Climate Change – Impact on Building Design and Energy

Final Report

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Executive Summary

According to CSIRO, Australia has warmed by just over 1°C since 1910, with most warming occurring since 1950. Such change in the climate has considerable impacts on the built environment, not merely from the perspective of energy consumption but also on occupant thermal comfort and health. The Paris Climate Agreement states that climate change should be dealt with from the perspective of *mitigation* (through emissions reduction) and *adaptation*. Climate change adaptation within built environment design can be regarded as a process of imparting increased adaptive capacity to projects to take account of expected future climate changes.

DeltaQ, with the support of climate scientists and design engineers, have undertaken research on behalf of the COAG Energy Council's Major Projects Implementation Team and the Department of Industry, Science, Energy and Resources (DISER) to quantify the impacts of climate change on the built environment, and to better understand if and how building regulations need to change such that buildings can adapt to a changing climate.

In this report, we:

- Present our analysis of future climate files in National Construction Code (NCC) climate zones 2, 5 and 6 under the highest emissions Intergovernmental Panel on Climate Change (IPCC) scenario and of current climate files used for air-conditioning plant sizing and for building energy and thermal comfort modelling.
- Review how international jurisdictions are addressing building adaptation to climate change within building regulation, and existing work within Australia.
- Summarise international and local efforts to develop future climate files, including how microclimates such as the urban heat island effect is addressed.
- Present the HVAC plant sizing results for a daytime-operation (office) and overnight-operation (hotel) building using different climate files in climate zones 2, 5 and 6.
- Present building energy and thermal comfort modelling results for a daytime-operation (office) and overnight-operation (hotel) building using different climate files in climate zones 2, 5 and 6.
- Discuss the research questions proposed including the suitability of current climate files to address future climate risk in air-conditioning plant sizing and building energy modelling, as well as its impacts on building design features.
- Present our recommendations for how the building code should respond to ensure resilient building with the ability to adapt to climate change.

A high-level summary of the key recommendations is presented overleaf, with the full list of recommendations provided in Section 6 of this report.

Key Recommendations:

1. Update Section J Performance Requirements to reference the full life span of the building and systems.
2. Introduce the requirement for the climatic data used for energy and thermal comfort modelling to be a future climate file (nominally 10-15 years into the future, or 2030) in Specification JVb(3)(a)(iii). At present, Section J Specification JVb does not stipulate the use of specific climate files beyond requiring the proposed and reference building to be modelled using the same location where climatic data is available. In order to ensure alignment between the Verification Methods JV1, JV2 and JV3, the ABCB should coordinate with NABERS and the GBCA to update their NABERS Commitment Agreement handbook and Green Star Design & As Built v1.3 Energy Consumption and Greenhouse Gas Emissions Calculation Guide to specify future climate modelling must occur.
3. To avoid an increase in building annual greenhouse gas emissions due to increased HVAC plant size, the stringency of Section J Deemed-to-Satisfy (DTS) provisions should be reviewed against updated cost-benefit analysis using future climate files, and increased where beneficial, particularly for requirements related to cooling equipment. Thermal comfort should also be included as an assessment criterion when reviewing changes to DTS provisions.
4. The ABCB or nominated government body should manage and host a centrally available database of ‘accredited’ climate files for 8 climate zones – weather station selections should be referenced against existing Bureau of Meteorology (BOM) data in consultation with climate experts. Climate files should be reviewed and updated at minimum once every decade to account for changes in climate and projection values. At time of writing, current options for future climate files include the Ersatz climate files developed by Exemplary Energy Partners. CSIRO’s recently-updated NatHERS climate files (up to 2016) and associated future climate files may also be suitable options although these are not publicly available at time of writing. As the CSIRO Electricity Sector Climate Information (ESCI) work is projected to be completed by 2022, we recommend that a review of the central database of climate files be scheduled in the next two years to coincide with this.
5. Commission research and development of future climate files for each climate zone incorporating impacts of urban heat island effects. Buildings within an urbanised environment should use an ‘urban’ climate file instead of a regional climate file such as the airport which is not representative of the localised climate where the building is located. It may be beneficial to commission case studies on mitigating urban heat island effects using trees or green-walls (evaporative effects) within the energy model, which is currently only capable of incorporating external shading impacts (easily) at time of writing).
6. The impact of changing greenhouse gas coefficients on design decisions should be assessed (currently covered in Specification JVb Table 3a). While our analysis shows that the design decision to trade off performance of certain building elements remains unchanged across different climate files, this may not be true when different greenhouse gas emissions factors are applied. A lower emissions factors for electricity may make it easier to trade off design elements, yet still comply with Code.
7. Introduce the requirement to conduct a risk assessment for extreme weather events (extreme heat, wind and floods) and the ability of the building to adapt to or mitigate those risks. Extreme risks such as the occurrence of hail may also need to be considered especially for buildings where rooftop solar panels are used to achieve NCC compliance. This requirement may not be directly applicable within the Section J Energy Efficiency section of the Code, and may require a new Building Resilience requirement to be created if this was adopted. This would require future Extreme Weather Files to be created for this assessment.

Opportunities for further work

The work in this report was conducted for a limited number of climate zones and climate files, and limited to examining the impact of future climate on building energy and design. There is opportunity to expand on the findings in this report through additional work, including:

1. The HVAC plant sizing and energy and thermal comfort modelling in this report have been conducted based on 2050 climate data generated for the highest-emissions scenario. This was done to assess the worst-case climate impact on building energy and design. We recommend that the analysis in this report be repeated using 2030 climate data on an emissions pathway that is agreed as a most-likely scenario (a scenario between IPCC RCP2.6 and RCP8.5). 2030 is also a useful point of analysis as it coincides with the 10- to 20-year HVAC plant end-of-life replacement cycle. A 2030 analysis would also be important in validating the findings and recommendations of this report.

2. Energy and thermal comfort modelling in this report revealed that a DTS 2019 compliant building does not necessarily achieve the thermal comfort requirements specified in JV1(a)(ii)(B), JV2(a)(iii) and JV3(a)(ii). For context, the thermal comfort requirement specified for the Section J Verification Method requires evidence that the Predicted Mean Vote (PMV) of ±1 is achieved not less than 95% floor area of occupied zones, for more than 98% of the annual hours of operation. Future work to update DTS provisions (Part J1 to J8) should consider thermal comfort in addition to cost effectiveness, ensuring that a DTS compliant building also meets the thermal comfort requirements.

3. The analysis in this report has been conducted for three climate zones that represent the most densely populated areas in Australia. Climate zones 2, 5 and 6 covers the major capital cities including Brisbane, Sydney, Perth, Adelaide and Melbourne. However, the findings may or may not be consistent across the other climate zones 1, 3, 4, 7 and 8 (Darwin, Hobart and Canberra). Climate change may lead to cooler climates resembling a warmer climate zone, or more extreme weather in warm and very humid climates. We recommend that the analysis in this report be repeated for other Australia climate zones to confirm this or otherwise.

4. It may be helpful to reassess the appropriateness of 8 climate zones, and whether the various locations should still be classified within the same climate zone. For example, a city like Canberra or Hobart may resemble climate zones 6 or 7 (instead of the existing 7 and 8).

List of Acronyms

ABCB	Australian Building Codes Board
ACDB	Australian Climate Data Bank
ACH	Air Changes per Hour
AEMO	Australian Energy Market Operator
AHRI	Air Conditioning, Heating, and Refrigeration Institute
AIRAH	Australian Institute of Refrigeration, Air conditioning and Heating
AR5	Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change
AS	Australian Standard
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning
BOM	Bureau of Meteorology
CAT	Canyon Air Temperature
CBECC	California Building Energy Code Compliance
CCAM	Conformal Cubic Atmospheric Model
CDD	Cooling Degree Days
CIBSE	Chartered Institution of Building Services Engineers
CMIP6	Coupled Model Inter-comparison Project phase 6
COP	Coefficient of Performance
CPD	Continuing Professional Development
CSIRO	Commonwealth Science and Industrial Research Organisation
CZ	Climate Zone
DA	Design Application
DB	Dry Bulb
DISER	Department of Science, Innovation, Energy and Resources
DSY	Design Summer Year
DTS	Deemed to Satisfy
EER	Energy Efficiency Rating
EFMY	Ersatz Future Meteorological Year
EPW	Energy Plus Weather
ESCI	Electricity Sector Climate Information
EUI	Energy Use Intensity
GB	Guobiao Standards
GBCA	Green Building Council of Australia
GCM	Global Climate Models
GHG	Greenhouse Gas
GLA	Greater London Authority
HDD	Heating Degree Days
HVAC	Heating, Ventilation and Air Conditioning
IBPSA	International Building Performance Simulation Association
IES VE	Integrated Environmental Solutions Virtual Solutions
IPCC	Intergovernmental Panel on Climate Change
IPLV	Integrated Part Load Value
IWEC	(ASHRAE) International Weather files for Energy Calculations

MEPS	Minimum Energy Performance Standards
MIT	Massachusetts Institute of Technology
NABERS	National Australian Built Environment Rating Scheme
NASA	National Aeronautics and Space Administration
NatHERS	National House Energy Rating Scheme
NCC	National Construction Code
NCCARF	National Climate Change Adaptation Research Facility
NSW	New South Wales
NZS	New Zealand Standard
PCA	Property Council of Australia
PCV	Projected Change Values
PMV	Predicted Mean Vote
QCoast 2100	Queensland Local Government Coastal Hazard Adaptation
RCP	Representative Concentration Pathway
RMY	Representative Meteorological Year
SA	South Australia
SEER	Seasonal Energy Efficiency Ratio
SHGC	Solar Gain Heat Coefficient
STG	Special Technical Group
Tas	Tasmania
TM	Technical Memorandum
TMY	Typical Meteorological Year
TRY	Test Reference Year
UCM-TAPM	Urban Climate Model - The Air Pollution Model
UHI	Urban Heat Island
UK	United Kingdom
UKCIP	United Kingdom Climate Impacts Program
UKCP	United Kingdom Climate Projections
USA	United States of America
USEPA	United States Environmental Protection Agency
VAV	Variable Air Volume
VIC	Victoria
VRF	Variable Refrigerant Flow
WB	Wet Bulb
WSROC	Western Sydney Regional Organisation of Councils
WYEC	Weather Year for Energy Calculations

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1 Project Objective

For this project, DeltaQ has undertaken research on behalf of the Department of Industry, Science, Energy and Resources (*the Department*) to better understand the impact of climate change on commercial building energy consumption and any HVAC and building design changes. The results from this research will inform the Department and the Australian Building Codes Board (ABCB) as to whether changes to the 2019 National Construction Code Section J (*NCC Section J)* or other regulation mechanisms are required to ensure future building resilience.

1.1 Relationship between Climate Change and the Built Environment

The global role of countries in stepping up to act on climate change was recognised in the 2015 Paris Climate Agreement, where the long-term goal is to keep the global average temperature to <1.5°C above pre-industrial levels. Countries address the issue of climate change using a two-prong approach:

- One, through mitigation – namely, by reducing emissions as much as possible and by using carbon sinks. Responses to climate change that are built on practices to reduce GHG emissions are described as mitigation strategies.
- Two, through adaptation – namely, by increasing the ability to adapt to adverse impacts of climate change such as climate-resilient development. Responses to climate change impacts are described as adaptation strategies.

According to the Intergovernmental Panel on Climate Change (IPCC) *Special Report on Global Warming of 1.5°C*[1], global warming is likely to reach 1.5°C between 2030 and 2052 if it continues to increase at the current rate.

NASA[2] has identified that some of the adverse long-term effects of global climate change include: rising global temperatures; changes in precipitation patterns (with substantially increased rainfall in some areas, and reduced rainfall in others); increased droughts and heat waves; increased intensity of hurricanes and extreme wind events; and rising sea-levels (causing increased flooding).

Closer to home in Australia, CSIRO[3] reports that Australia's climate has warmed by ~1°C since 1910 with effects that include: increasing frequency of extreme heat events; increasing bushfire risks and duration; a decline in shoulder and winter season rainfall in south-eastern and south-western Australia but increased rainfall in the north; and a higher number of extreme rainfall events. In order to deal with the effects described above, it is necessary for the built environment to adapt through resilient building design and development. The Resilient Design Institute[4] states that resilience is *the capacity to adapt to changing conditions and to maintain or regain functionality and vitality in the face of stress or disturbance. It is the capacity to bounce back after a disturbance or interruption*.

Relevant to the adaptation of the built environment to be resilient to impacts of climate change, is the need to consider how climate change will impact building heating and cooling demand, and whether existing HVAC design and building fabric requirements need to be adjusted in order to manage the increased thermal load

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[1] https://www.ipcc.ch/sr15/

[2] https://climate.nasa.gov/effects/

[3] https://www.csiro.au/en/Research/OandA/Areas/Assessing-our-climate/State-of-the-Climate-2018/Australias-changing-climate

[4] https://www.resilientdesign.org/what-is-resilience/

on the building. The World Health Organisation 2004 report[5] points out that increased use of air conditioning would protect against heat stress but could also increase emissions of both greenhouse gases and conventional air pollutants. As such, it is important to ensure that passive building design is considered ahead of increased air-conditioning in the adaptation strategy for the built environment.

The 2014 IPCC climate modelling and research in AR5[6] references a few representative concentration pathways (RCPs), namely RCP2.6, RCP4.5, RCP6.0 and RCP8.5. RCPs project the possible trajectory of atmospheric greenhouse gas concentrations between 1850 and 2100[7], where RCP8.5 is the high-emissions '*business-as-usual'* scenario assuming a non-climate mitigation-policy position, increasing global population and primary energy demand met primarily by fossil fuels.[8] We note that the RCP2.6 pathway is the only pathway that has a likelihood (albeit low according to the 2014 IPCC AR5 report) of maintaining the average temperature <1.5°C.

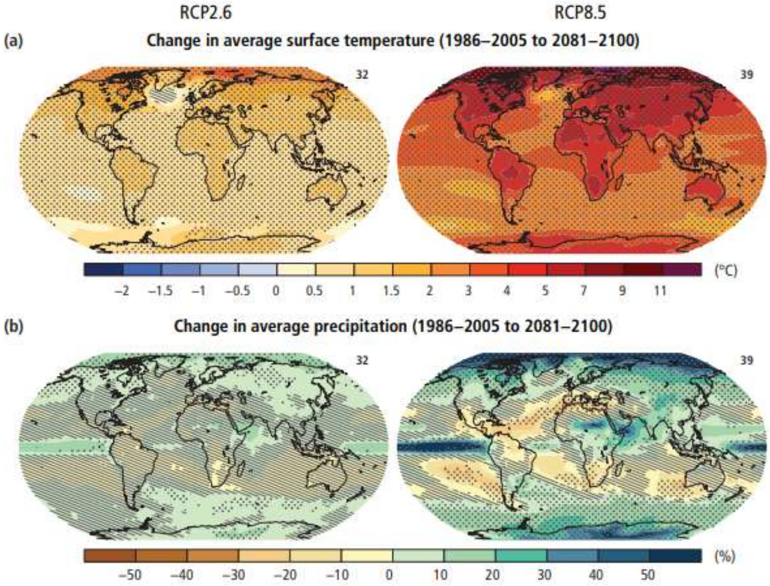

Figure 1. Infographic illustrating the difference between the RCP2.6 and RCP8.5 scenario for average temperature and precipitation. [Source: IPCC Climate Change Synthesis Report Figure SPM.7, 2014][9]

Climate files using the RCP8.5 pathway were chosen for the energy and thermal modelling work in this project due to its nature as 'worst-case' scenario. Effectively, this informs us of the largest magnitude of change required in the built environment, specifically within building fabric and HVAC systems, to adapt to such a scenario.

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[5] McMichael, AJ *et al* (2004). *Climate Change and Human Health – Risks and Responses.* World Health Organisation. Accessed: https://www.who.int/globalchange/publications/climchange.pdf

[6] IPCC, 2014: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baselinem, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. Accessed: https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_full.pdf

[7] van Vuuren, D.P., Edmonds, J., Kainuma, M. *et al.* The representative concentration pathways: an overview. *Climatic Change* **109,** 5 (2011). https://doi.org/10.1007/s10584-011-0148-z

[8] Riahi, K., Rao, S., Krey, V. *et al.* RCP 8.5—A scenario of comparatively high greenhouse gas emissions. *Climatic Change* **109,** 33 (2011). https://doi.org/10.1007/s10584-011-0149-y

[9] IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp. Accessed: https://www.ipcc.ch/site/assets/uploads/2018/02/AR5_SYR_FINAL_SPM.pdf

2 Climate Files Analysis

Key Findings:

1. **Daytime and overnight dry bulb temperatures in the future are projected to be higher than those used in current climate files. In Melbourne, no temperatures >40°C were observed in baseline climate files up to 1999, but was observed to occur 17 times a year in 2050.**
2. **Wet bulb temperatures are projected to increase in the future, which increases latent load.**
3. **Future climate projections show that annual heating degree days will decrease and cooling degree days will increase across all climate zones.**
4. **Average wind speeds generally increase, except for climate zone 6 (Melbourne), where wind speeds decrease in the future.**
5. **Total direct solar irradiance increases, suggesting that rooftop solar generation potential may increase. However, this potential may be reduced due to lower solar PV efficiency with increased panel temperatures.**

The purpose of this section of the report is to quantify how the climate is projected to change under a RCP8.5 scenario, relative to baseline climate data used by building energy modellers. The climate files used in this comparison are:

- *Baseline climate files used for desktop analysis and energy/thermal modelling:* IWEC[10] files developed by ASHRAE and licensed for distribution by the US Department of Energy (using observations from 1982-1999[11]), available in EnergyPlus .epw file format.
- *Future climate files for year 2030 and 2050 projection under the highest carbon emissions/warmest scenario*:[12] Ersatz climate files[13] developed by Exemplary Energy Partners using underlying data owned by Bureau of Meteorology (BoM) and applying Projected Change Values provided by CSIRO for that purpose.
- *Future climate files for year 2030 and 2050* sourced from CSIRO. Note these files sourced from CSIRO are only intended for comparison purposes as these files have not been approved for public distribution. Minor differences between the Exemplary Ersatz and CSIRO future climate files will not be discussed in this report.

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[10] International Weather Energy Consumption (IWEC), developed in 2001. Accessed: https://www.techstreet.com/ashrae/standards/rp-1015-typical-weather-years-for-international-locations?gateway_code=ashrae&product_id=1719102

[11] While more recent climate data (i.e. ASHRAE IWEC2) was developed a decade later in December 2011, the decision was made to conduct the analysis in this report using on legacy IWEC files. This is because the IWEC files are still widely used by design engineers as it is the default free weather file supplied with EnergyPlus.

[12] The climate file for year 2030 projection under the highest emissions scenario A1FI provided by Exemplary Energy Partners will also be analysed; however, only the year 2050 climate file will be used for HVAC load estimation, energy and thermal modelling in CAMEL and EnergyPlus.

[13] http://www.exemplary.com.au/solar_climate_data/EFMY.php

In agreement with the Department, three representative climate zones containing some of the most densely populated Australian cities were chosen. These are climate zone 2 (Brisbane), 5 (Sydney[14]) and 6 (Melbourne).

2.1 Overview

Existing literature, notably Guan (2005)[15] has been referred to for sensitivity analysis on the impact of changing climate variables on building energy consumption described below:

- Solar radiation – As global radiation increases (or cloud cover reduces), building cooling load increases. However, the magnitude of change in building cooling load is smaller in hotter climates.
- Relative humidity – As relative humidity increases, building cooling load increases. The hotter the climate, the stronger the effect of relative humidity on building cooling load.
- Wind speed – As wind speed increases, building cooling load decreases, with the expectation that more heat is removed from the building envelope. Guan (2005)[13] also found that the effect of wind speed on building cooling load is quite weak (10% wind speed change causes <2% change in building cooling load). It is unclear how air infiltration is treated in the study. Lee (2011)[16] states that for larger buildings where centre zones dominate performance (buildings with low surface area to volume ratios), temperature and humidity are more important than solar radiation and wind is only of minor interest.

A summary of the findings across climate zones are provided below for comparisons between baseline climate file (IWEC) to the future climate file (Exemplary Ersatz 2030) used in our energy and thermal comfort modelling.

Detailed climate files comparisons including comparison between the baseline climate file, 2030 and 2050 future climate files by CSIRO and Exemplary are presented in Section 2.2, 2.3 and 2.4 respectively.

Figure 2 shows the statistical distribution of the dry bulb temperatures for the three climate zones currently (IWEC) and in the future (2030). All climate zones show that the median dry bulb temperatures increase in 2030, with Melbourne experiencing more extreme heat temperatures in 2030. Minimum temperatures in all climate zones also increase in 2030.

To interpret the box and whisker plots presented in Figure 2 to Figure 4, the middle line is the median, the x is the mean, the top line of the box is the 3rd quartile (Q3) of data, bottom line is the 1st quartile (Q1) of data, the whiskers extend to the minimum and maximum values excluding outliers. Outliers are data points that exceed a distance of 1.5 times the inter quartile range (Q3 minus Q1).

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[14] Adelaide and Perth are also in Climate Zone 5 so the results for Sydney will be reliably indicative for those two cities too.

[15] Bell, John & Guan, Lishan & Yang, Jay. (2005). A Method of Preparing Future Hourly Weather Data for the Study of Global Warming Impact on the Built Environment.

[16] Lee, Trevor (2011). Climate Data For Building Optimisation In Design And Operation In Australia. Proceedings of Building Simulation 2011: 12th Conference of International Building Performance Simulation Association, Sydney, 14-16 November

Figure 2. Box and whisker plot for all climate zones (current, 2030 and 2050 climate files) – Dry bulb temperature.

Figure 3 shows that the mean and median wet bulb temperatures increase in 2030 across all climate zones. An increase in peak wet bulb temperature is also observed in the future.

Figure 3. Box and whisker plot for all climate zones (current, 2030 and 2050 climate files) – Wet bulb temperature.

Figure 4 shows that median wind speed increases in Brisbane and Sydney, but decreases in Melbourne in the future. No extreme wind speeds as defined by BOM (90 km/h or 25 m/s) are observed.

Figure 4. Box and whisker plot for all climate zones (current, 2030 and 2050 climate files) - Wind Speed.

Figure 5 and Figure 6 show that the number of heating degree days (HDD) decreases and cooling degree days increases (CDD) across all climate zones in 2030. HDD and CDDs are based on the average daily temperature, indicating the level of comfort. The average daily temperature is calculated as the average between the maximum daily temperature and minimum daily temperature. If the average daily temperature falls below comfort levels (the base temperature), heating is required and if it is above comfort levels, cooling is required. The HDDs or CDDs are determined by the difference between the calculated average daily temperature and the base temperature. The base values used in this analysis are 18°C for heating and 21°C for cooling.

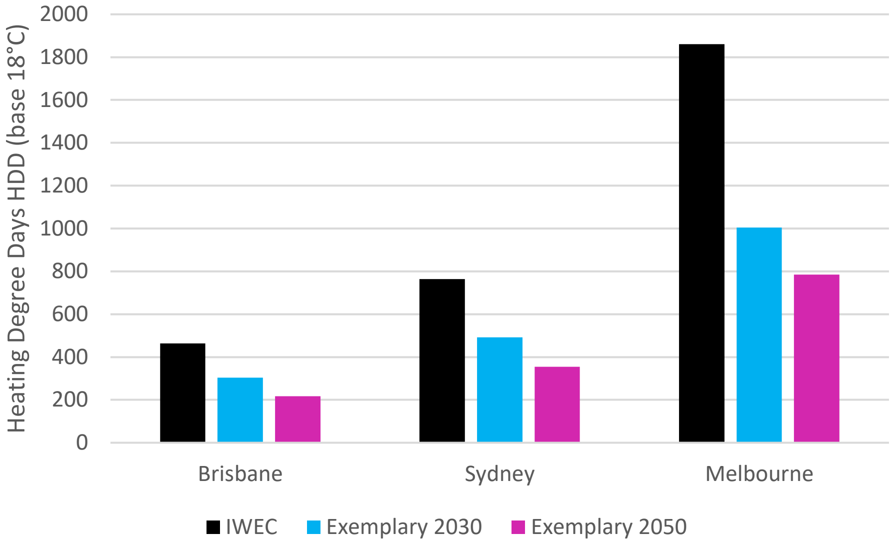


Figure 5. Heating degree days (Base 18°C) for all climate zones (current and 2030 climate files).

