)

4.3 Recommendations for implementation

Four recommendations are made with regard to the implementation of the comfort rating.

Recommendation 1: The comfort bands for the kitchen/living zone and the worst bedroom should be assigned as per the look-up table (Table 10) for total DD relevant to each zone. An alternative could be to assign comfort ratings in 0.1 increments within these bands (as currently happens for energy star ratings).

Recommendation 2: Consideration should be given by designers of housing specifically meant for vulnerable populations to use the comfort threshold formulae relating to 90% acceptability. This could apply to demographics known to have higher incidence of chronic disease (e.g. indigenous, elderly, disabled) or known susceptibility to overheating (e.g. very young children, pregnant women, elderly), and to demographics with limited financial resources (e.g. social or private rental housing for lower socio-economic clients) This is because there is ample evidence to suggest that these population groups are more likely to have health conditions that may make them more susceptible to overheating and/or have difficulty in affording the high costs of air conditioning.

Recommendation 3: Designs should strive for a comfort band rating of 9 for living zones. This equates to an approximate maximum of 4% of annual occupied hours over the comfort threshold (compared to the TM59 Standard[8] that requires no more than 3% exceedance hours). For bedrooms a minimum comfort rating of 7 is recommended, representing 2.7% of annual occupied hours over the comfort threshold (compared to the TM59 Standard that requires no more than 1% exceedance during sleeping hours of 10pm – 7am).

Recommendation 4: Designs should consider both current and future weather conditions, as dwellings constructed today are likely to be in operation in 2050. The data analysis suggests that this housing in 2050 could have 30% more annual hours above the comfort threshold compared to current overheating based on the 2016 weather file (at 80% acceptability). This assumes that there are no changes to occupant behaviour or to the housing (to adapt to the changing climate). Perceptions of discomfort may change over time, compared to the present.

Three limitations are also presented here. It is not proposed that these limitations inhibit the roll out of the current proposed trial of the comfort rating for Darwin. They are raised to highlight that additional work could be carried out to further extend the communication and implementation of comfort ratings in Darwin.

Limitation 1: None of the comfort criteria communicate the distribution of overheating. For example, are the occasions when the comfort threshold is exceeded in consecutive hours or days, or more distributed / random? This is an important issue particularly when zones have a high DD count and exceedance is often above 1°C, because accumulative exposure to overheating can have a different impact on occupants compared to short term exposure.

Limitation 2: the medium and good variants of the simulated designs changed multiple features. It may be helpful for the housing industry to understand the implications of individual changes to design (e.g. increase in insulation only; in glazing only; in ventilation only etc). In addition, parametric modelling is recommended to investigate what combinations of improvements can provide the most benefit.

Limitation 3: Neither the 2016 nor the 2050 weather files utilised in this project take into account heat wave conditions (i.e. both files are based on a Reference Meteorological Year that uses average weather conditions). As such, the building performances simulated do not reflect the full extent of 'discomfort' that might be experienced during sequential or extreme hot days that exceed the average maximum temperature and humidity for each month.

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[8] CIBSE TM59. https://www.cibse.org/knowledge-research/knowledge-portal/technical-memorandum-59-design-methodology-for-the-assessment-of-overheating-risk-in-homes

Image 3: Light coloured roof and walls reduce solar absorption (Supplied: Wendy Miller)

Glossary

ASHRAE	American Society of Heating, Refrigeration, and Air-Conditioning Engineers
CEV	Cooling effect of ventilation (at each hour)
DD	Degree (hours) of Discomfort. A count of the degrees (°C) above the comfort threshold for each hour of the year
IPCC	Intergovernmental Panel on Climate Change
ET*	New Effective Temperature. An index that combines the effects of dry-bulb temperature, humidity, radiant conditions and air movement.
NatHERS	National House Energy Rating Scheme (Australia)
NCC	National Construction Code (Australia)
PPD	Predicted Percentage Dissatisfied (with thermal comfort). It is a means of trying to quantify thermal discomfort, i.e. the percentage of a population who would find indoor conditions too hot or too cold.
RCP	Representative Concentration Pathway (relating to possible future climate scenarios in terms of greenhouse gas emissions and atmospheric concentrations). RCP8.5 used in this report refers to the highest baseline emissions scenario.
RMY	Reference Meteorological Year. These are TMY weather files for use in residential building energy simulations which use NatHERS. The current RMY files, for each NatHERS climate zone in Australia, are based on 1990 to 2015 weather data from the Bureau of Meteorology.
TMY	Typical Meteorological Year, containing one year of hourly data representing median weather conditions over a historical period. The reference to TMY in graphs in this report refers specifically to the 2016 RMY weather files (historical period 1990 to 2015).
T_{outmm}	Mean monthly outdoor temperature
TRG	Technical Reference Group

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