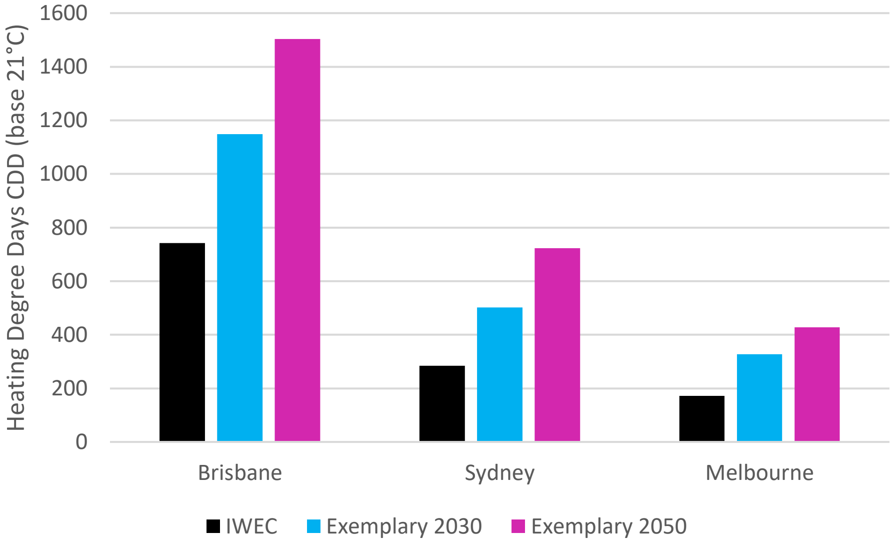


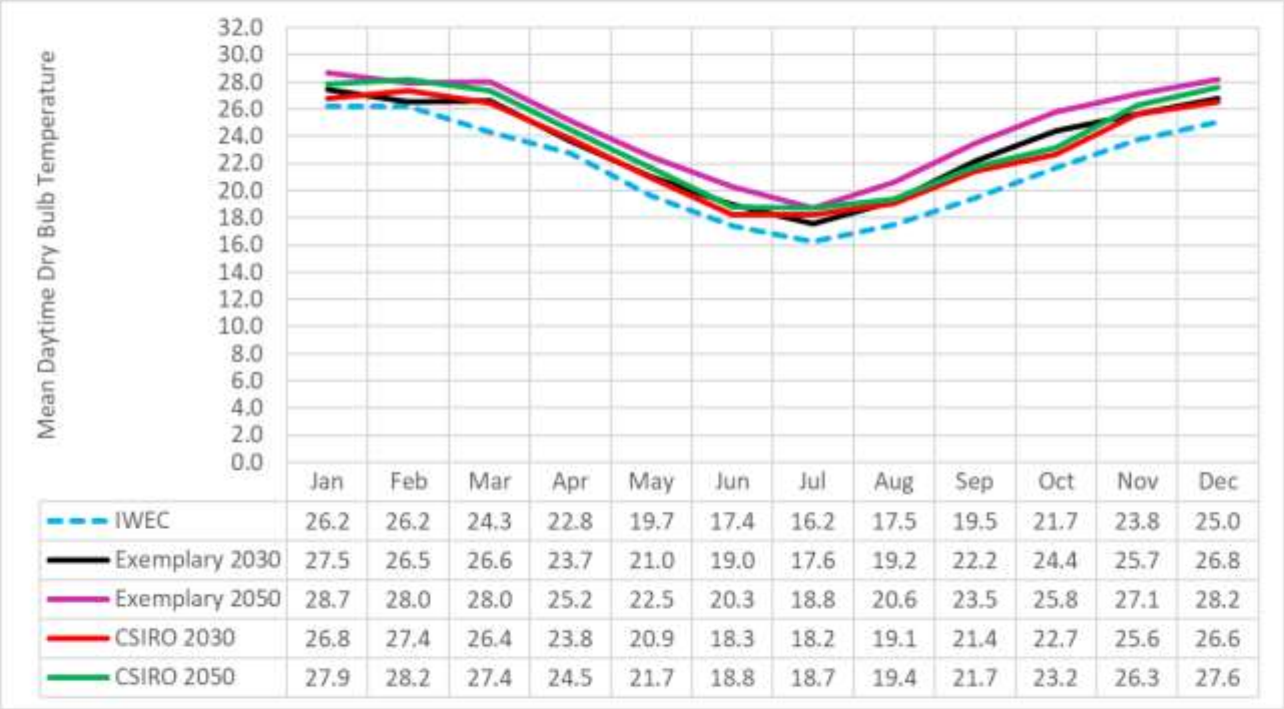
Figure 6. Cooling degree days (Base 21°C) for all climate zones (current and 2030 climate files).

2.2 Climate Zone 2 (Brisbane)

Key observations from the climate files comparison for climate zone 2 include:

- Under a RCP8.5 scenario, mean daytime and overnight dry bulb temperatures are projected to be 2°C to 4°C higher by 2050, with a consistent temperature increase across the year (Figure 7 and Figure 9).
- Maximum dry bulb temperatures are projected to increase, although to varying extents across the year. The largest projected increases (between 3°C and 8°C by 2050) occur between August and December (Figure 8). We note that the maximums in the IWEC dataset do not always follow a seasonal trend; the April maximum of 34°C appears particularly anomalous. None of the datasets analysed for this climate zone contain any hours where the temperature exceeded 40°C (classified as an extreme heatwave under this analysis), as shown in Figure 15.

- Minimum overnight dry bulb temperatures are projected to increase by an average of 2°C to 3°C across the year (Figure 10). There is a large amount of variation seen, however, with summer minimums generally projected to be similar, and winter minimums much higher.
- Mean daytime and overnight wet bulb temperatures are projected to be 2°C to 4°C higher by 2050 (Figure 11 and Figure 12).
- The average wind speed across the year is projected to be approximately 4.5 m/s, an increase of approximately 1 m/s (Figure 13), which according to Kraniotis (2014)[17] becomes the dominant driving potential causing infiltration. This is expected to result in higher air infiltration and increased importance of building air tightness. There is much less monthly average wind speed variation in future climate projection data than in the IWEC dataset. The reason for this is unclear. There is limited evidence for an increase in days where both high temperatures and high wind are experienced (Figure 14).
- The datasets show an increase in total direct solar irradiance relative to the IWEC baseline (Figure 16). This may indicate that solar generation potential may increase, although this will be tempered to some extent by higher panel temperatures. Higher direct irradiance can also be expected to increase the building fabric heat load.
- A 3% decrease in heating degree days (base 18°C) and a 131% increase in cooling degree days (base 21°C) is seen between the Exemplary dataset for 2050 relative to baseline IWEC (Table 1).



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
IWEC	26.2	26.2	24.3	22.8	19.7	17.4	16.2	17.5	19.5	21.7	23.8	25.0
Exemplary 2030	27.5	26.5	26.6	23.7	21.0	19.0	17.6	19.2	22.2	24.4	25.7	26.8
Exemplary 2050	28.7	28.0	28.0	25.2	22.5	20.3	18.8	20.6	23.5	25.8	27.1	28.2
CSIRO 2030	26.8	27.4	26.4	23.8	20.9	18.3	18.2	19.1	21.4	22.7	25.6	26.6
CSIRO 2050	27.9	28.2	27.4	24.5	21.7	18.8	18.7	19.4	21.7	23.2	26.3	27.6

Figure 7. Mean daytime[18] dry bulb temperature - Climate Zone 2

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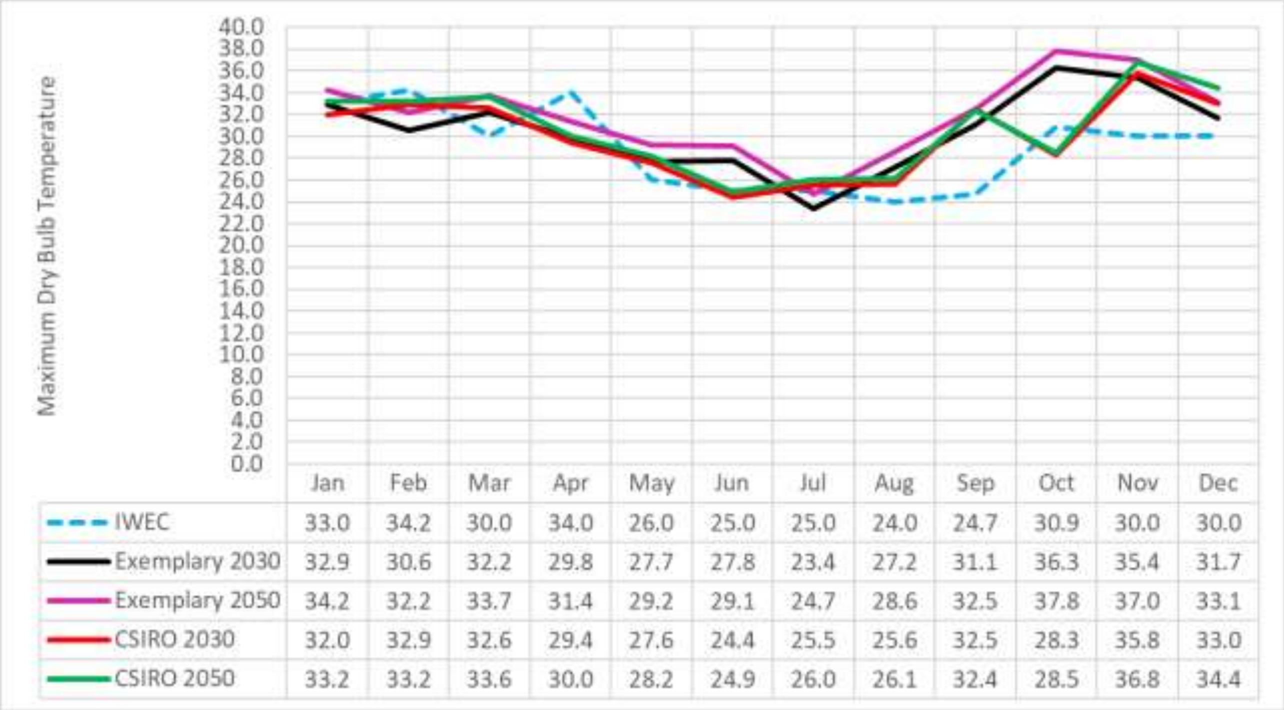
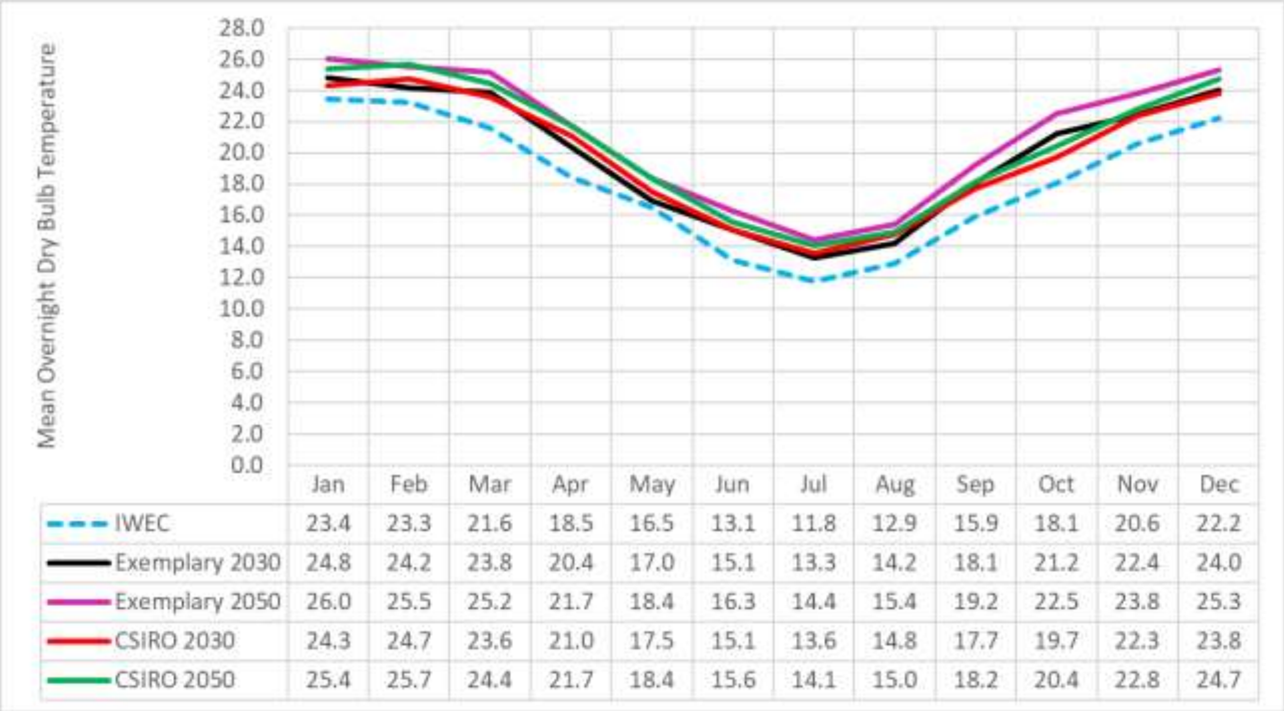
[17] Kraniotis, Dimitrios. (2014). Dynamic characteristics of wind-driven air infiltration in buildings - The impact of wind gusts under unsteady wind conditions. 10.13140/RG.2.1.3607.9444.

[18] Daytime 6am – 9pm and Overnight 6pm – 9am as defined by Bureau of Meteorology (BOM)



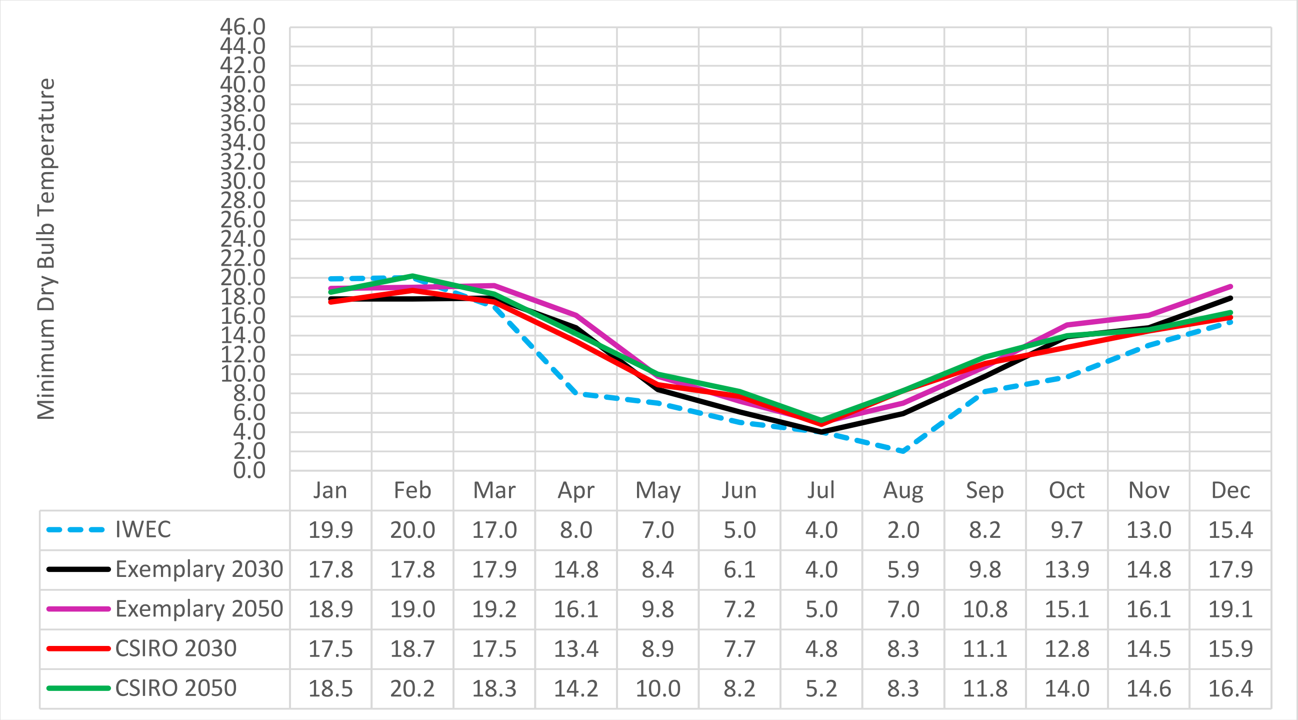
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
IWEC	33.0	34.2	30.0	34.0	26.0	25.0	25.0	24.0	24.7	30.9	30.0	30.0
Exemplary 2030	32.9	30.6	32.2	29.8	27.7	27.8	23.4	27.2	31.1	36.3	35.4	31.7
Exemplary 2050	34.2	32.2	33.7	31.4	29.2	29.1	24.7	28.6	32.5	37.8	37.0	33.1
CSIRO 2030	32.0	32.9	32.6	29.4	27.6	24.4	25.5	25.6	32.5	28.3	35.8	33.0
CSIRO 2050	33.2	33.2	33.6	30.0	28.2	24.9	26.0	26.1	32.4	28.5	36.8	34.4

Figure 8. Maximum daytime dry bulb temperature - Climate Zone 2



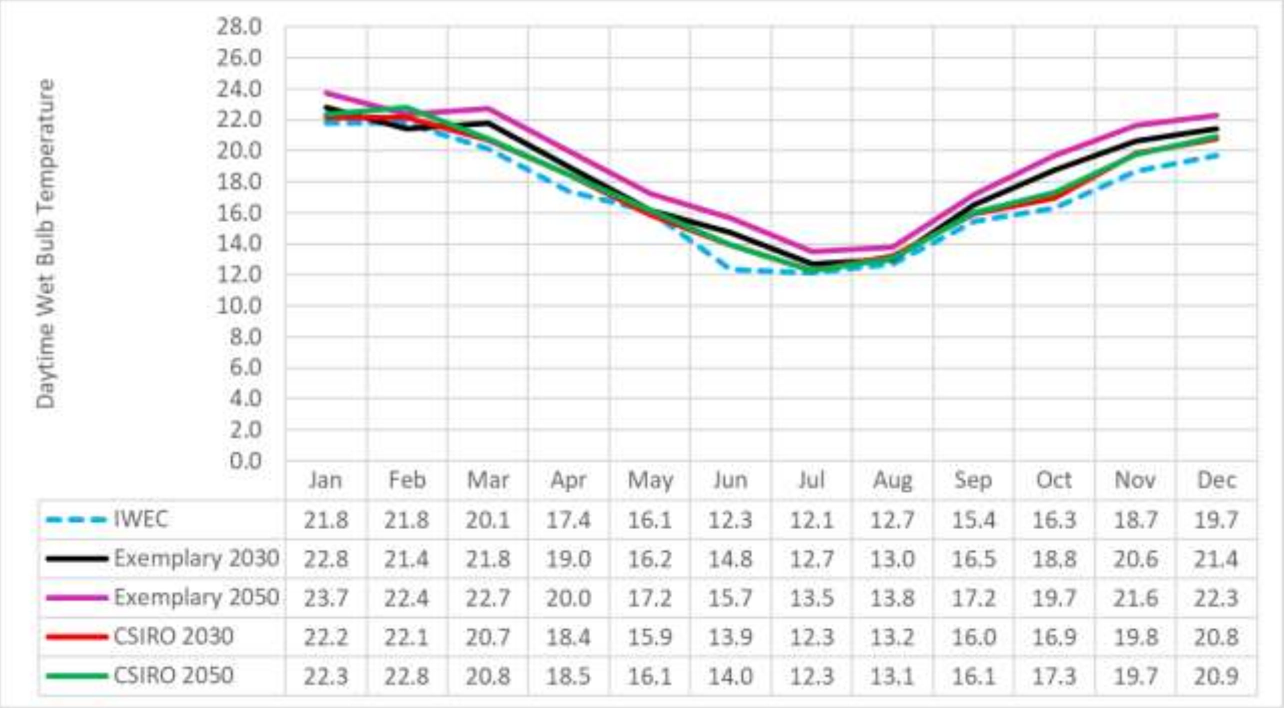
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
IWEC	23.4	23.3	21.6	18.5	16.5	13.1	11.8	12.9	15.9	18.1	20.6	22.2
Exemplary 2030	24.8	24.2	23.8	20.4	17.0	15.1	13.3	14.2	18.1	21.2	22.4	24.0
Exemplary 2050	26.0	25.5	25.2	21.7	18.4	16.3	14.4	15.4	19.2	22.5	23.8	25.3
CSIRO 2030	24.3	24.7	23.6	21.0	17.5	15.1	13.6	14.8	17.7	19.7	22.3	23.8
CSIRO 2050	25.4	25.7	24.4	21.7	18.4	15.6	14.1	15.0	18.2	20.4	22.8	24.7

Figure 9. Mean overnight dry bulb temperature - Climate Zone 2



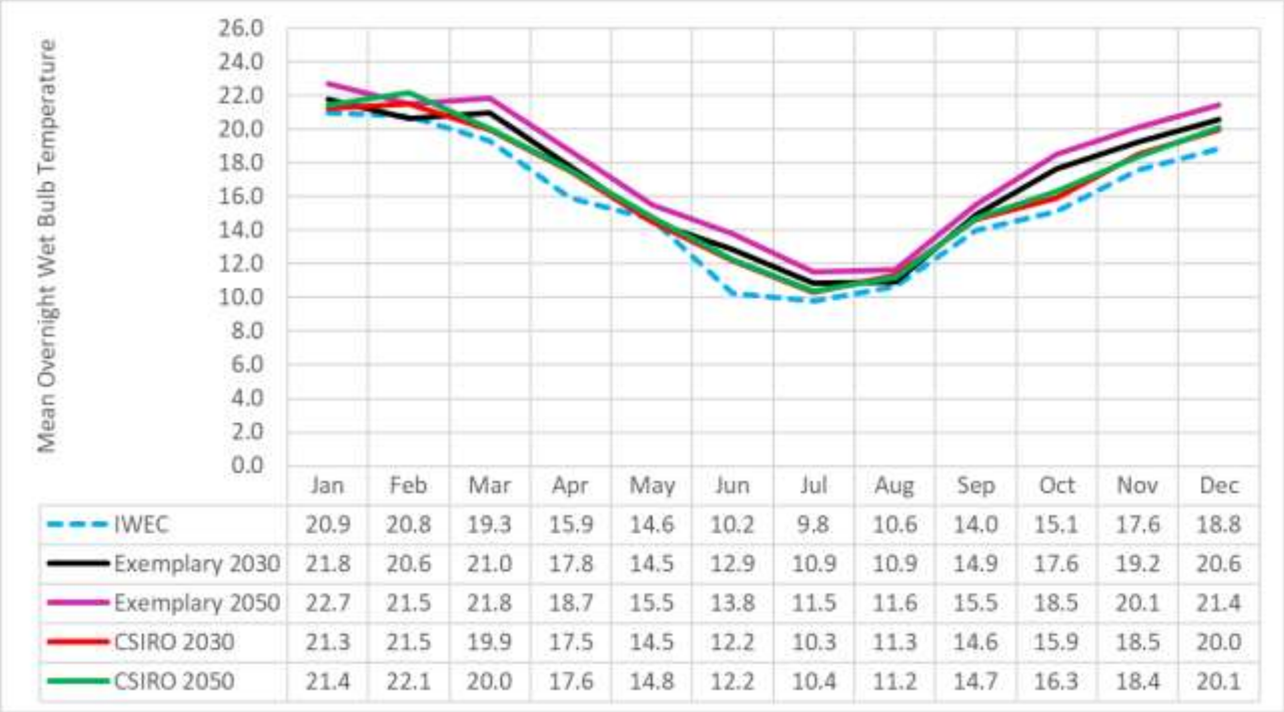
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
IWEC	19.9	20.0	17.0	8.0	7.0	5.0	4.0	2.0	8.2	9.7	13.0	15.4
Exemplary 2030	17.8	17.8	17.9	14.8	8.4	6.1	4.0	5.9	9.8	13.9	14.8	17.9
Exemplary 2050	18.9	19.0	19.2	16.1	9.8	7.2	5.0	7.0	10.8	15.1	16.1	19.1
CSIRO 2030	17.5	18.7	17.5	13.4	8.9	7.7	4.8	8.3	11.1	12.8	14.5	15.9
CSIRO 2050	18.5	20.2	18.3	14.2	10.0	8.2	5.2	8.3	11.8	14.0	14.6	16.4

Figure 10. Minimum overnight dry bulb temperature - Climate Zone 2



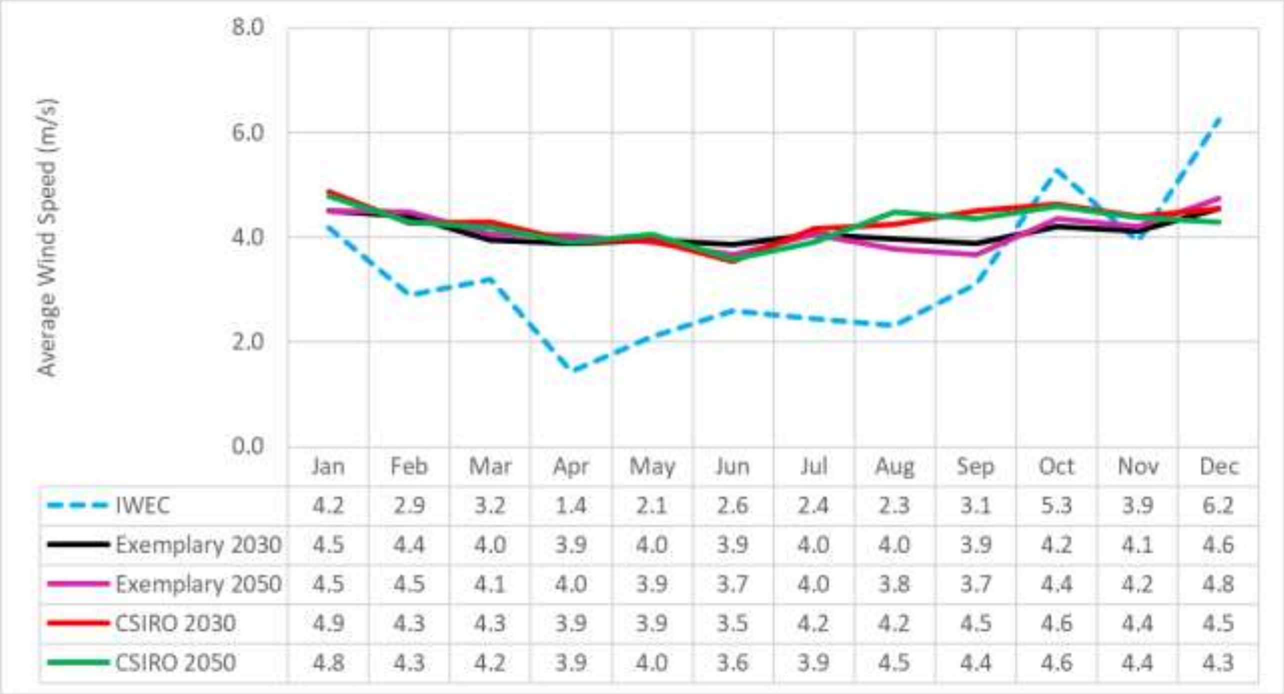
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
IWEC	21.8	21.8	20.1	17.4	16.1	12.3	12.1	12.7	15.4	16.3	18.7	19.7
Exemplary 2030	22.8	21.4	21.8	19.0	16.2	14.8	12.7	13.0	16.5	18.8	20.6	21.4
Exemplary 2050	23.7	22.4	22.7	20.0	17.2	15.7	13.5	13.8	17.2	19.7	21.6	22.3
CSIRO 2030	22.2	22.1	20.7	18.4	15.9	13.9	12.3	13.2	16.0	16.9	19.8	20.8
CSIRO 2050	22.3	22.8	20.8	18.5	16.1	14.0	12.3	13.1	16.1	17.3	19.7	20.9

Figure 11. Mean daytime wet bulb temperature - Climate Zone 2



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
IWEC	20.9	20.8	19.3	15.9	14.6	10.2	9.8	10.6	14.0	15.1	17.6	18.8
Exemplary 2030	21.8	20.6	21.0	17.8	14.5	12.9	10.9	10.9	14.9	17.6	19.2	20.6
Exemplary 2050	22.7	21.5	21.8	18.7	15.5	13.8	11.5	11.6	15.5	18.5	20.1	21.4
CSIRO 2030	21.3	21.5	19.9	17.5	14.5	12.2	10.3	11.3	14.6	15.9	18.5	20.0
CSIRO 2050	21.4	22.1	20.0	17.6	14.8	12.2	10.4	11.2	14.7	16.3	18.4	20.1

Figure 12. Mean overnight wet bulb temperature - Climate Zone 2



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
IWEC	4.2	2.9	3.2	1.4	2.1	2.6	2.4	2.3	3.1	5.3	3.9	6.2
Exemplary 2030	4.5	4.4	4.0	3.9	4.0	3.9	4.0	4.0	3.9	4.2	4.1	4.6
Exemplary 2050	4.5	4.5	4.1	4.0	3.9	3.7	4.0	3.8	3.7	4.4	4.2	4.8
CSIRO 2030	4.9	4.3	4.3	3.9	3.9	3.5	4.2	4.2	4.5	4.6	4.4	4.5
CSIRO 2050	4.8	4.3	4.2	3.9	4.0	3.6	3.9	4.5	4.4	4.6	4.4	4.3

Figure 13. Average Wind Speeds - Climate Zone 2

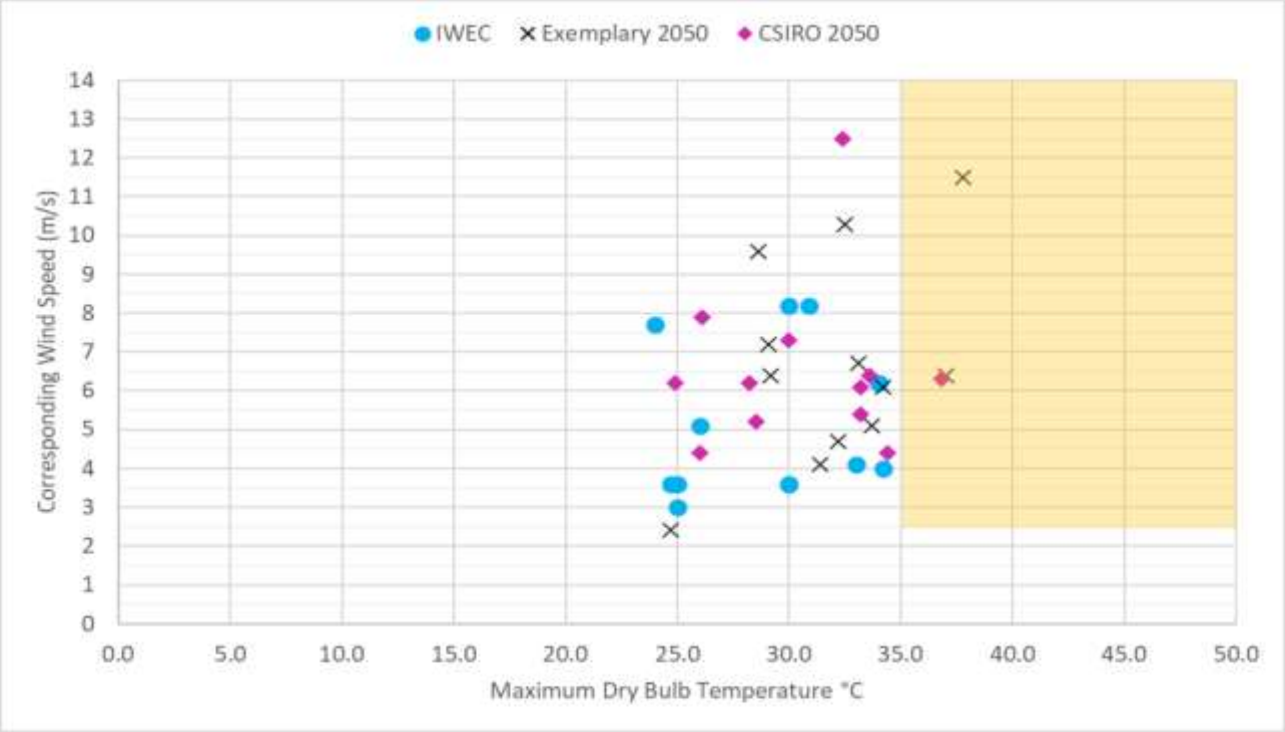
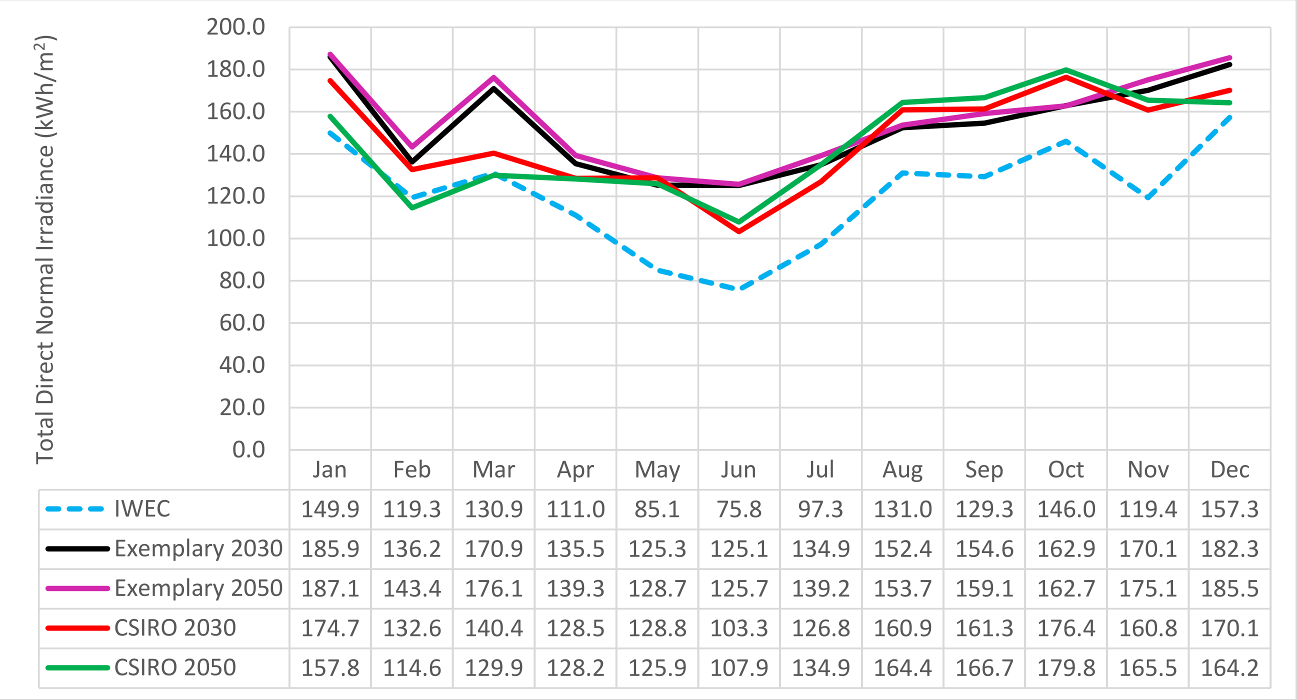


Figure 14. Wind speeds corresponding to the hottest dry bulb temperature each month - Climate Zone 2

Figure 15. Extreme heatwave - frequency of occurrences - Climate Zone 2



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
IWEC	149.9	119.3	130.9	111.0	85.1	75.8	97.3	131.0	129.3	146.0	119.4	157.3
Exemplary 2030	185.9	136.2	170.9	135.5	125.3	125.1	134.9	152.4	154.6	162.9	170.1	182.3
Exemplary 2050	187.1	143.4	176.1	139.3	128.7	125.7	139.2	153.7	159.1	162.7	175.1	185.5
CSIRO 2030	174.7	132.6	140.4	128.5	128.8	103.3	126.8	160.9	161.3	176.4	160.8	170.1
CSIRO 2050	157.8	114.6	129.9	128.2	125.9	107.9	134.9	164.4	166.7	179.8	165.5	164.2

Figure 16. Total Direct Normal Irradiance - Climate Zone 2

Table 1. Annual Heating and Cooling Degree Days – Climate Zone 2

	HDD (18°C)	**% Change (2050 relative to IWEC)**	**CDD (21°C)**	**% Change (2050 relative to IWEC)**
IWEC	464		742	
Exemplary 2030	304		1149	
Exemplary 2050	217	53%	1504	203%
CSIRO 2030	287		1088	
CSIRO 2050	245	47%	1271	85%

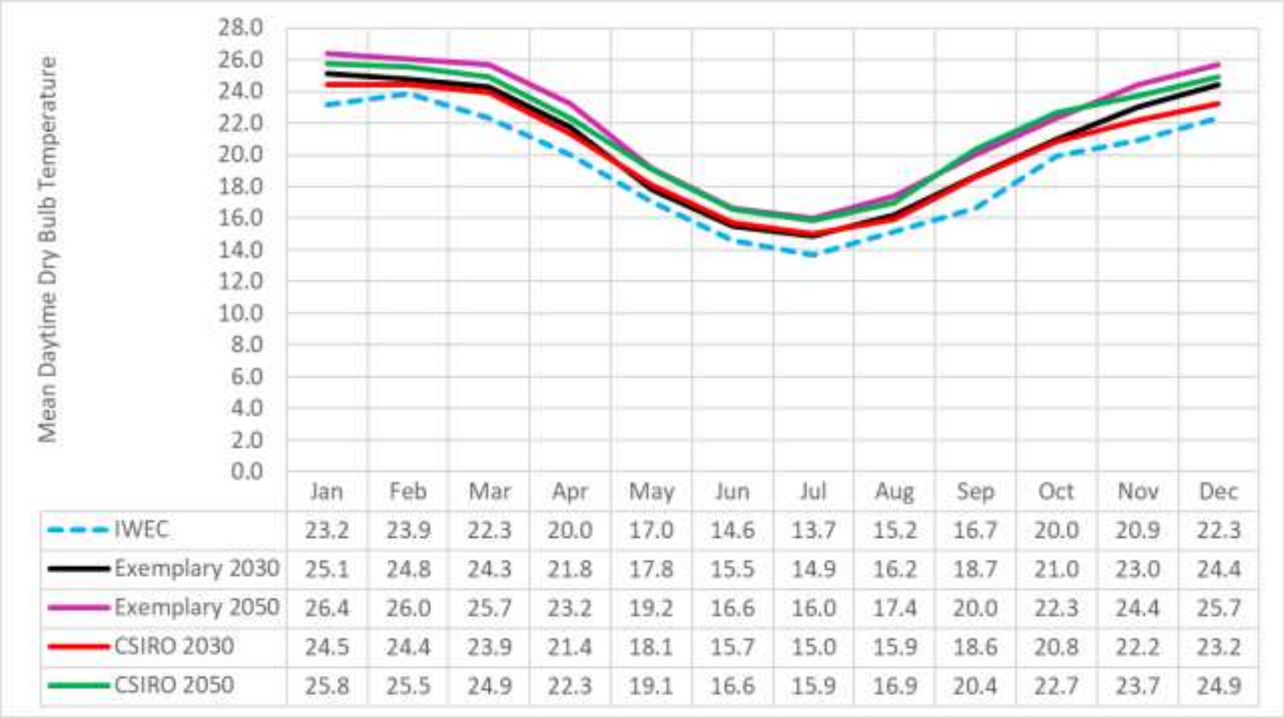
2.3 Climate Zone 5 (Sydney, Perth and Adelaide)

The Sydney climate file was used to represent climate zone 5. Key observations from the climate files comparison for climate zone 5 include:

- In 2050, mean daytime and overnight temperatures are projected to be 2°C to 4°C higher than the baseline climate files used to model new buildings (Figure 17 and Figure 19).
- Maximum dry bulb temperature is slightly higher across the year; however, March and November maximum temperatures are substantially higher (see Figure 18). The IWEC data exhibits a notable dip in the seasonal trend in the maximum temperature during November 2020.
- Figure 20 shows that in 2050, minimum dry bulb temperatures have increased substantially (up to ~6°C higher). This means that the overnight passive cooling enjoyed by buildings in milder climate zones may no longer be available, though this effect may be tempered by a slight increase in overnight average wind speed in the future in Sydney.
- Mean daytime and overnight wet bulb temperatures are projected to increase by 2°C to 3°C
- The average wind speeds across the year increases to above 4 m/s (Figure 23); it is reasonable to expect this will result in increased air infiltration under this projection, causing building air tightness

to gain greater importance. The wind speed corresponding to extreme temperature (>40°C) is largely >2.5m/s (Figure 24).

- In the future, heat waves are projected to occur earlier in November (instead of December) and more frequently.
- No extreme wind events (>90 km/h) were observed.
- As in other climate zones, the datasets show an increase in total direct solar irradiance relative to the IWEC baseline, particularly during winter (Figure 26). This may indicate that solar generation potential will increase, although any increase will be tempered to some extent by higher panel temperatures.
- A 54% decrease in heating degree days (base 18°C) and a 255% increase in cooling degree days (base 21°C) is seen between the Exemplary datasets for 2050 relative to the IWEC baseline (Table 2).



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
IWEC	23.2	23.9	22.3	20.0	17.0	14.6	13.7	15.2	16.7	20.0	20.9	22.3
Exemplary 2030	25.1	24.8	24.3	21.8	17.8	15.5	14.9	16.2	18.7	21.0	23.0	24.4
Exemplary 2050	26.4	26.0	25.7	23.2	19.2	16.6	16.0	17.4	20.0	22.3	24.4	25.7
CSIRO 2030	24.5	24.4	23.9	21.4	18.1	15.7	15.0	15.9	18.6	20.8	22.2	23.2
CSIRO 2050	25.8	25.5	24.9	22.3	19.1	16.6	15.9	16.9	20.4	22.7	23.7	24.9

Figure 17. Mean daytime[19] dry bulb temperature - Climate Zone 5

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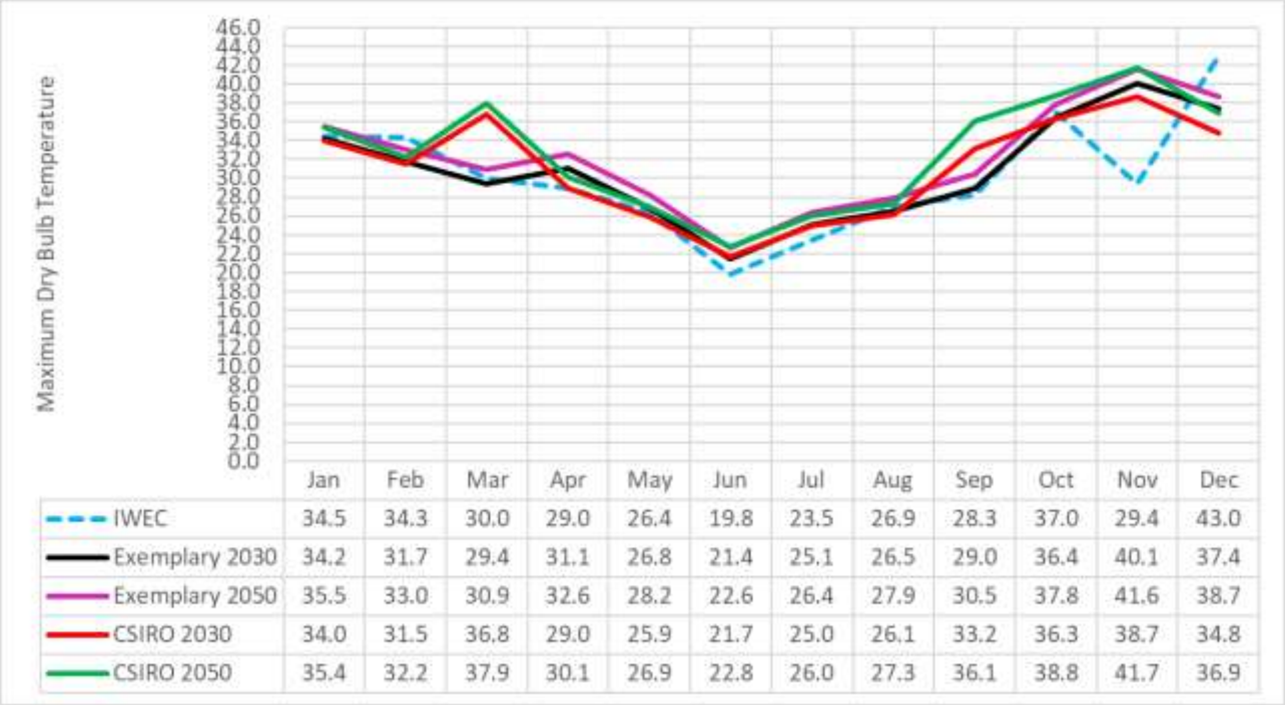
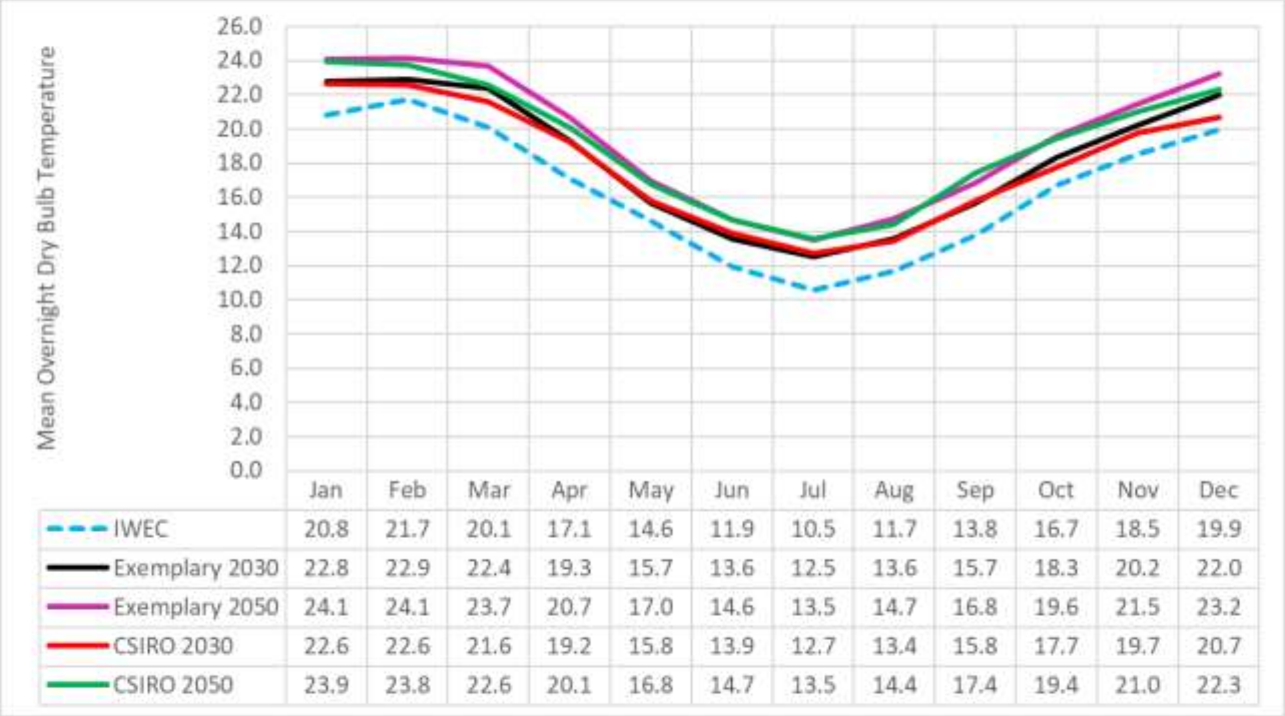
[19] Daytime 6am – 9pm and Overnight 6pm – 9pm as defined by Bureau of Meteorology (BOM)



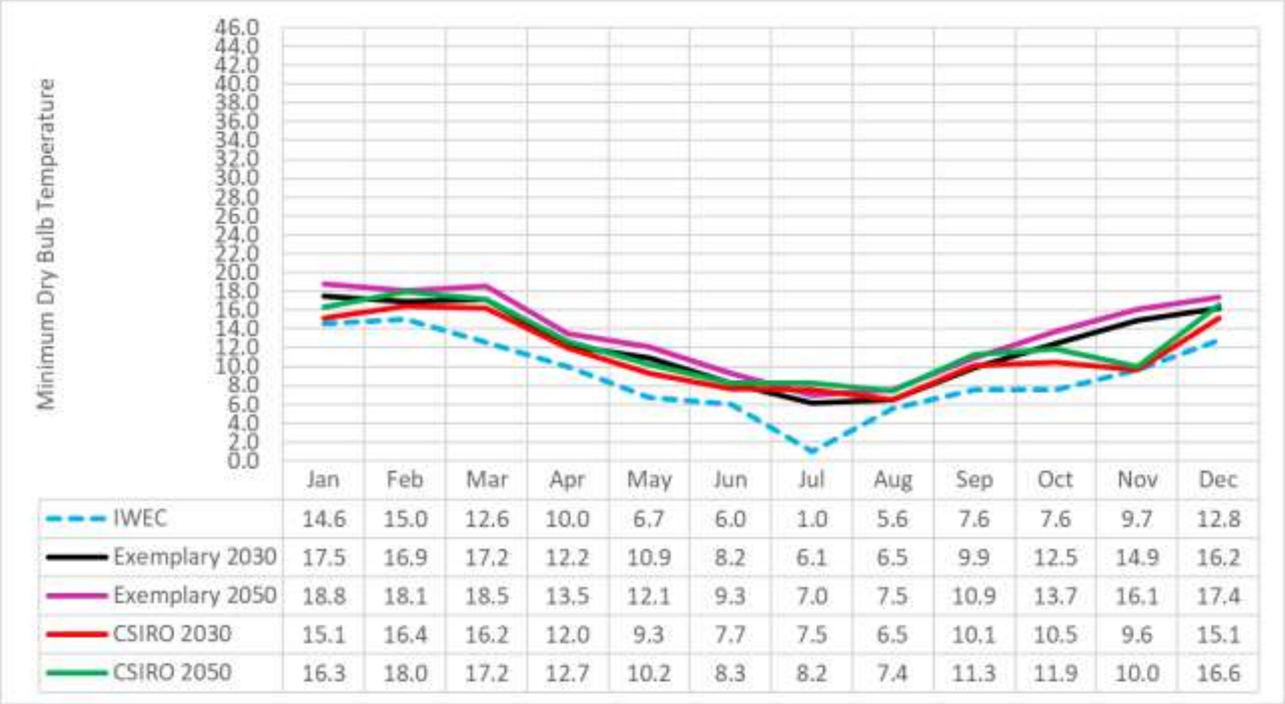
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
IWEC	34.5	34.3	30.0	29.0	26.4	19.8	23.5	26.9	28.3	37.0	29.4	43.0
Exemplary 2030	34.2	31.7	29.4	31.1	26.8	21.4	25.1	26.5	29.0	36.4	40.1	37.4
Exemplary 2050	35.5	33.0	30.9	32.6	28.2	22.6	26.4	27.9	30.5	37.8	41.6	38.7
CSIRO 2030	34.0	31.5	36.8	29.0	25.9	21.7	25.0	26.1	33.2	36.3	38.7	34.8
CSIRO 2050	35.4	32.2	37.9	30.1	26.9	22.8	26.0	27.3	36.1	38.8	41.7	36.9

Figure 18. Maximum daytime dry bulb temperature - Climate Zone 5



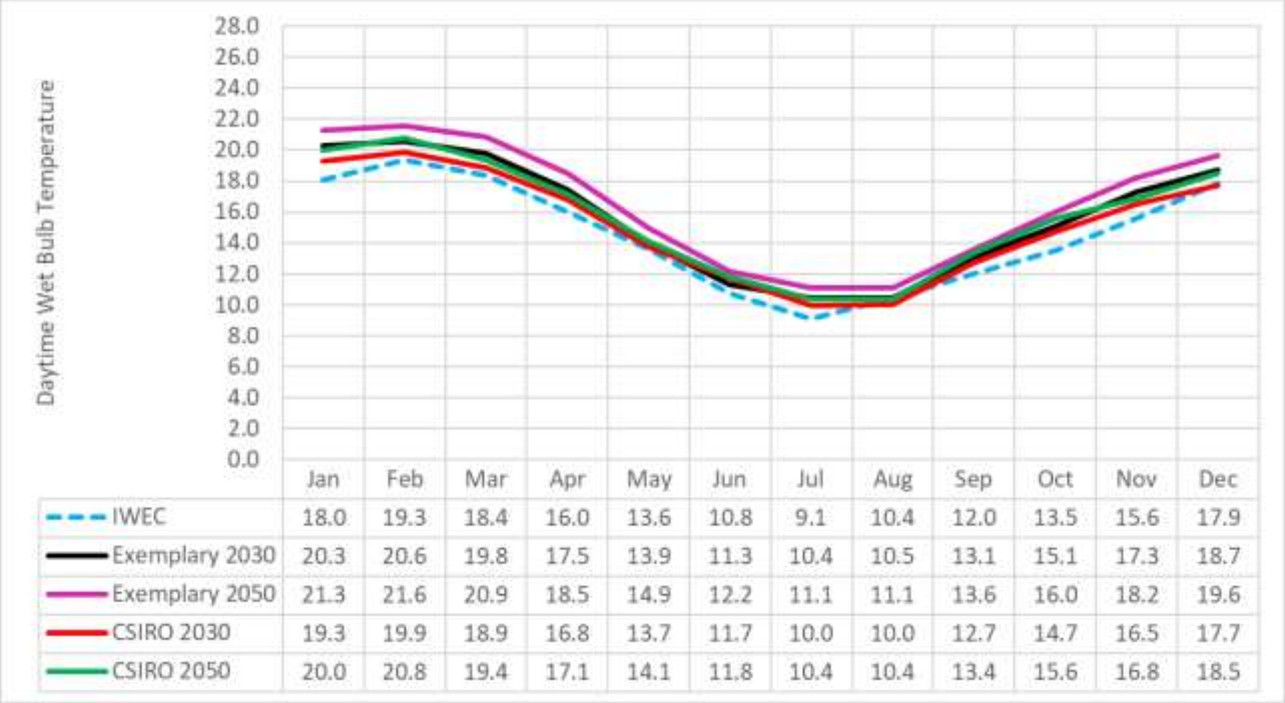
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
IWEC	20.8	21.7	20.1	17.1	14.6	11.9	10.5	11.7	13.8	16.7	18.5	19.9
Exemplary 2030	22.8	22.9	22.4	19.3	15.7	13.6	12.5	13.6	15.7	18.3	20.2	22.0
Exemplary 2050	24.1	24.1	23.7	20.7	17.0	14.6	13.5	14.7	16.8	19.6	21.5	23.2
CSIRO 2030	22.6	22.6	21.6	19.2	15.8	13.9	12.7	13.4	15.8	17.7	19.7	20.7
CSIRO 2050	23.9	23.8	22.6	20.1	16.8	14.7	13.5	14.4	17.4	19.4	21.0	22.3

Figure 19. Mean overnight dry bulb temperature - Climate Zone 5



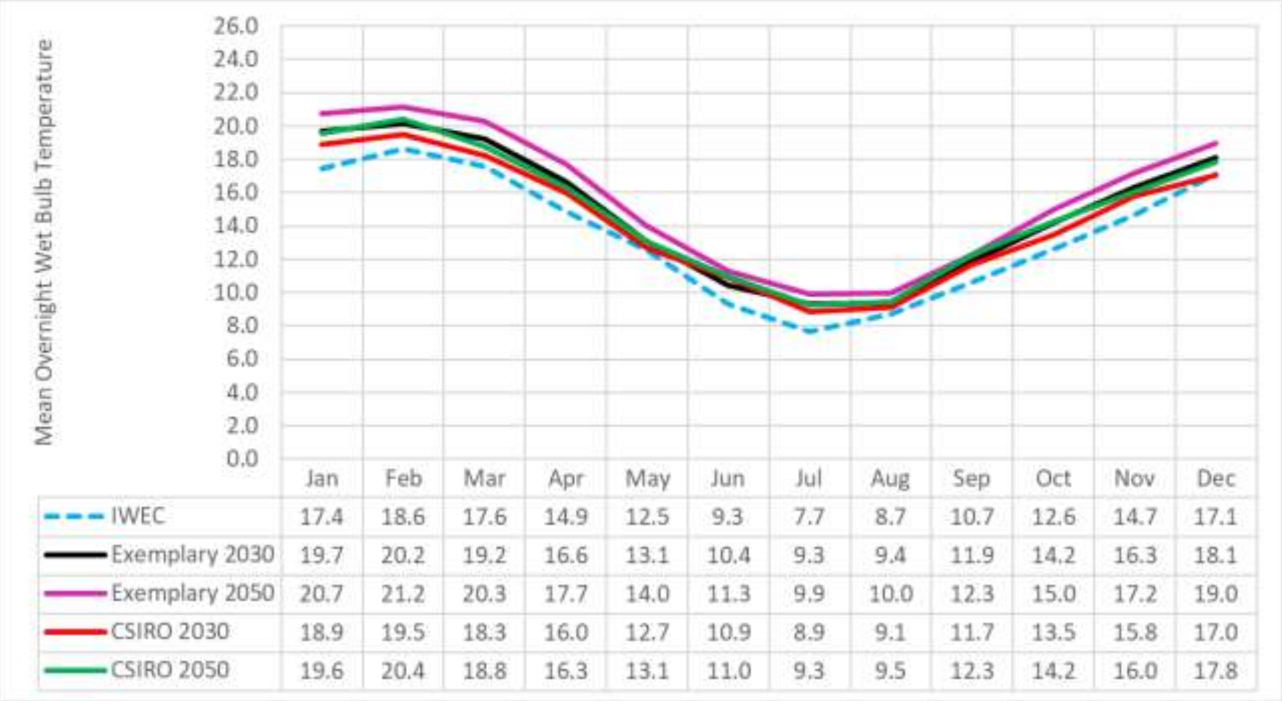
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
IWEC	14.6	15.0	12.6	10.0	6.7	6.0	1.0	5.6	7.6	7.6	9.7	12.8
Exemplary 2030	17.5	16.9	17.2	12.2	10.9	8.2	6.1	6.5	9.9	12.5	14.9	16.2
Exemplary 2050	18.8	18.1	18.5	13.5	12.1	9.3	7.0	7.5	10.9	13.7	16.1	17.4
CSIRO 2030	15.1	16.4	16.2	12.0	9.3	7.7	7.5	6.5	10.1	10.5	9.6	15.1
CSIRO 2050	16.3	18.0	17.2	12.7	10.2	8.3	8.2	7.4	11.3	11.9	10.0	16.6

Figure 20. Minimum overnight dry bulb temperature - Climate zone 5



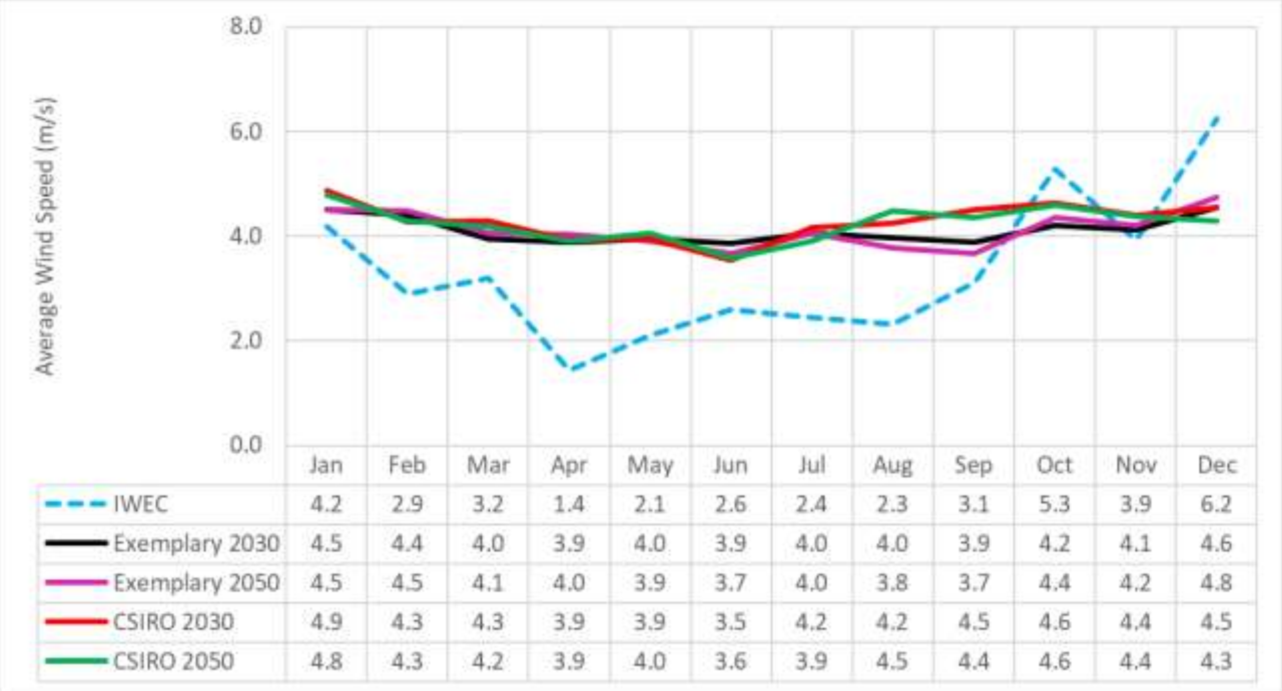
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
IWEC	18.0	19.3	18.4	16.0	13.6	10.8	9.1	10.4	12.0	13.5	15.6	17.9
Exemplary 2030	20.3	20.6	19.8	17.5	13.9	11.3	10.4	10.5	13.1	15.1	17.3	18.7
Exemplary 2050	21.3	21.6	20.9	18.5	14.9	12.2	11.1	11.1	13.6	16.0	18.2	19.6
CSIRO 2030	19.3	19.9	18.9	16.8	13.7	11.7	10.0	10.0	12.7	14.7	16.5	17.7
CSIRO 2050	20.0	20.8	19.4	17.1	14.1	11.8	10.4	10.4	13.4	15.6	16.8	18.5

Figure 21. Mean daytime wet bulb temperature - Climate zone 5



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
IWEC	17.4	18.6	17.6	14.9	12.5	9.3	7.7	8.7	10.7	12.6	14.7	17.1
Exemplary 2030	19.7	20.2	19.2	16.6	13.1	10.4	9.3	9.4	11.9	14.2	16.3	18.1
Exemplary 2050	20.7	21.2	20.3	17.7	14.0	11.3	9.9	10.0	12.3	15.0	17.2	19.0
CSIRO 2030	18.9	19.5	18.3	16.0	12.7	10.9	8.9	9.1	11.7	13.5	15.8	17.0
CSIRO 2050	19.6	20.4	18.8	16.3	13.1	11.0	9.3	9.5	12.3	14.2	16.0	17.8

Figure 22. Mean overnight wet bulb temperature - Climate zone 5



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
IWEC	4.2	2.9	3.2	1.4	2.1	2.6	2.4	2.3	3.1	5.3	3.9	6.2
Exemplary 2030	4.5	4.4	4.0	3.9	4.0	3.9	4.0	4.0	3.9	4.2	4.1	4.6
Exemplary 2050	4.5	4.5	4.1	4.0	3.9	3.7	4.0	3.8	3.7	4.4	4.2	4.8
CSIRO 2030	4.9	4.3	4.3	3.9	3.9	3.5	4.2	4.2	4.5	4.6	4.4	4.5
CSIRO 2050	4.8	4.3	4.2	3.9	4.0	3.6	3.9	4.5	4.4	4.6	4.4	4.3

Figure 23. Average Wind Speeds - Climate Zone 5

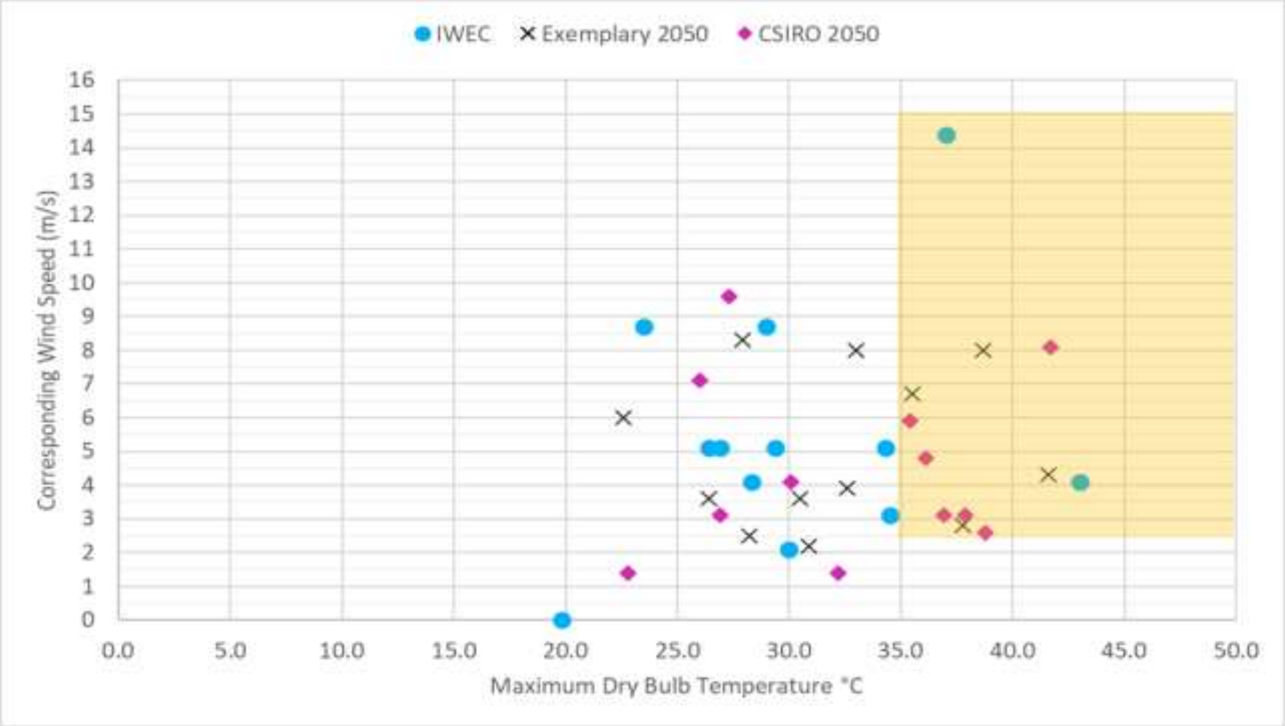


Figure 24. Wind speeds corresponding to the hottest dry bulb temperature each month - Climate zone 5

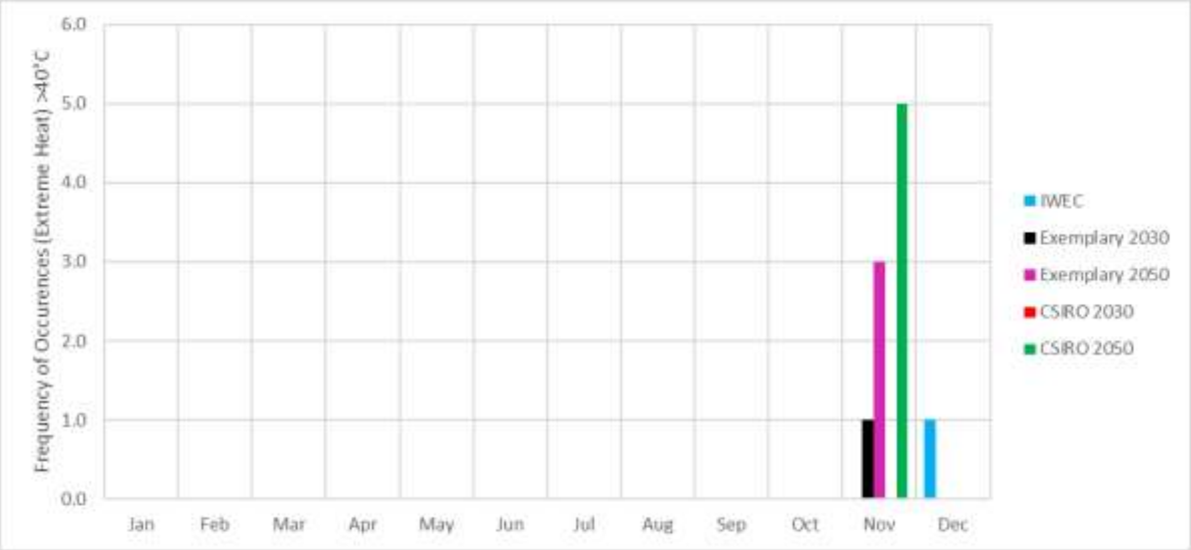
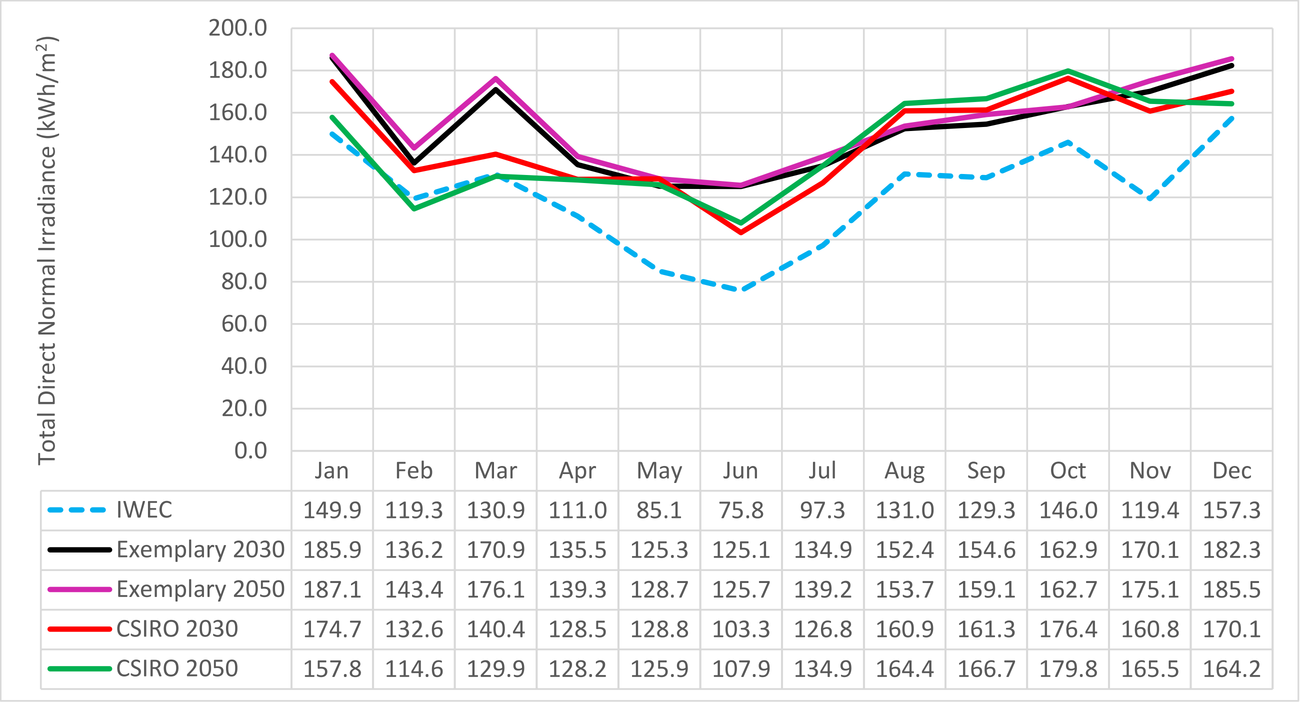


Figure 25. Extreme heat - frequency of occurrences - Climate Zone 5. No heatwaves (extreme heat on consecutive days) observed.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
IWEC	149.9	119.3	130.9	111.0	85.1	75.8	97.3	131.0	129.3	146.0	119.4	157.3
Exemplary 2030	185.9	136.2	170.9	135.5	125.3	125.1	134.9	152.4	154.6	162.9	170.1	182.3
Exemplary 2050	187.1	143.4	176.1	139.3	128.7	125.7	139.2	153.7	159.1	162.7	175.1	185.5
CSIRO 2030	174.7	132.6	140.4	128.5	128.8	103.3	126.8	160.9	161.3	176.4	160.8	170.1
CSIRO 2050	157.8	114.6	129.9	128.2	125.9	107.9	134.9	164.4	166.7	179.8	165.5	164.2

Figure 26. Total direct normal irradiance - Climate Zone 5

Table 2. Annual Heating and Cooling Degree Days - Climate Zone 5

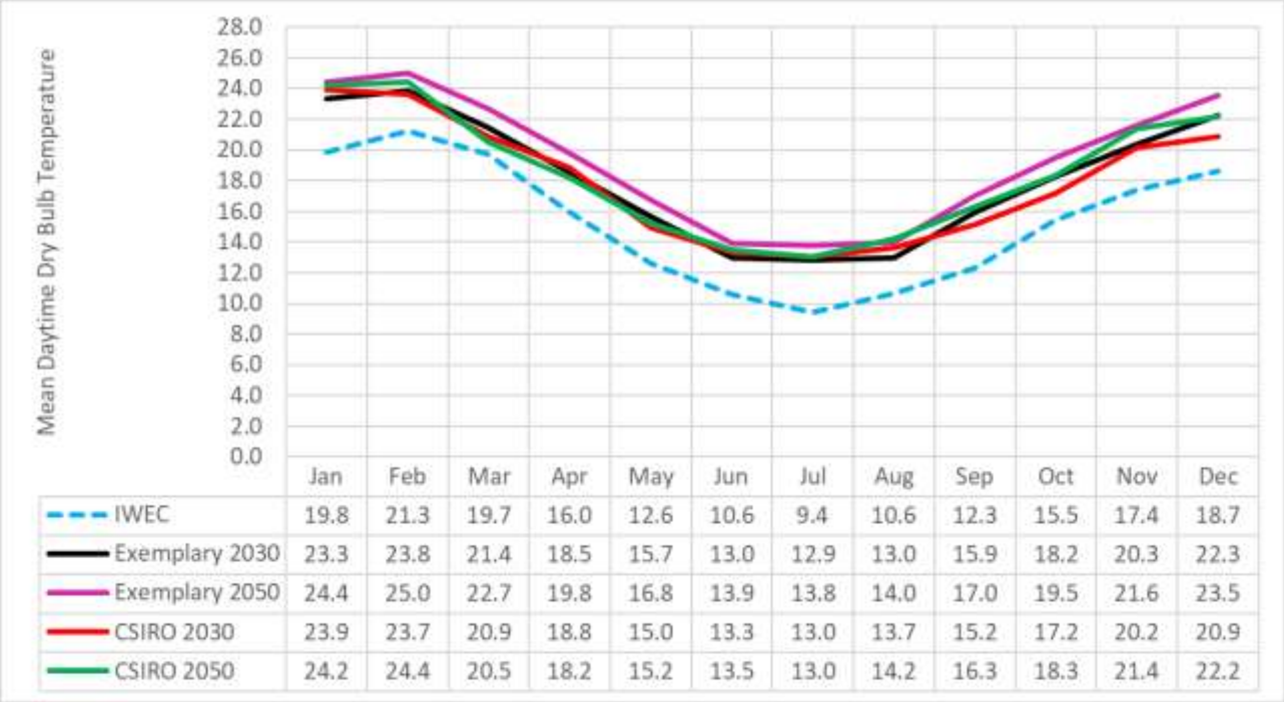
	HDD (18°C)	% Change (2050 relative to IWEC)	CDD (21°C)	% Change (2050 relative to IWEC)
IWEC	764		284	
Exemplary 2030	492		501	
Exemplary 2050	354	54%	723	255%
CSIRO 2030	506		431	
CSIRO 2050	375	51%	643	89%

2.4 Climate Zone 6 (Melbourne)

Key observations for climate files comparison for climate zone 6 include:

- In 2050, mean daytime and overnight temperatures are projected to be 3°C to 5°C higher than the baseline climate files used to model new buildings (Figure 27 and Figure 29).
- Maximum dry bulb temperature is substantially higher (up to 9°C) throughout the year (Figure 28).
- Figure 30 shows that in 2050, minimum dry bulb temperatures have increased substantially (up to ~6°C higher). This means that the overnight passive cooling enjoyed by buildings in milder climate zones may no longer be available.
- Mean daytime and overnight wet bulb temperatures are projected to increase by 2°C to 3°C
- Average wind speed is projected to decrease across the year, although the corresponding wind speed on extreme heat (>40°C) days are largely projected to be >4m/s.
- In the future, extreme temperatures (>40°C) are projected to occur earlier much more frequently, particularly during December and February (Figure 35).
- No extreme wind events (>90 km/h) were observed.

- As in other climate zones, the datasets show an increase in total direct solar irradiance relative to the IWEC baseline (Figure 37). This may indicate that solar generation potential will increase, although any increase will be tempered to some extent by higher panel temperatures.
- A 58% decrease in heating degree days (base 18°C) and a 249% increase in cooling degree days (base 21°C) is seen between the Exemplary datasets for 2050 relative to the IWEC baseline (Table 3).



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
IWEC	19.8	21.3	19.7	16.0	12.6	10.6	9.4	10.6	12.3	15.5	17.4	18.7
Exemplary 2030	23.3	23.8	21.4	18.5	15.7	13.0	12.9	13.0	15.9	18.2	20.3	22.3
Exemplary 2050	24.4	25.0	22.7	19.8	16.8	13.9	13.8	14.0	17.0	19.5	21.6	23.5
CSIRO 2030	23.9	23.7	20.9	18.8	15.0	13.3	13.0	13.7	15.2	17.2	20.2	20.9
CSIRO 2050	24.2	24.4	20.5	18.2	15.2	13.5	13.0	14.2	16.3	18.3	21.4	22.2

Figure 27. Mean daytime[20] dry bulb temperature - Climate Zone 6

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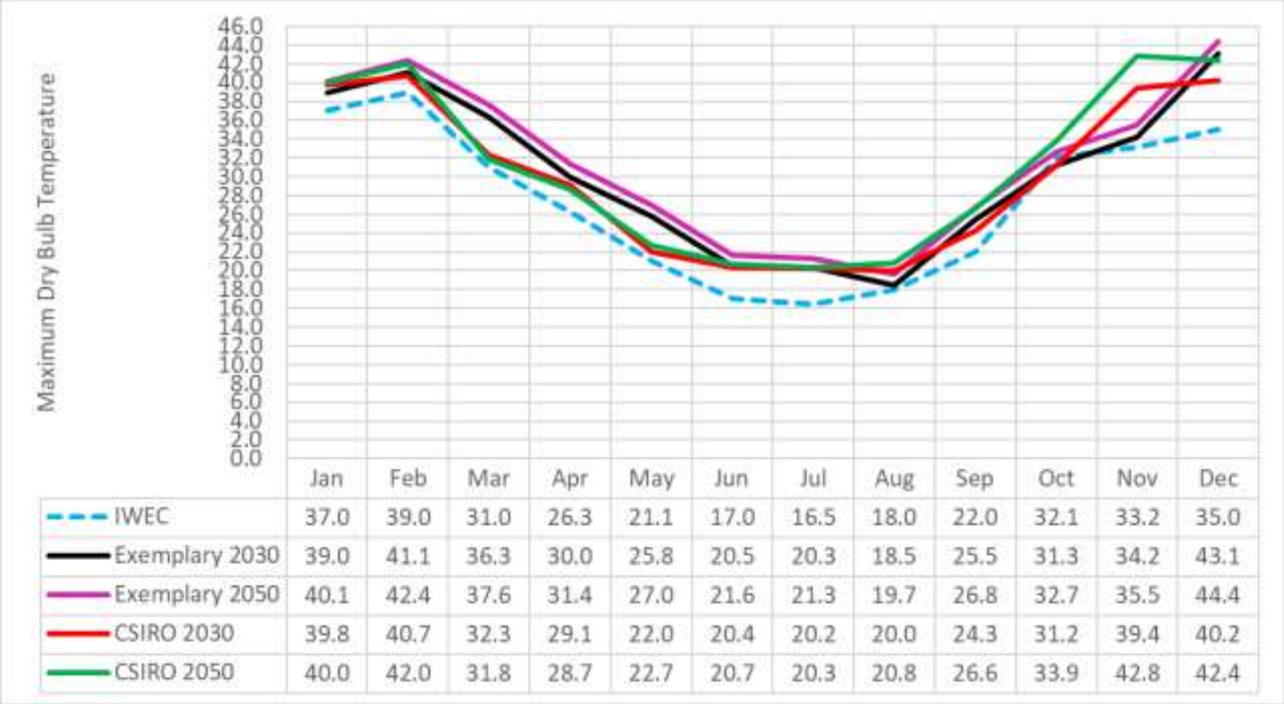
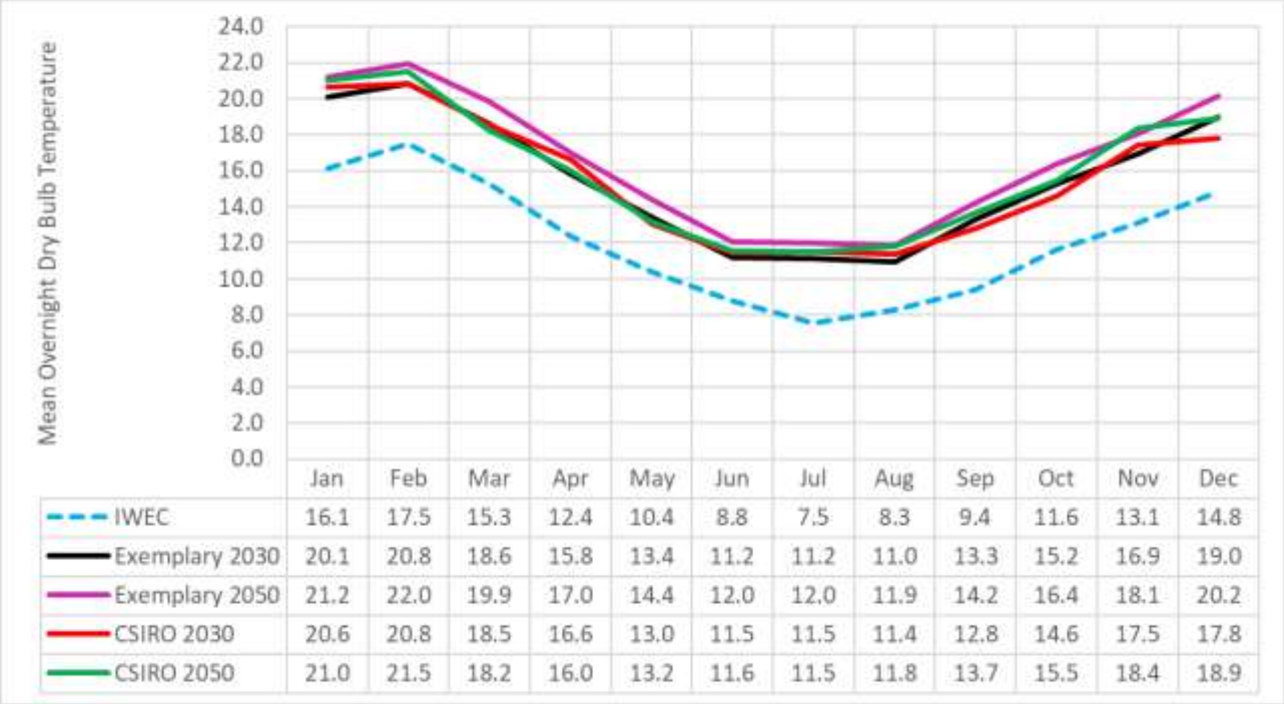
[20] Daytime 6am – 9pm and Overnight 6pm – 9pm as defined by Bureau of Meteorology (BOM)



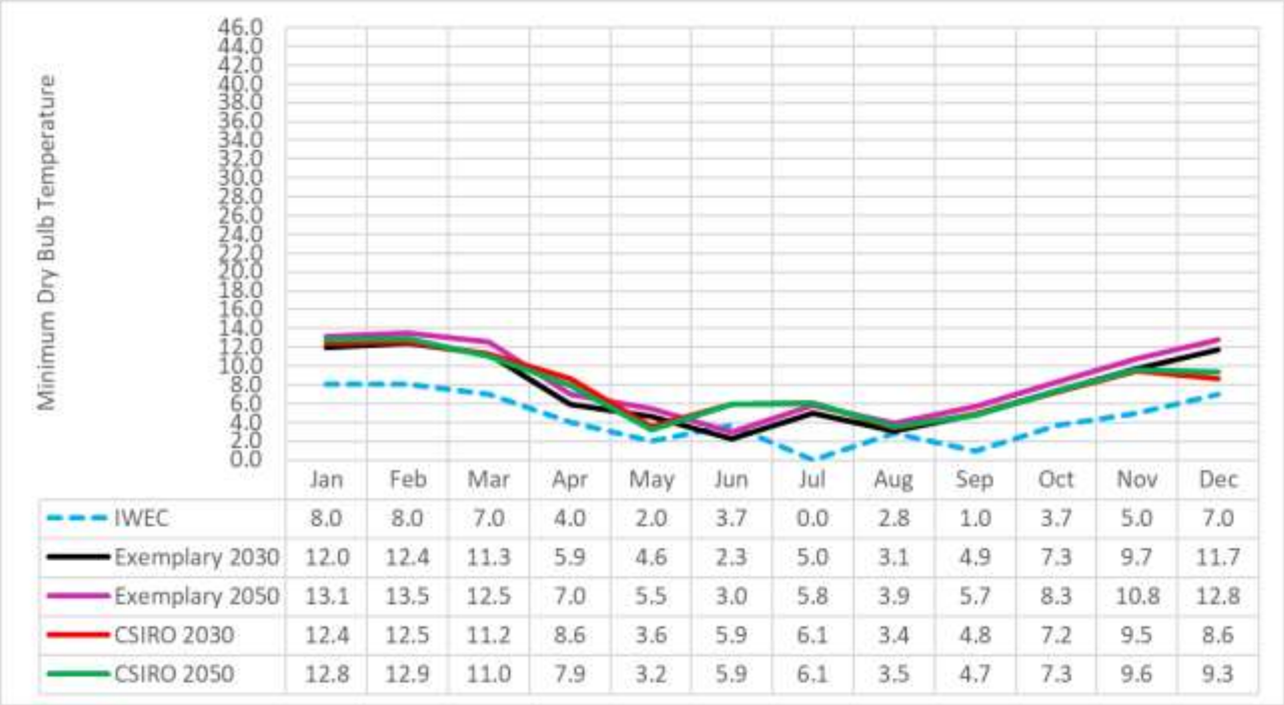
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
IWEC	37.0	39.0	31.0	26.3	21.1	17.0	16.5	18.0	22.0	32.1	33.2	35.0
Exemplary 2030	39.0	41.1	36.3	30.0	25.8	20.5	20.3	18.5	25.5	31.3	34.2	43.1
Exemplary 2050	40.1	42.4	37.6	31.4	27.0	21.6	21.3	19.7	26.8	32.7	35.5	44.4
CSIRO 2030	39.8	40.7	32.3	29.1	22.0	20.4	20.2	20.0	24.3	31.2	39.4	40.2
CSIRO 2050	40.0	42.0	31.8	28.7	22.7	20.7	20.3	20.8	26.6	33.9	42.8	42.4

Figure 28. Maximum daytime dry bulb temperature - Climate Zone 6



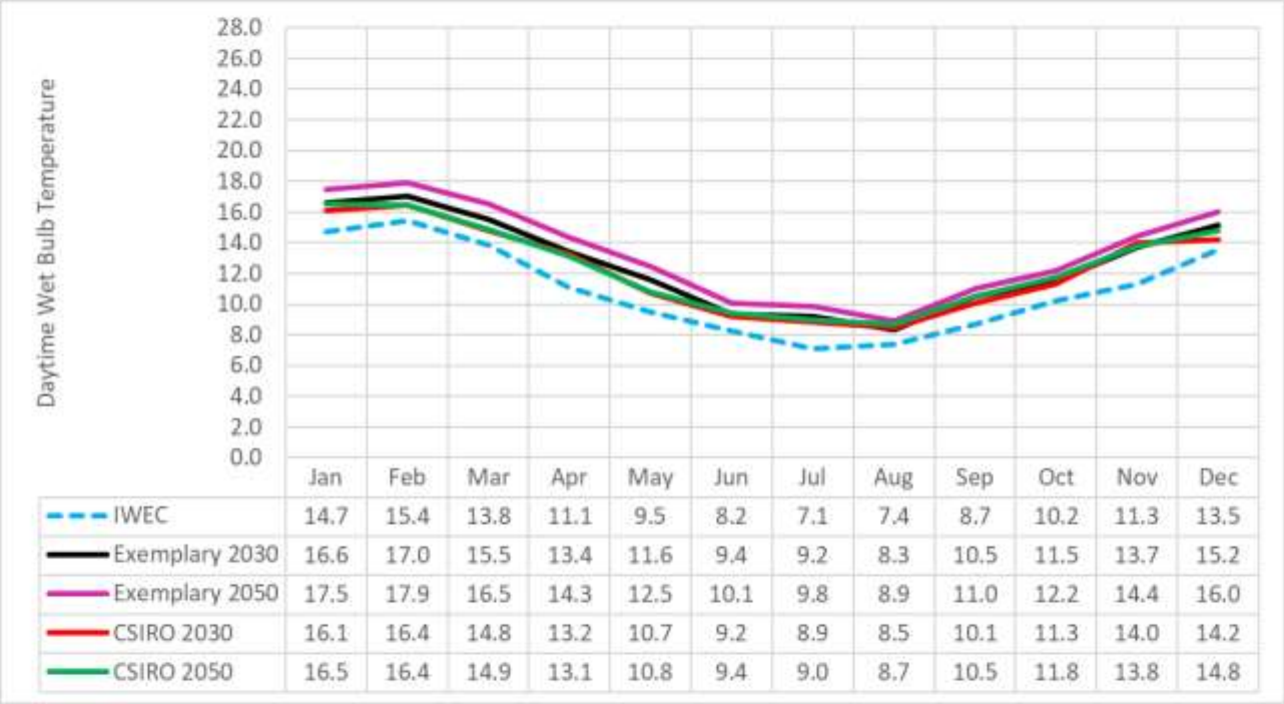
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
IWEC	16.1	17.5	15.3	12.4	10.4	8.8	7.5	8.3	9.4	11.6	13.1	14.8
Exemplary 2030	20.1	20.8	18.6	15.8	13.4	11.2	11.2	11.0	13.3	15.2	16.9	19.0
Exemplary 2050	21.2	22.0	19.9	17.0	14.4	12.0	12.0	11.9	14.2	16.4	18.1	20.2
CSIRO 2030	20.6	20.8	18.5	16.6	13.0	11.5	11.5	11.4	12.8	14.6	17.5	17.8
CSIRO 2050	21.0	21.5	18.2	16.0	13.2	11.6	11.5	11.8	13.7	15.5	18.4	18.9

Figure 29. Mean overnight dry bulb temperature - Climate Zone 6



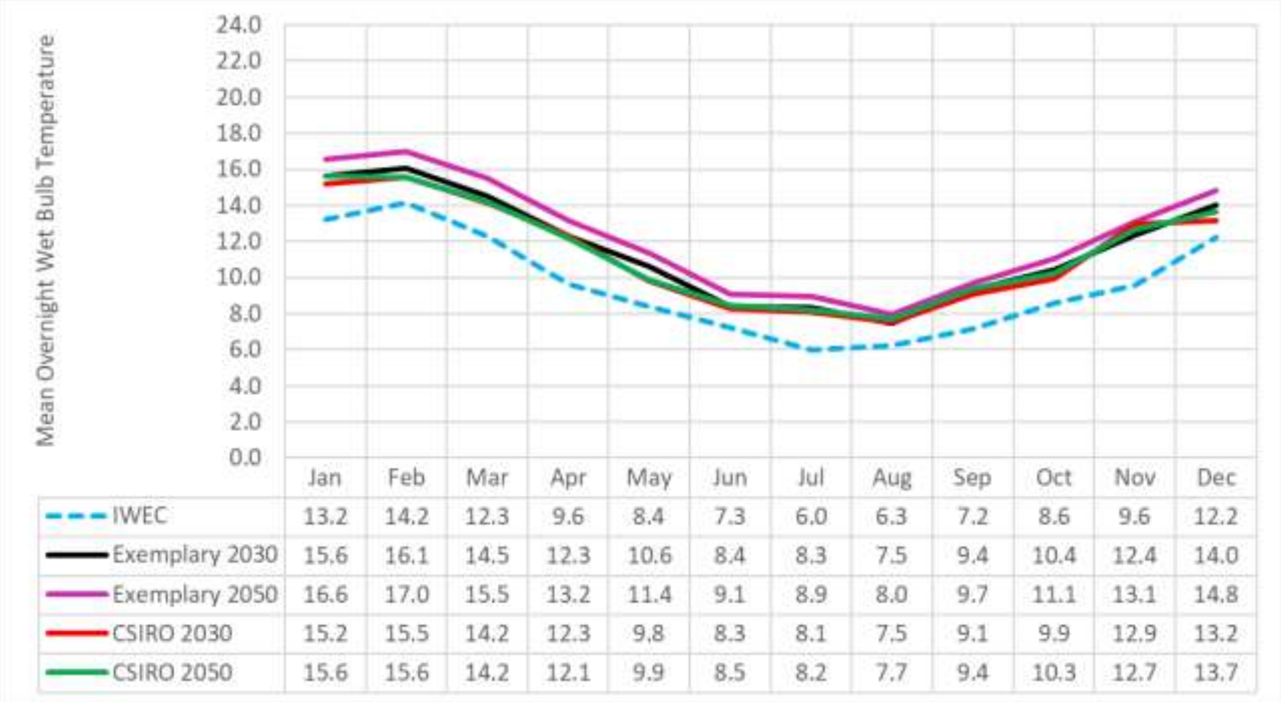
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
IWEC	8.0	8.0	7.0	4.0	2.0	3.7	0.0	2.8	1.0	3.7	5.0	7.0
Exemplary 2030	12.0	12.4	11.3	5.9	4.6	2.3	5.0	3.1	4.9	7.3	9.7	11.7
Exemplary 2050	13.1	13.5	12.5	7.0	5.5	3.0	5.8	3.9	5.7	8.3	10.8	12.8
CSIRO 2030	12.4	12.5	11.2	8.6	3.6	5.9	6.1	3.4	4.8	7.2	9.5	8.6
CSIRO 2050	12.8	12.9	11.0	7.9	3.2	5.9	6.1	3.5	4.7	7.3	9.6	9.3

Figure 30. Minimum overnight dry bulb temperature - Climate Zone 6



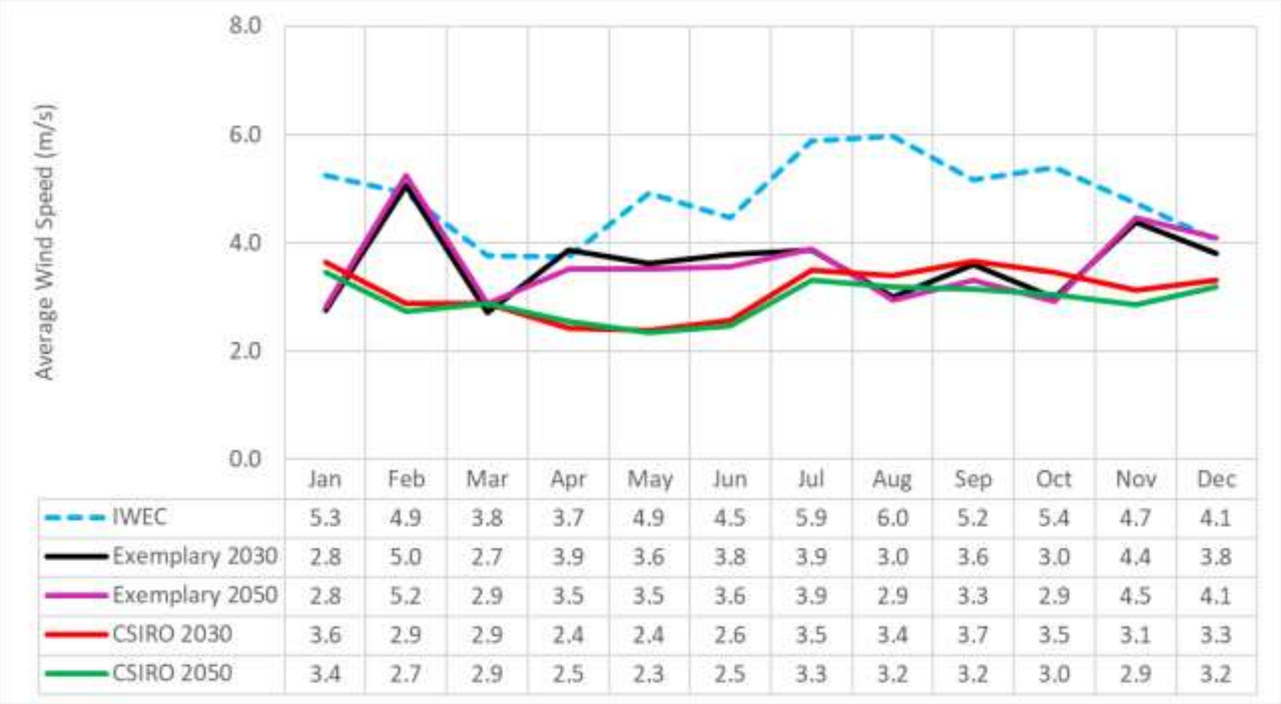
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
IWEC	14.7	15.4	13.8	11.1	9.5	8.2	7.1	7.4	8.7	10.2	11.3	13.5
Exemplary 2030	16.6	17.0	15.5	13.4	11.6	9.4	9.2	8.3	10.5	11.5	13.7	15.2
Exemplary 2050	17.5	17.9	16.5	14.3	12.5	10.1	9.8	8.9	11.0	12.2	14.4	16.0
CSIRO 2030	16.1	16.4	14.8	13.2	10.7	9.2	8.9	8.5	10.1	11.3	14.0	14.2
CSIRO 2050	16.5	16.4	14.9	13.1	10.8	9.4	9.0	8.7	10.5	11.8	13.8	14.8

Figure 31. Mean daytime wet bulb temperature - Climate Zone 6



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
IWEC	13.2	14.2	12.3	9.6	8.4	7.3	6.0	6.3	7.2	8.6	9.6	12.2
Exemplary 2030	15.6	16.1	14.5	12.3	10.6	8.4	8.3	7.5	9.4	10.4	12.4	14.0
Exemplary 2050	16.6	17.0	15.5	13.2	11.4	9.1	8.9	8.0	9.7	11.1	13.1	14.8
CSIRO 2030	15.2	15.5	14.2	12.3	9.8	8.3	8.1	7.5	9.1	9.9	12.9	13.2
CSIRO 2050	15.6	15.6	14.2	12.1	9.9	8.5	8.2	7.7	9.4	10.3	12.7	13.7

Figure 32. Mean overnight wet bulb temperature - Climate Zone 6



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
IWEC	5.3	4.9	3.8	3.7	4.9	4.5	5.9	6.0	5.2	5.4	4.7	4.1
Exemplary 2030	2.8	5.0	2.7	3.9	3.6	3.8	3.9	3.0	3.6	3.0	4.4	3.8
Exemplary 2050	2.8	5.2	2.9	3.5	3.5	3.6	3.9	2.9	3.3	2.9	4.5	4.1
CSIRO 2030	3.6	2.9	2.9	2.4	2.4	2.6	3.5	3.4	3.7	3.5	3.1	3.3
CSIRO 2050	3.4	2.7	2.9	2.5	2.3	2.5	3.3	3.2	3.2	3.0	2.9	3.2

Figure 33. Average Wind Speeds - Climate Zone 6

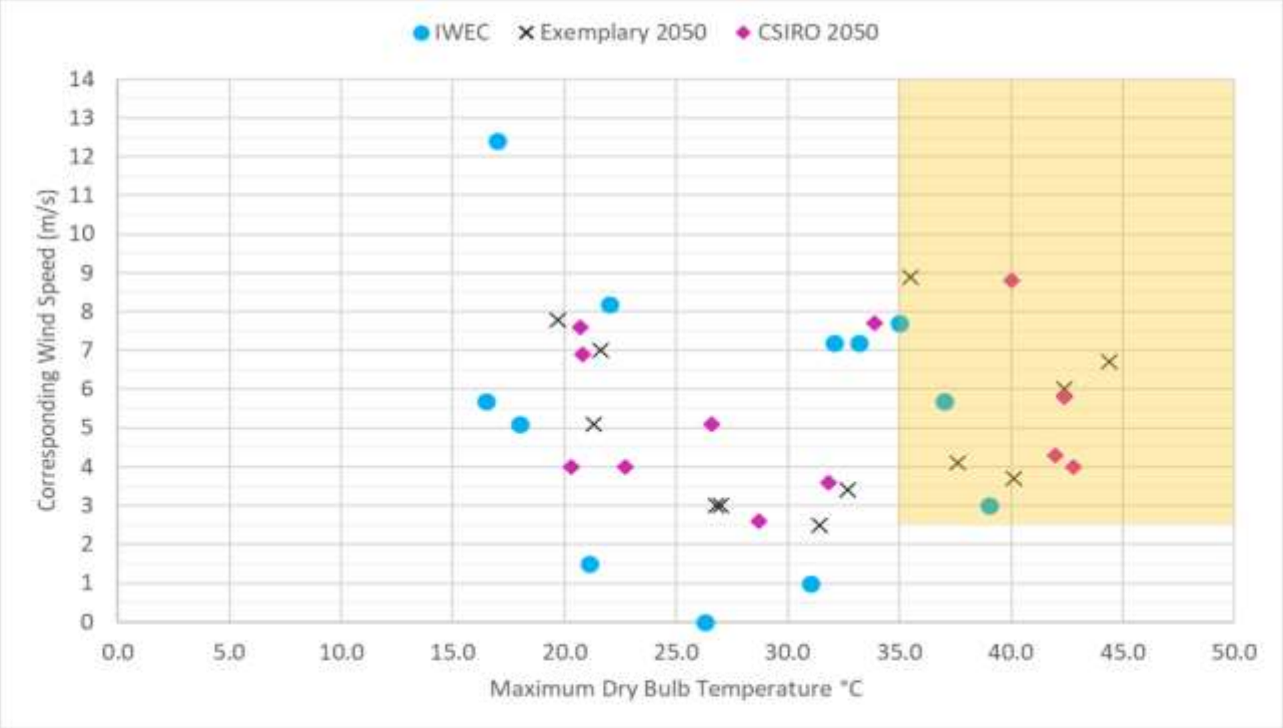


Figure 34. Wind speeds corresponding to the hottest dry bulb temperature each month - Climate zone 6

Figure 35. Extreme heat - frequency of occurrences (in hours) - Climate Zone 6

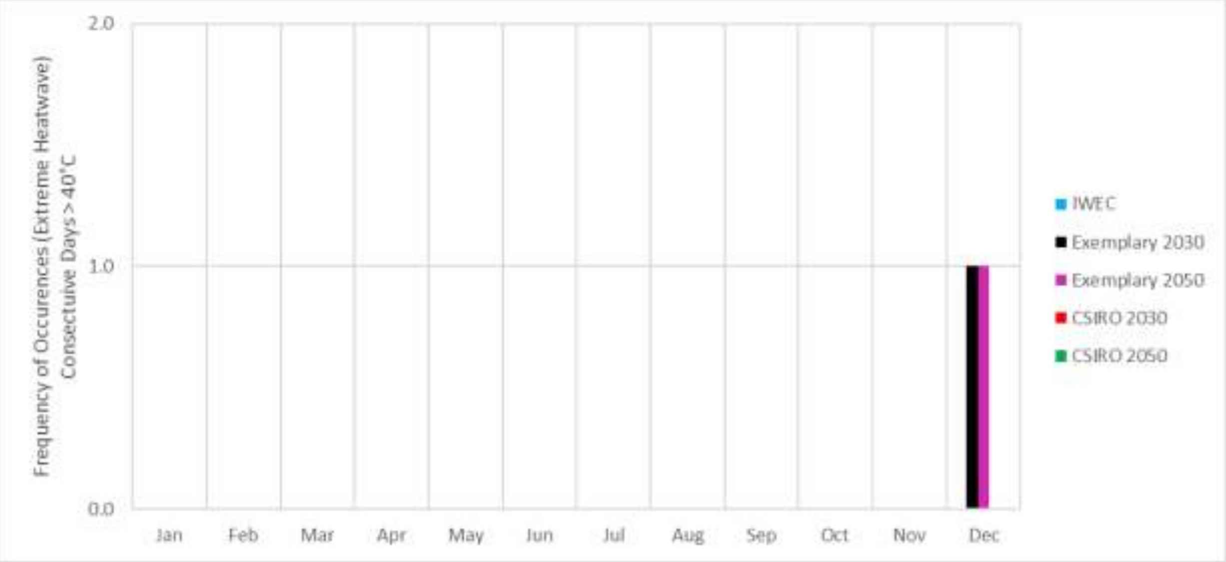
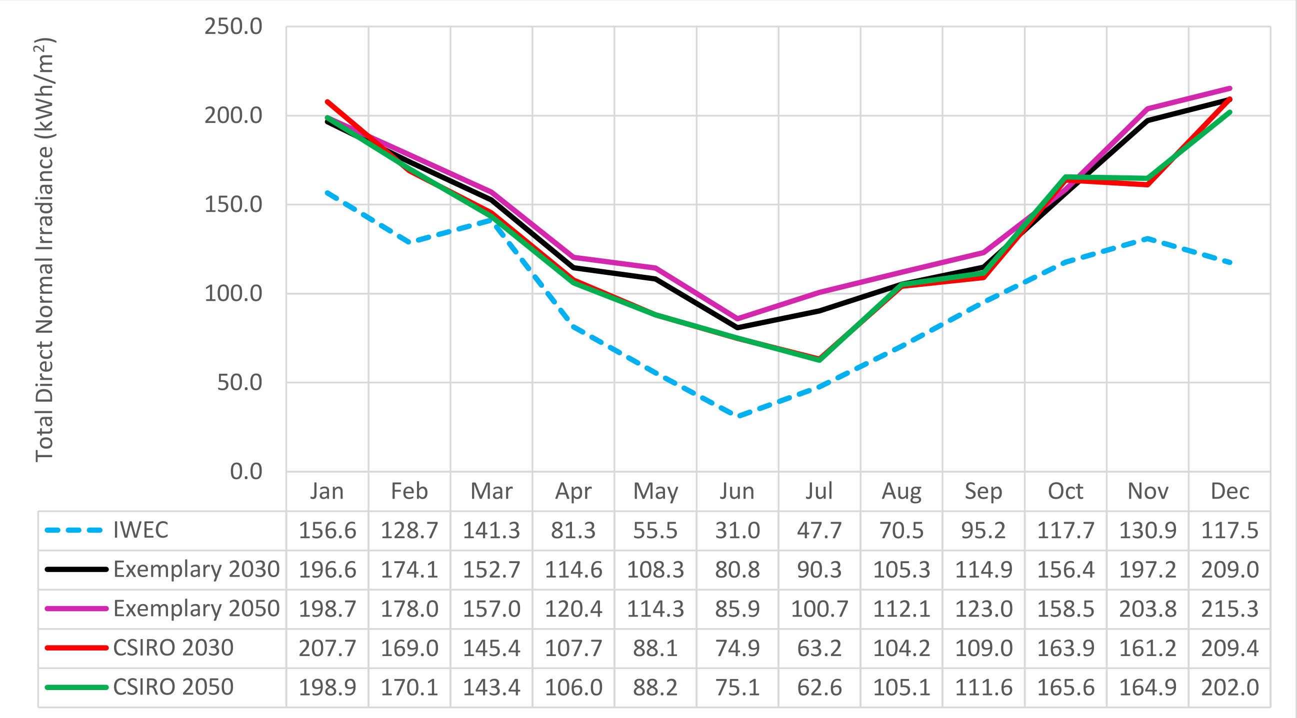


Figure 36. Extreme heatwave (40°C across consecutive days) – Climate zone 6.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
IWEC	156.6	128.7	141.3	81.3	55.5	31.0	47.7	70.5	95.2	117.7	130.9	117.5
Exemplary 2030	196.6	174.1	152.7	114.6	108.3	80.8	90.3	105.3	114.9	156.4	197.2	209.0
Exemplary 2050	198.7	178.0	157.0	120.4	114.3	85.9	100.7	112.1	123.0	158.5	203.8	215.3
CSIRO 2030	207.7	169.0	145.4	107.7	88.1	74.9	63.2	104.2	109.0	163.9	161.2	209.4
CSIRO 2050	198.9	170.1	143.4	106.0	88.2	75.1	62.6	105.1	111.6	165.6	164.9	202.0

Figure 37. Total direct normal irradiance - Climate Zone 6

Table 3. Annual Heating and Cooling Degree Days - Climate Zone 6

	HDD (18°C)	% Change (2050 relative to IWEC)	CDD (21°C)	% Change (2050 relative to IWEC)
IWEC	1861		172	
Exemplary 2030	1004		327	
Exemplary 2050	785	58%	428	249%
CSIRO 2030	1007		295	
CSIRO 2050	935	50%	352	82%

3 Literature Review

Key Findings:

1. **Internationally, adaptation efforts for climate have been focussed on building and community resilience to extreme weather events resulting from climate change. There is substantial work within the research community on all continents assessing impacts of climate change on building energy consumption, and to develop robust 'future' climate files.**
2. **Within the context of building regulation and regulated impacts of climate change on building energy modelling and thermal comfort, the California and Greater London Authority are the most advanced. The approach taken by California is for current climate files to be updated regularly and embedded within its building energy code compliance modelling software. The approach taken by the Greater London Authority (GLA) is for two types of climate files to be administered by CIBSE – GLA building energy consumption is modelled using the 'current' climate file provided by CIBSE, and summer overheating risk modelled using the an extreme and/or 'future' climate file also provided by CIBSE. The climate files are available for urban, suburban and regional buildings to account for differences in microclimate.**
3. **In Australia, CSIRO has undertaken substantial work for various state governments (NSW, QLD and VIC) to develop future climate files on 5 to 10 km grids. These future climate files are available for download by the general public from the government websites, but are not in an hourly format suitable for use in building energy modelling.**
4. **Beyond code schemes such as GBCA and NABERS, and industry bodies such as AIRAH are responding to importance of building resilience by preparing Best Practice Guides and requesting building designers to conduct design risk assessments using a future climate file linked to an appropriate Representative Concentration Pathway. These materials have not been published at time of writing.**
5. **The only Australian sources for future climate files usable in building energy modelling and HVAC sizing are currently CSIRO (recently developed updated climate files for NatHERS) and Exemplary Energy Partners (EFMY weather data using projected change values generated by CSIRO for a range of RCPs). Other international sources may not be available for Australian locations (CIBSE UK) or require further validation for use in Australian building code (CCWorldGen, WeatherShift, UrbanWeatherGenerator).**

The literature review focusses on adaptation initiatives internationally and domestically to address the impacts of climate change, specifically in the domain of building HVAC equipment and building fabric design. It also summarises existing work on projected climate files development, and if/how these are applied within building regulation or building energy modelling. As the focus is on building resilience in thermal comfort and energy consumption, impacts with associated ecological resilience considerations, and safety impacts from natural disasters such as flooding, storms and disease, are not explored at length.

Where mitigation initiatives are undertaken to counter climate change (such as net zero emissions targets), this literature review does not attempt to provide additional detail as mitigation is not the focus of this study.

Broadly speaking, our research has found that there has been substantial work conducted within the research and academic community globally on all continents since the early 2000s on the impact of changing climates on building energy consumption, for both commercial and residential buildings. In the past decade, there has an been increasing number of publications discussing different methods to generate future weather or climate files, based on the IPCC projections for various greenhouse gas emissions scenarios (discussed in Section 3.3).

3.1 Lessons from International Jurisdictions – Application within Building Regulation

In this section, we summarise the initiatives present in the USA, UK, Canada, Europe and select Asian countries, and how these countries are approaching the issue of climate change and its impacts on building fabric and HVAC design. Specifically, our interest is in how the existing building regulation treats climate change.

3.1.1 California - United States of America (USA)

The current energy code systems in California have three pathways for code compliance: (1) code-defined prescriptive measures, (2) model-based whole building performance measures derived with building simulations, and (3) model-based envelope performance measures derived with building simulations.[21] The California Energy Commission updates the Building Energy Efficiency Standards (Title 24, Parts 6 and 11) every three years. Consultation on the 2022 Building Regulation is currently underway. Based on the October 2019 *2022 Energy Pre-code Rulemaking* workshop presentations [22]published on the California Energy Commission's website, the primary goals for 2022 include maintaining and encouraging thermal-resilient building envelope features that perform well both in heating and cooling climate zones even with consideration to global warming. Currently, the California Building Energy Code Compliance (CBECC) software is used by development applicants to demonstrate compliance with energy codes or beyond-code programs. According to the workshop presentation, new weather files, reflecting the planet's warming trends, will be introduced into the 2022 CBECC software version and are expected to impact measure trade-offs. The Weather Data for 2022 Standards[23] presentation states 2013 standards are based on historical weather data (satellite solar data) from 1998 to 2009 – the 2022 standard will update the weather data to a 1998-2017 dataset to better reflect changing climate conditions in California. The CA Energy Commission found that cooling load increases, heating load decreases and the largest changes when using updated climate files are in transitional climate zones.

In their *Position Document on Climate Change (*2018)[24]*,* ASHRAE committed to continuously updating design guide documents, handbooks, standards, and other publications that reflect best understanding of design conditions, including expected climatic conditions. A review of the position document suggests an interest in mitigation activities, not adaptation, specifically, reducing refrigerant emissions, optimising energy efficiency during design and operation, following best practice design choices for building fabric including fenestration, plug loads and installing on-site renewable energy. It also appears that ASHRAE's focus is on updating climate data more regularly, instead of specifically creating future climate files and incorporating design requirements to consider future climate. This is reflected in ASHRAE 169-2013 *Climatic Data for Building Design Standards*.

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[21] Yan, Da & Hong, Tianzhen & Li, Cheng & Zhang, Qi & An, Jingjing & Hu, Shan. (2017). A Thorough Assessment of China's Standard for Energy Consumption of Buildings. Energy and Buildings. 143. 10.1016/j.enbuild.2017.03.019.

[22] https://www.energy.ca.gov/programs-and-topics/programs/building-energy-efficiency-standards/2022-building-energy-efficiency

[23] https://efiling.energy.ca.gov/GetDocument.aspx?tn=230286&DocumentContentId=61829

[24] https://www.ashrae.org/file%20library/about/position%20documents/ashrae-position-document-on-climate-change.pdf

3.1.2 United Kingdom (UK)

Currently there is no requirement in the Building Regulations (Part L2A and L2B[25]) to use 'future' climate files. So far, there is also no evidence that energy modelling must be undertaken using 'future' climate files.

London

In London, Greater London Authority (GLA) requires all developments to undertake overheating risk analysis[26] by undertaking dynamic overheating modelling adhering to CIBSE TM52[27] and TM49[28]. Table 5 in the GLA Energy Assessment Guidance April 2020 shows that for non-domestic applications, development applications are required to provide evidence of how the development performs against the overheating criteria along with an outline of the assumptions made in the energy assessment. It states that the results of the overheating analysis should be incorporated into the building design as design evolves, and substantive changes from Stage 1 proposals will require revised overheating analysis. The CIBSE TM52 criteria must be met for the DSY1[29] weather scenario though it is unclear how each London Borough[30] ensures that compliance to these requirements are met.

Where passive or other measures proposed have successfully addressed the risk of overheating, active cooling is not meant to be specified to avoid increasing the development's energy demand and carbon emissions. The hierarchy of overheating risk mitigation initiatives in the Mayor of London Policy 5.9[31] are, in order preference:

- Minimise internal heat generation through energy efficient design
- Reduce the amount of heat entering a building in summer through orientation, shading, albedo, fenestration, insulation and green roofs and walls
- Manage the heat within the building through exposed internal thermal mass and high ceilings
- Passive ventilation
- Mechanical ventilation
- Active cooling systems (ensuring lowest carbon options).

This risk-based approach by London may be applicable to Australian building regulation.

The CIBSE Guide F (Energy Efficiency) Section 3.3.2 *Adapting Buildings for climate change*[32] recommends best practice designs to consider predicted rise in summertime temperatures due to climate change. Examples of recommendations include employing solar shading, reducing occupant density and plug loads, reducing lighting power density and minimising outdoor ventilation during hot periods of the day. For buildings with

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[25] Part L2A covers requirements for new non-domestic buildings. Part L2B covers requirements for existing non-domestic buildings.

[26] https://www.london.gov.uk/sites/default/files/gla_energy_assessment_guidance_april_2020.pdf

[27] CIBSE TM 52 *The Limits of Thermal Comfort: Avoiding Overheating in European Buildings*.

[28] CIBSE TM 49 *Design Summer Years for London*

[29] DSY1 is the design summer year for the 2020s, high emissions, 50% percentile scenario. The GLA also states that additional testing should be undertaken using more extreme design weather years DSY2 (a year with a very intense single warm spell) and DSY3 (a year with a prolonged period of sustained warmth), but it is unclear if this is mandatory or recommended.

[30] GLA sits above 32 London Boroughs which are the planning authority in each area.

[31] https://www.london.gov.uk/what-we-do/planning/london-plan/current-london-plan/london-plan-chapter-five-londons-response/poli-8

[32] https://www.cibse.org/Knowledge/knowledge-items/detail?id=a0q20000008I7oTAAS

exposed thermal mass, it is acknowledged that overnight cooling (night purge) may not be beneficial due to urban heat island effects causing overnight temperatures to be 5-6°C warmer than in rural areas.

GLA requires modelling to be carried out using weather data and best practice guidelines from the CIBSE TM48, which propose weather files that account for both the urban heat island effect and for future climate change. At time of writing according to TM48, CIBSE and GLA are collaborating to provide more suitable Design Summer Year (DSY) files for London accounting for the effects of urban heat island and climate change. The updated DSY files will be based on updated UKCP09 climate projection data; the current files are based on UKCP02 data[33]. The GLA guidance document[34] specifies three different weather files for urban, suburban and rural sites should be used in overheating analysis, namely a year with prolonged period of sustained warmth, a moderately warm summer and a year with a very intense single warm spell. The three types of sites are provided as part of the CIBSE TM49:2014 climate files in order to account for the varying urban heat island effect.

Climate files (TRY[35] and DSY[36]) are supplied by CIBSE in collaboration with the UK Climate Impacts Programme (UKCIP), Arup and Exeter University for 'current' weather data and 'future' hourly weather data for three time periods – 2011-2040; 2041-2070; and 2071-2100. For each file, there is an option to select either a low, medium, or high emissions scenario. These are within the CIBSE TM49 dataset. Furthermore, CIBSE recommends that buildings where overheating impacts are more crucial should be modelled using more extreme 'future' weather data in addition to the proposed climate files above.

Other research

Hacker and Holmes (2007)[37] compared two types of adaptive methods (comfort ventilation[38] and mechanical cooling) using the 2050s climate file (2041-2070), and found that overheating increased in buildings with high reliance on *comfort ventilation*, due to higher outdoor temperatures. They identified an increased percentage of occupied hours where interior temperatures >28°C increased mechanical cooling emissions and decreased heating emissions, under the medium-high emissions scenario.

Holmes and Hacker (2007)[39] looked at how thermal comfort and energy in London buildings could be managed in the face of climate change. We note that in order to reduce reliance on mechanical cooling, London designs often incorporate natural ventilation – either in the form of natural ventilation, advanced natural ventilation by using natural forces and thermal chimneys, or mixed-mode operation. This approach is not widely adopted in Australia which largely relies on mechanical ventilation. Holmes and Hacker proposed four basic principles when considering adaptation – 'switch off' solar gain through shade, 'spread out' gain to reduce peak demand

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[33] According to CIBSE TM49, this is produced using a coupled atmosphere–ocean global circulation model (AOGCM) and a spatial resolution of 50km grids.

[34] https://www.london.gov.uk/sites/default/files/gla_energy_assessment_guidance_april_2020.pdf

[35] Test Reference Year – used to assess energy consumption and thermal comfort. Currently based on 30 years (1984 – 2013)

[36] Design Summer Year – used to assess overheating risk.

[37] HACKER, JACOB N., and MICHAEL J. HOLMES. "Thermal Comfort: Climate Change and the Environmental Design of Buildings in the United Kingdom." Built Environment (1978-), vol. 33, no. 1, 2007, pp. 97–114. JSTOR, www.jstor.org/stable/23289475.

[38] Basically natural ventilation using operable windows

[39] Holmes, Michael & Hacker, Jacob. (2007). Climate change, thermal comfort and energy: Meeting the design challenges of the 21st century. Energy and Buildings. 39. 802-814. 10.1016/j.enbuild.2007.02.009.

through thermal mass, 'blow away' heat gain through night purge, 'cool' only when necessary and consider mixed-mode operation or static cooling devices such as chilled beams.

3.1.3 Europe

In Europe, member countries adhere to Directives issued through the European Union. The most relevant directive is 2002/91/EC which covers energy performance of buildings. While the directive mentions building performance needs to account for climatic and local conditions, it does not specify that future climate needs to be taken into account.

Beyond regulation, numerous studies have been conducted in the past 20 years to assess the impact of climate change on building energy consumption.

- Frank (2005)[40] assessed climate change impacts on building heating and cooling energy demand in Switzerland for the time horizon 2050-2100. The research found cooling demand increased 223% to 1050%, while heating demand fell by 36-58%. The study showed that efficient solar protection and night ventilation strategies capable of keeping indoor air temperatures within an acceptable comfort range and obviating the need for cooling plant are set to become a crucial building design issue.

3.1.4 China - Asia

The Chinese GB 50189-2005[41] debuted in 2005 and lays out the energy efficiency requirements for commercial buildings. According to Hong, Li and Yan (2015)[42], Chinese codes are mandatory at the national level, but provide local governments with the ability to adopt more stringent standards. GB 50189-2014 offers prescriptive compliance pathways for new building construction and retrofits. According to Hong *et* al (2015), JGJ/T 288-2012 "Standard for building energy performance certification" is a voluntary standard that aims to promote a performance benchmarking system based on the actual energy performance of commercial buildings though uptake is low and implementation poor. The second national standard GB/T51161-2016 "Standard for energy consumption of buildings," carries more responsibility in regulating the actual energy consumption of commercial buildings in China, awarding two levels of ratings based on the energy use intensity of the building – level 1 which is the EUI that must not be exceeded and level 2 representing efficiency buildings. In summary, there does not appear to be a performance-based energy efficiency compliance pathway incorporating the use of building energy modelling and climate files to predict performance of the building.

In Hong Kong, Chan (2011)[43] developed a set of weather data files for subtropical Hong Kong, accounting for climate change using the morphing method. Through this work, six sets of future weather files for subtropical Hong Kong were produced. In this work, a high rise (40-storey) office building with zoned variable air volume (VAV) air handlers and air-cooled chillers with no heating was assumed. Chan's building energy simulations indicated that there will be substantial increase in air conditioning energy consumption under the impact of future climate change, ranging from 2.6% to 14.3% for office buildings.

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[40] Frank, Th. (2005). Climate Change Impacts on Building Heating and Cooling Energy Demand in Switzerland. Energy and Buildings - ENERG BLDG. 37. 1175-1185. 10.1016/j.enbuild.2005.06.019.

[41] https://www.codeofchina.com/standard/GB50189-2015.html

[42] Hong, Tianzhen & Li, Cheng & Yan, Da. (2015). Updates to the China Design Standard for Energy Efficiency in Public Buildings. Energy Policy. 87. 10.1016/j.enpol.2015.09.013.

[43] Chan, A.L.S.. (2011). Developing future hourly weather files for studying the impact of climate change on building energy performance in Hong Kong. Energy and Buildings. 43. 2860-2868. 10.1016/j.enbuild.2011.07.003.

3.2 Existing Work in Australia – Building Resilience and Adaptation

3.2.1 CSIRO

The CSIRO program, Climate Change in Australia, aims to share both predictions on future extreme events as well as strategies for adaptation and tools for decision-makers to use today in implementing resilience strategies. Key initiatives include:

- The **CSIRO Energy Business Unit** is developing national gridded future climate datasets for use within NatHERS models. These would likely be in a format suitable for use in energy and thermal comfort modelling.
- Global climate models (GCM) under the **Coupled Model Inter-comparison Project phase 6 (CMIP6)**[44] will soon be available. GCMs are used by climate scientists to adjust baseline climate or reference climate data to reflect future projected climate for the future Australian climate.
- High-level climate projections for **Victoria Climate Projections 2019**[45] developed by CSIRO for the Victorian State Government. The 5 km grid projection data were produced using the Conformal Cubic Atmospheric Model (CCAM) to downscale six host global climate models (GCMs) for two greenhouse gas emissions pathways, medium emissions (RCP4.5) and high emissions (RCP8.5), for ten regions - Barwon, Central Highlands, Gippsland, Goulburn, Great South Coast, Greater Melbourne, Loddon Campaspe, Mallee, Ovens Murray and Wimmera Southern Mallee. Data appears to be in daily format (only manipulated variables e.g. rainfall, mean temperature, minimum and maximum temperatures), and projected change values can be downloaded for users who may want to morph/adjust their own climate files. As far as can be seen, hourly data is not available.
- Climate projections for **Queensland Future Climate Dashboard**[46] (sponsored by Queensland Government). 10km grid modelling for Queensland, though hourly data suitable for building simulation is not available.
- **Electricity Sector Climate Information (ESCI)** project, which is a collaboration between CSIRO, BOM and AEMO, with an emphasis on supply-side/network impact. The ESCI work is expected to be complete by December 2021.

3.2.2 NSW Government

The NSW Government program, AdaptNSW, offers detailed descriptions of anticipated climate changes, and is furthermore developing Adaptation Research Hubs to help provide focussed guidance for groups within industry and government.

The Turn Down the Heat Strategy is a Western Sydney Regional Organisation of Councils (WSROC) initiative, laying out a five-year framework to support a greener, cooler, more liveable and resilient future for Western Sydney. The action plan 2018 published by WSROC [47] states that the average temperature difference between Sydney and Penrith on an extreme heat day is 10°C, and attributes this largely as an urban heat island driven

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[44] https://www.essoar.org/doi/abs/10.1002/essoar.10501525.1

[45] https://www.climatechangeinaustralia.gov.au/en/climate-projections/future-climate/victorian-climate-projections-2019/

[46] https://longpaddock.qld.gov.au/qld-future-climate/dashboard/#responseTab1

[47] https://wsroc.com.au/media-a-resources/reports/send/3-reports/287-summary-document-wsroc-turn-down-the-heat-strategy-and-action-plan-2018

by human activity and development (Figure 38). Research by Santamouris, M *et al* (April 2017)[48] found that while westerly winds from the inlands and sea breeze in the east caused the temperature differential observed, the urban heat island effect made this differential worse. Relevant initiatives to building design include greening of urban areas for shade and evapotranspiration and 'cool' building materials to prevent absorption of solar radiation. We note that that the NCC 2019 Volume One Section J Part J1.3(b) already requires light-coloured roofs through its solar absorptance requirement of <0.45.

Figure 38. Illustration of urban heat island effect in Parramatta (Source: City of Parramatta[49])

3.2.3 Queensland Government

The QCoast210014 program is led by the Local Government Association of Queensland in conjunction with the Queensland Department of Environment and Science. According to the Property Council of Australia (PCA) April 2020 submission to the Bushfire Royal Commission, the program focuses on building the capacity of coastal councils across the state. The aim of the program is to respond to the impacts of climate change related coastal hazards risks over the long-term through the development of Coastal Hazard Adaptation Strategies.

3.2.4 Australian Institute of Refrigeration, Air-conditioning and Heating (AIRAH)

The AIRAH Resilience Special Technical Group (STG) has been working on developing a Resilience Best Practice Guide for building and HVAC equipment. The STG has investigated climate files and presented modelling results showing impacts of climate change on building energy consumption at past AIRAH conferences.

3.2.5 NABERS

Future climate is not currently considered within the NABERS Commitment Agreement modelling handbook, but NABERS has indicated anecdotally that they are likely to mimic GBCA requirements as an off-axis scenario. For more information on the NABERS Commitment Agreement modelling requirements, refer to the NABERS Handbook for Estimating NABERS ratings[50].

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[48] Santamouris, M.; Haddad, S.; Fiorito, F.; Osmond, P.; Ding, L.; Prasad, D.; Zhai, X.; Wang, R. Urban Heat Island and Overheating Characteristics in Sydney, Australia. An Analysis of Multiyear Measurements. *Sustainability* **2017**, *9*, 712. Accessed: https://www.mdpi.com/2071-1050/9/5/712/htm

[49] http://coolparramatta.com.au/about_us

[50] https://www.nabers.gov.au/file/2291/download?token=gUCKg5tF

3.2.6 Green Building Council of Australia (GBCA)

In 2018, the International Building Performance Simulation Association (IBPSA) Australasia hosted an event available for GBCA CPD points titled weather data: past, present and future[51]. The GBCA noted that this event was relevant because buildings need to start considering and adopting measures to mitigate the effect of climate change to their energy efficiency performance.

A new addition to the Energy Modelling credit is the link to the Climate change resilience credit (not yet publicly released). Where the Resilience credit achievement is claimed, an additional requirement appears in the Energy Modelling credit ensuring the energy modelling appropriately accounts for future changes in weather. The credit requires that a model be done ensuring the design can address future climactic conditions. Discussions with the GBCA Future Focus revealed that they are likely to remove the requirement to demonstrate that energy use consumption in the buildings' future does not rise over 10%, and convert this to a qualitative risk assessment instead. Instead of referencing specific climate files, the GBCA is likely to specify future climate file criteria such as an intermediate RCP.

3.2.7 National Climate Change Adaptation Research Facility (NCCARF)

In 2013, NCCARF published a report *A Framework for Adaptation of Australian Householders to Heat* Waves[52], which identified that by 2030, it is likely that all cities on the Australian mainland will use more electricity for cooling than for heating, as well as an anticipation that peak demand in all capital cities will increase due to climate change. The report identifies current building and air conditioning regulation primarily focusing on energy usage rather than peak cooling demand.

New TMY climatic data was developed for 2030 and 2070, for which the recommendation was to update NaTHERS climate data and air conditioning design calculations revised to reflect changing climate. Regulations for new buildings are to include a rating, through NaTHERS, for the maximum peak power demand from building designs.

The 2013 NCCARF report recommends that an adaptation framework for Australian households adopt adaptive thermal designs comfort settings in air conditioning guides and standards, and have these standards regularly updated. We note that the ABCB has released a performance solution allowing the use of the Adaptive Thermal Comfort method for naturally ventilated buildings to comply with Performance Requirement JP1(b) of the NCC Volume One Section J. Albatayneh *et al* (January, 2019)[53] explains that one of the key theories of adaptive theory is that people in warmer climates can tolerate warmer temperatures indoors than those living in colder climates. In fact, their modelling results found that when thermal comfort temperatures in residential houses were expanded to 22.7 and 29.7°C in summer, and 19.6 and 26.6°C in winter, these wider ranges saved massive amounts of operational energy. As most commercial buildings are generally mechanically cooled, the recommendation for adaptive thermal designs would require careful planning during the design and building operational and maintenance phase before being applied directly to existing or new Australian commercial buildings.

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[51] https://www.gbca.org.au/events/ibpsa-australasia-2018-sydney-weather-data-past-present-and-future/

[52] Saman, W, Boland, J, Pullen, S, de Dear, R, Soebarto, V, Miller, W, Pocock, B, Belusko, M, Bruno, F, Whaley, D, Pockett, J, Bennetts, H, Ridley, B, Palmer, J, Zuo, J, Ma, T, Chileshe, N, Skinner, N, Chapman, J, Vujinovic, N, Walsh, M, Candido, C, Deuble, M 2013 A framework for adaptation of Australian households to heat waves, National Climate Change Adaptation Research Facility, Gold Coast, pp. 242.

[53] Albatayneh, A.; Alterman, D.; Page, A.; Moghtaderi, B. The Significance of the Adaptive Thermal Comfort Limits on the Air-Conditioning Loads in a Temperate Climate. *Sustainability* **2019**, *11*, 328.

Typical design adaptations proposed by the 2013 NCCARF report include external shading, utilisation of thermal mass to reduce diurnal variation, increased insulation to reduce heat gain through conduction, promotion of ventilation to remove heat from the interior and appropriate spatial planning with reference to orientation. Of interest is also the recommendation for ceiling fans, which do not affect the internal temperatures but are a cost-efficient method of improving occupant comfort sensations by up to 2-3°C due to increased air-movement. While this may not be practical for application within an office-based setting, it is already widely used in warehouses and schools.

3.2.8 University of Technology Sydney

Guan (January 2009)[54]'s research on the sensitivity of building zones to potential global warming showed that when compared with the middle and top floors, except for in cool climate (i.e. Hobart), the ground floor appears to be the most sensitive to the effect of global warming and has the highest tendency towards overheating. From the analysis of the responses of different zone orientations to the outdoor air temperature increase, it was also found that there are widely varied responses between zone orientations, with South zone (in the southern hemisphere) being the most sensitive. With an increased external air temperature, the variation between different floors or zone orientations will become more significant, up to 53% increase in overheating hours in Darwin and 47% increase in cooling load in Hobart.

3.3 Climate Files Development

3.3.1 Methodology

There is substantial literature available within the scientific community on different methods to manipulate baseline weather/climate data into a 'future' weather/climate file based on the underpinning projection assumptions selected by the scientist. Belcher and Powell (2005)[55] and Guan (2009)[56] describe four methods to produce weather files for future, warmer climates, these are:

- **Dynamical downscaling (Global Climate Models, GCMs).** According to CSIRO[57], GCMs are a mathematical representation of the climate system, solved on a super-computer on a three-dimensional grid in the ocean and atmosphere across 200 km. Dynamical downscaling is a method used to translate the GCM outputs to finer resolution using regional climate models. This method is computationally expensive and due to complexity and need for specialist knowledge, are often only available to meteorologic specialists.
- **Stochastic weather generation.** This method requires large data sets for model training and is computationally expensive.
- **Extrapolating statistical method (degree-day method).** This method uses the approach of extrapolating statistical historical weather data to predict future weather conditions. This is a simplified methodology that is used as a preliminary assessment ahead of detailed climate modelling.

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[54] Guan, Lisa. (2009). Sensitivity of Building Zones to Potential Global Warming. Architectural Science Review. 52. 279-294. 10.3763/asre.2009.0035.

[55] Belcher, S., Hacker, J., & Powell, D. (2005). Constructing design weather data for future climates. Building Services Engineering Research and Technology, 26(1), 49–61. https://doi.org/10.1191/0143624405bt112oa

[56] Guan, Lisa. (2009). Preparation of future weather data to study the impact of climate change on buildings. Building and Environment. 44. 793-800. 10.1016/j.buildenv.2008.05.021.

[57] https://www.climatechangeinaustralia.gov.au/en/climate-campus/modelling-and-projections/climate-models/downscaling/#:~:text=Downscaling,a%20number%20of%20time%2Dsteps.

- **Imposed offset method (morphing).** This method imposes the predicted future climate information due to global warming from the more complex climate models on top of the recorded current reference year weather data. This method is the most practical, with the morphed design weather for the future climate exhibiting character and variability of present-day climate.

Of the methods above, it appears that the morphing approach is the most popular method amongst the scientific community.

Figure 39 (courtesy of Yassaghi *et al*, 2019) provides a good summary of existing publications and its location to date. However, official sources of 'future' climate files ready for direct application by industry practitioners such as building energy modellers or design engineers are rare. This finding was shared in 2014 by Schuetter, Debaillie and Ahl (2014)[58], who stated in the ASHRAE Journal that *a standardized approach has yet to emerge for the selection of appropriate future or baseline climate data*.

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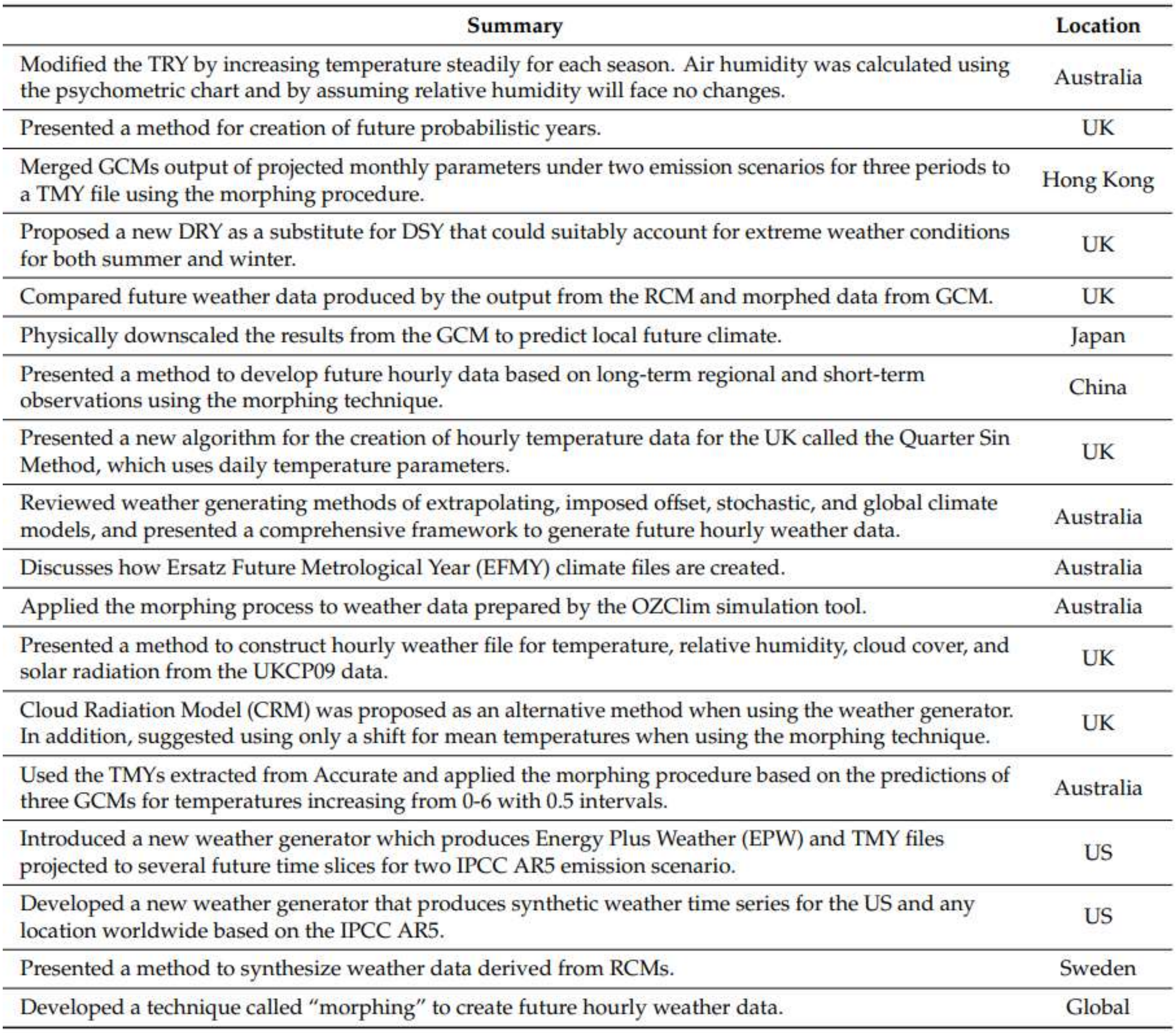
[58] http://www.calmac.com/stuff/contentmgr/files/0/ea4afe82e740c257680ac9e8d454ce18/pdf/future_climate_impacts_on_building_design.pdf



Summary	Location
Modified the TRY by increasing temperature steadily for each season. Air humidity was calculated using the psychometric chart and by assuming relative humidity will face no changes.	Australia
Presented a method for creation of future probabilistic years.	UK
Merged GCMs output of projected monthly parameters under two emission scenarios for three periods to a TMY file using the morphing procedure.	Hong Kong
Proposed a new DRY as a substitute for DSY that could suitably account for extreme weather conditions for both summer and winter.	UK
Compared future weather data produced by the output from the RCM and morphed data from GCM.	UK
Physically downscaled the results from the GCM to predict local future climate.	Japan
Presented a method to develop future hourly data based on long-term regional and short-term observations using the morphing technique.	China
Presented a new algorithm for the creation of hourly temperature data for the UK called the Quarter Sin Method, which uses daily temperature parameters.	UK
Reviewed weather generating methods of extrapolating, imposed offset, stochastic, and global climate models, and presented a comprehensive framework to generate future hourly weather data.	Australia
Discusses how Ersatz Future Metrological Year (EFMY) climate files are created.	Australia
Applied the morphing process to weather data prepared by the OZClim simulation tool.	Australia
Presented a method to construct hourly weather file for temperature, relative humidity, cloud cover, and solar radiation from the UKCP09 data.	UK
Cloud Radiation Model (CRM) was proposed as an alternative method when using the weather generator. In addition, suggested using only a shift for mean temperatures when using the morphing technique.	UK
Used the TMYs extracted from Accurate and applied the morphing procedure based on the predictions of three GCMs for temperatures increasing from 0-6 with 0.5 intervals.	Australia
Introduced a new weather generator which produces Energy Plus Weather (EPW) and TMY files projected to several future time slices for two IPCC AR5 emission scenario.	US
Developed a new weather generator that produces synthetic weather time series for the US and any location worldwide based on the IPCC AR5.	US
Presented a method to synthesize weather data derived from RCMs.	Sweden
Developed a technique called "morphing" to create future hourly weather data.	Global

Figure 39. Summary of future hourly weather files for building applications [Source: Table 2, Yassaghi *et al* (2019)[59]]

3.3.2 Future climate files

Our review of publicly available information revealed the following shortlist of 'future' climate files with hourly weather data outputs suitable for use in energy modelling software:

- Australia
  - The **Ersatz Future Metrological Year (EFMY) Weather Data** developed by Exemplary Energy Partners was created using projected change values (PCVs) provided by CSIRO and is available for 80 Australian locations for 6 scenarios (low, mid and high emissions; and for each emissions projection, a 'most likely' and 'highest emissions' scenario). The 2050 high emissions, warmest scenario Ersatz climate files (A1FI IPCC fossil-intensive scenario) were used in this study.

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[59] Yassaghi, H.; Hoque, S. An Overview of Climate Change and Building Energy: Performance, Responses and Uncertainties. *Buildings* **2019**, *9*, 166.

Further detail on the generation of EFMY future climate data is described in the paper by Lee, T (November, 2011)[60].

  - The **CSIRO Energy Business Unit** is developing national gridded future climate datasets for use within NatHERS models. At time of writing this is not publicly available, but when released, is expected to be in a format suitable for energy modelling use. However, it should be noted that there are currently 69 NatHERS climate zones, whereas the ABCB commercial buildings only designates 8 climate zones. NatHERS climate files are generally embedded within the approved modelling software such as AccuRate, BERS Pro and FirstRate5.
- United Kingdom
  - The **CIBSE future weather years** are 'climate change adjusted' counterparts of the current CIBSE Test Reference Year (TRY) and Design Summer Year (DSY) weather data files, currently provided for 14 locations in the UK. Further detail is provided in CIBSE TM49.
- Worldwide
  - The **CCWorldWeatherGen** climate change world weather file generator developed by the University of Southampton. The tool is Microsoft® Excel based and transforms 'present-day' EPW weather files into climate change EPW or TMY2 weather files which are compatible with the majority of building performance simulation programs. The software only allows for the IPCC 'medium high emission' scenario A2. Further detail on the underlying methodology used can be found in the publication by Jentsch M.F *et al* (2013)[61].
  - The **WeatherShift** tool[62] uses data from global climate change modelling to produce EnergyPlus (.epw) weather files adjusted for changing climate conditions. It is also compatible with other simulation platforms like IES<VE>[63]. WeatherShift is a collaborative project of Arup North America Ltd (Arup), Argos Analytics LLC, and Slate Policy and Design. Users can customise the country, city, emissions scenario (RCP6.5 or RCP8.5) and the warming percentile, for which the platform will generate a 'future' weather file appropriate for use in EnergyPlus.
  - The **Urban Weather Generator 4.1**[64] developed by the Building Technology Program at MIT outputs EnergyPlus weather files based on user-input morphological and geometric characteristics capturing the urban heat island effect. Some technical variables include average building height, how close buildings are built, façade surface area to urban plan area, tree coverage *etc*. The tool has been tested successfully in Toulouse, Basel and Singapore.

3.4 Urban Heat Island (UHI) Effects

In the 1800s, Luke Howard measured the temperature differences between urban centre and the countryside for a number of years, finding that overnight temperatures were warmer and daytime temperatures were slightly cooler in the city than in the country (Howard, 1833), recognising what we call the urban heat island

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[60] Lee, T. Changing Climate: Ersatz Future Weather Data for Lifelong System Evaluation. In Proceedings of the Building Simulation, 12th Conference of International Building Performance Simulation Association, Sydney, Australia, 14–16 November 2011.

[61] Jentsch M.F., James P.A.B., Bourikas L. and Bahaj A.S. (2013) Transforming existing weather data for worldwide locations to enable energy and building performance simulation under future climates, Renewable Energy, Volume 55, pp 514-524.

[62] http://www.weather-shift.com/

[63] https://www.iesve.com/support/weather-files/user-guidelines.pdf

[64] https://urbanmicroclimate.scripts.mit.edu/uwg.php

(UHI) effect today. An UHI refers to a metropolitan area that has a higher temperature or heat content than its surrounding rural areas (Ren, 2012).

Crawley (2007)[65] proposes that heat islands can be represented as a change to the diurnal temperature patterns, and by modifying dry bulb temperatures and recalculating humidity ratio in an existing weather file. This can be cross-checked against USEPA (US Environmental Protection Agency, 2007) Heat Island Reduction Initiative estimates that the heat island effect is in the range of 1–5°C.

Conventional building designs and thermal simulations are based on observed local weather station information, such as typical meteorological year (TMY) weather files, which have the UHI effect embedded to some extent but without consideration of potential changes following future urban development. This may be inadequate for locations where an urban weather station is unavailable or areas with rapid urban development changes. In Australia, Ren Z *et al* (2012) published an article on the construction of weather data for building simulation considering UHI effects[66]. Ren (2012) proposes that base climate data be 'morphed' to account for UHI using the 'UCM-TAPM' method developed by Thatcher and Hurley (2012) for the Australian climate. The proposed approach will allow academics and building engineers to construct realistic urban hourly weather data to analyse the impacts of urban heat islands on energy requirements and thermal stress for different urban planning and design options.

Another method is the Canyon Air Temperature (CAT) model developed by Erell and Williamson (2006)[67] which generates site-specific weather data from time-series data measured at a reference meteorological station in the region, accounting for urban geometry, materials and surrounding hydrological conditions (Kalman, Pearlmutter and Erell, 2013)[68]. In Tel Aviv, Israel; Erell and Kalman (2015)[69] found that energy consumption on the topmost floor is 1.6 times higher than an intermediate level floor, for which the effect can be dampened by installing better roof insulation. Wind speed is reduced substantially, and overnight dry bulb temperatures increase, as the street canyons deepen (higher buildings). The study found that different depths of urban canyons had minimal impact on daytime temperatures.

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[65] Crawley, Drury. (2007). Creating Weather Files for Climate Changes and Urbanization Impacts Analysis.

[66] Ren, Z., Wang, X., Chen, D., Wang, C., & Thatcher, M. (2014). Constructing weather data for building simulation considering urban heat island. Building Services Engineering Research and Technology, 35(1), 69–82. https://doi.org/10.1177/0143624412467194

[67] Erell, Evyatar & Williamson, T.. (2006). Simulating air temperature in an urban street canyon in all weather conditions using measured data at a reference meteorological station. International Journal of Climatology. 26. 1671 - 1694. 10.1002/joc.1328.

[68] Kalman, Yannai & Pearlmutter, D. & Erell, Evyatar. (2013). Impact of Increasing the Height of Tel Aviv Buildings on Pedestrian Comfort and Building Energy Efficiency.

[69] Kalman, Y & Erell, E. (2015). 'Impact of increasing the depth of urban street canyons on building heating and cooling loads in Tel Aviv, Israel'. *ICUC9 – 9th International Conference on Urban Climate jointly with 12th Symposium on the Urban Environment,* Toulouse France, 20-24th July 2015.

4 Modelling Results

Details on the model are provided in Appendix A.III below.

4.1 HVAC Plant Sizing

CAMEL is a widely used heat load estimation software used by design engineers to size HVAC plant. Design conditions can be selected based on 'Comfort' or 'Critical' criterion, for which most commercial building applications use the comfort criteria. In Australia, the AIRAH DA09 (released in 2016) also provides design temperature data for HVAC plant sizing, covering 46 locations (or weather stations) and for comfort or critical applications.

When estimating cooling and heating loads for buildings, ambient outdoor design dry bulb and wet bulb temperatures are needed to calculate:

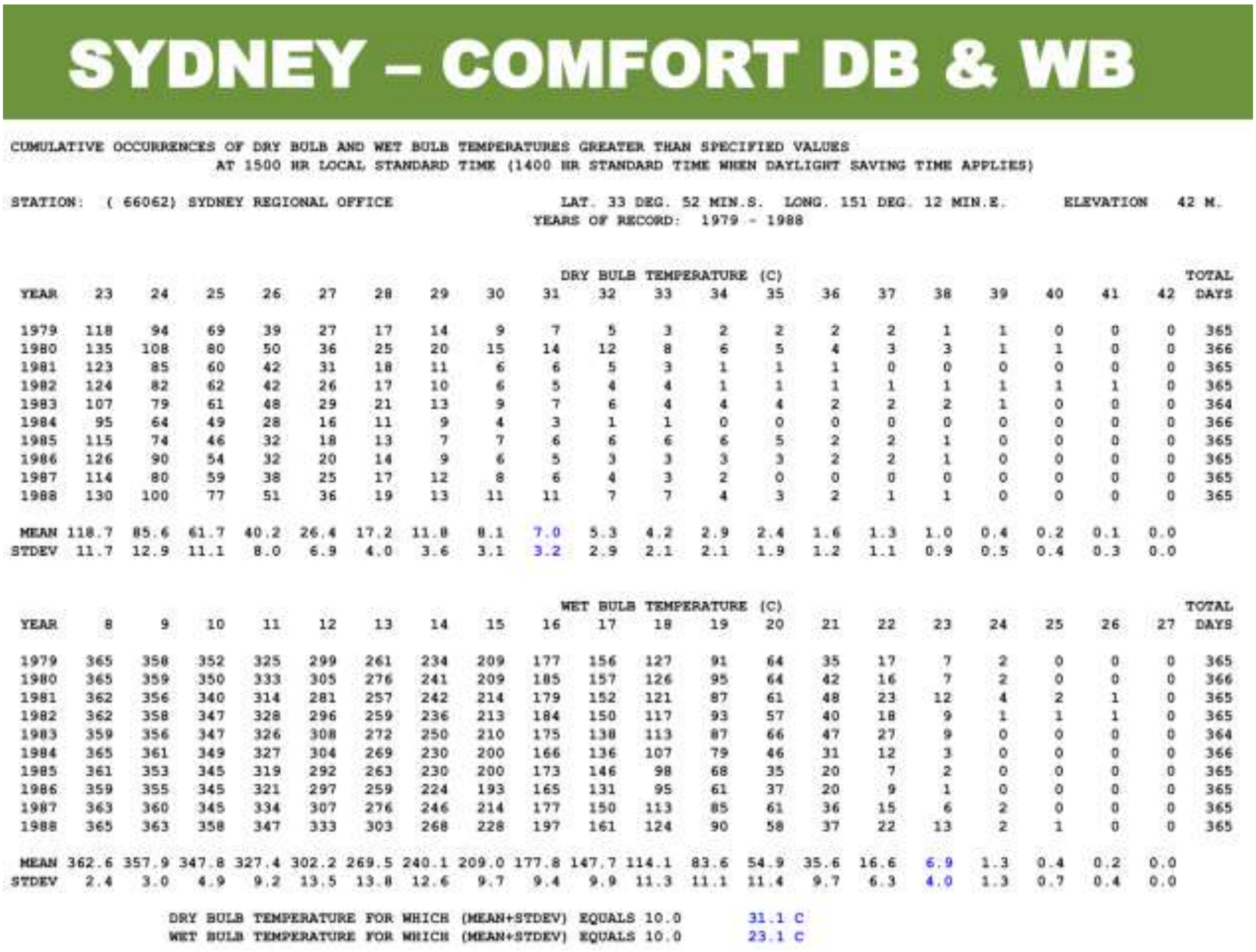
- Sensible conduction loads through the building fabric
- Sensible and latent load due to outdoor air purposely introduced into the building
- Sensible and latent load due to infiltration of outdoor air into the building

CAMEL does not directly account for wind speed. There is a field in CAMEL for the entry of infiltration rate which will be impacted by wind. Current practice is for the designer to determine the value of the infiltration rate and is generally in the range of 0.1 to 1 Air changes per hour. It is not typical practice for the designer to calculate the infiltration rate based on changing wind speed – in most cases, the NCC Specification JVb requirements are used – 0.35 ACH during building operation hours.

CAMEL Comfort Summer Design conditions are the 3:00pm dry-bulb (DB) and wet-bulb (WB) temperatures which are individually exceeded (non-coincident) on 10 days per year (inclusive of one standard deviation). The 3 pm temps for each year are put into 1°C bins and Figure 40 records how many days are in (and above) each bin (cumulatively).

This data is compiled for each year in the sample. The mean number of days/bin and also the standard deviation for that bin are then calculated. The comfort design temperature is then the temperature for which the mean + std dev =10. A similar approach is used to determine the wet bulb design temperature.

Figure 40 shows more detail on how the CAMEL Design Conditions are calculated.



SYDNEY – COMFORT DB & WB

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CUMULATIVE OCCURRENCES OF DRY BULB AND WET BULB TEMPERATURES GREATER THAN SPECIFIED VALUES
                     AT 1500 HR LOCAL STANDARD TIME (1400 HR STANDARD TIME WHEN DAYLIGHT SAVING TIME APPLIES)

STATION:  ( 66062) SYDNEY REGIONAL OFFICE                LAT. 33 DEG. 52 MIN.S.  LONG. 151 DEG. 12 MIN.E.     ELEVATION   42 M.
                                                      YEARS OF RECORD:  1979 - 1988

                                                        DRY BULB TEMPERATURE (C)                                         TOTAL
 YEAR    23    24    25    26    27    28    29    30    31    32    33    34    35    36    37    38    39    40    41    42  DAYS

 1979   118    94    69    39    27    17    14     9     7     5     3     2     2     2     2     1     1     0     0     0   365
 1980   135   108    80    50    36    25    20    15    14    12     8     6     5     4     3     3     1     1     0     0   366
 1981   123    85    60    42    31    18    11     6     6     5     3     1     1     1     0     0     0     0     0     0   365
 1982   124    82    62    42    26    17    10     6     5     4     4     1     1     1     1     1     1     1     1     0   365
 1983   107    79    61    48    29    21    13     9     7     6     4     4     4     2     2     2     1     0     0     0   364
 1984    95    64    49    28    16    11     9     4     3     1     1     0     0     0     0     0     0     0     0     0   366
 1985   115    74    46    32    18    13     7     7     6     6     6     6     5     2     2     1     0     0     0     0   365
 1986   126    90    54    32    20    14     9     6     5     3     3     3     3     2     2     1     0     0     0     0   365
 1987   114    80    59    38    25    17    12     8     6     4     3     2     0     0     0     0     0     0     0     0   365
 1988   130   100    77    51    36    19    13    11    11     7     7     4     3     2     1     1     0     0     0     0   365

 MEAN 118.7  85.6  61.7  40.2  26.4  17.2  11.8   8.1   7.0   5.3   4.2   2.9   2.4   1.6   1.3   1.0   0.4   0.2   0.1   0.0
STDEV  11.7  12.9  11.1   8.0   6.9   4.0   3.6   3.1   3.2   2.9   2.1   2.1   1.9   1.2   1.1   0.9   0.5   0.4   0.3   0.0

                                                        WET BULB TEMPERATURE (C)                                         TOTAL
 YEAR     8     9    10    11    12    13    14    15    16    17    18    19    20    21    22    23    24    25    26    27  DAYS

 1979   365   358   352   325   299   261   234   209   177   156   127    91    64    35    17     7     2     0     0     0   365
 1980   365   359   350   333   305   276   241   209   185   157   126    95    64    42    16     7     2     0     0     0   366
 1981   362   356   340   314   281   257   242   214   179   152   121    87    61    48    23    12     4     2     1     0   365
 1982   362   358   347   328   296   259   236   213   184   150   117    93    57    40    18     9     1     1     1     0   365
 1983   359   356   347   326   308   272   250   210   175   138   113    87    66    47    27     9     0     0     0     0   364
 1984   365   361   349   327   304   269   230   200   166   136   107    79    46    31    12     3     0     0     0     0   366
 1985   361   353   345   319   292   263   230   200   173   146    98    68    35    20     7     2     0     0     0     0   365
 1986   359   355   345   321   297   259   224   193   165   131    95    61    37    20     9     1     0     0     0     0   365
 1987   363   360   345   334   307   276   246   214   177   150   113    85    61    36    15     6     2     0     0     0   365
 1988   365   363   358   347   333   303   268   228   197   161   124    90    58    37    22    13     2     1     0     0   365

 MEAN 362.6 357.9 347.8 327.4 302.2 269.5 240.1 209.0 177.8 147.7 114.1  83.6  54.9  35.6  16.6   6.9   1.3   0.4   0.2   0.0
STDEV   2.4   3.0   4.9   9.2  13.5  13.8  12.6   9.7   9.4   9.9  11.3  11.1  11.4   9.7   6.3   4.0   1.3   0.7   0.4   0.0

                  DRY BULB TEMPERATURE FOR WHICH (MEAN+STDEV) EQUALS 10.0         31.1 C
                  WET BULB TEMPERATURE FOR WHICH (MEAN+STDEV) EQUALS 10.0         23.1 C
```

Figure 40. Camel Design Conditions - Comfort criteria selection. This example demonstrates the principle using pre-1990s data. The CAMEL modelling in this report uses post-1990s data as its baseline climate data.

4.2 Assumptions

It is not possible to use this methodology to extract data from the 2050 weather files to calculate the CAMEL design conditions because this methodology requires multiple years of weather data. The approach that Northrop have used to determine the CAMEL Design Conditions for 2050 is as follows:

The current CAMEL design conditions were compared to the baseline IWEC[70] weather file used for building Energy simulations. For each location, the percentile corresponding to each Cooling DB, Cooling WB, and Heating DB design condition was calculated, based on the distribution of hourly dry bulb and wet bulb temperatures across the year. This same percentile was then applied to the 2050 weather data to determine the 2050 design conditions.

The results are seen in Table 4.

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[70] International Weather for Energy Calculations

Table 4. Design ambient dry bulb (DB) and wet bulb (WB) temperatures used to size HVAC plant

	Brisbane			Sydney			Melbourne		
	Cooling		Heating	Cooling		Heating	Cooling		Heating
	DB	WB	DB	DB	WB	DB	DB	WB	DB
Baseline Camel (1990-2012) °C	30.3	24.7	9.2	31.5	22.6	7.1	34.5	20.2	3.2
Percentile (%)	99.606	99.82	3.093	99.475	99.995	1.585	99.713	99.859	0.62
Design Conditions 2050 °C	32.9	26.3	12.2	35.5	25	9.6	38.9	20.5	6.5
Design temperatures difference between 2050 and baseline Camel (1990-2012) °C	**2.6**	**1.6**	**3**	**4**	**2.4**	**2.5**	**4.4**	**0.3**	**3.3**

4.3 HVAC Plant Sizing Results

4.3.1 Office (Daytime Building)

HVAC CAMEL sizing, using appropriately selected NCC 2019 glazing and wall insulation values, was completed for a standard 2 storey office building. Table 5 shows a summary of the various glazing and insulation values that were used within the CAMEL calculation.

Table 5. Glazing and insulation values used in CAMEL calculation – Office building (daytime)

		Windows		Walls	Roof	Infiltration
	Climate Zones	**U Val**	**Shade Factor[71]**	**U Val**	**U Val**	**ACH**
Brisbane	2	5.8	0.53	0.5	0.27	0.35
Sydney	5	5.8	0.53	0.5	0.27	0.35
Melbourne	6	5.8	0.53	0.5	0.31	0.35

Changes to the required capacities of mechanical units between baseline-day and 2050 remained consistent between the various climate zones. Results show that in 2050, chiller units will require an increase of approximately 13% of their capacity. Increases in chiller size (kW) ranged between 9% and 18% between climate zones. Boiler units will be able to run on approximately 20% less of their required capacity, with decreases in size (kW) ranging between 18% and 23%. Required total airflow for the office building requires a slight capacity increase of approximately 8%, with total airflow (L/s) increases between 5% and 11% in different zones.

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[71] Shade factor is defined as the ratio of the Solar Heat Gain for the actual window glass, to Solar Heat Gain for reference glass (taken as 3mm clear glass). In other words, a conversion to shade factor is to divide the window SHGC by 0.88. The window SHGC was determined using the Berkeley Lab WINDOW5 software to calculate total window thermal performance. This window SHGC was used in the energy and thermal comfort modelling (presented in Section 5).

Table 6. HVAC plant sizing outcomes – Office

	Brisbane		Sydney		Melbourne	
	Baseline	**2050**	**Baseline**	**2050**	**Baseline**	**2050**
Chiller Size (kW)	360	404	342	403	328	356
Boiler Size (kW)	154	119	183	150	244	193
Total air flow (L/s)	15,975	16,820	16,860	18,277	18,418	20,428

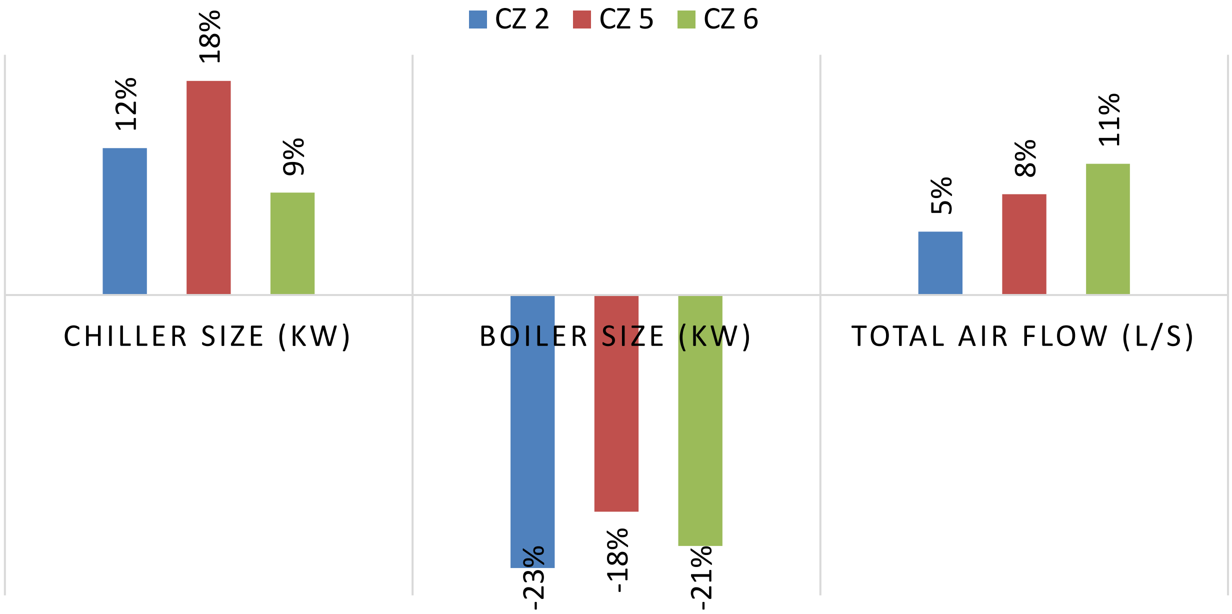

Figure 41. HVAC plant sizing - percentage change in 2050 relative to baseline climate (Office)

A further HVAC plant sizing exercise was conducted using CAMEL to determine the extent of changes required to building fabric in order to keep the HVAC plant size in a future 2050 climate as similar to the baseline HVAC plant size.

Table 7. Building fabric requirements to minimise HVAC plant size changes

		Brisbane		Sydney		Melbourne	
	Parameter	**Current**	**2050 with fabric upgrade**	**Current**	**2050 with fabric upgrade**	**Current**	**2050 with fabric upgrade**
Windows	**U Value**	5.8	3.5	5.8	2.5	5.8	5
	Glass Shade Factor	0.53	0.29	0.53	0.29	0.53	0.46
Walls	**U Val**	0.5	0.25	0.5	0.29	0.5	0.46
Roof	**U Val**	0.27	0.143	0.27	1.143	0.31	0.143
Infiltration	**ACH**	0.35	0.35	0.35	0.35	0.35	0.35
Chiller	**Chiller Size (kW)**	360	362	342	344	328	327
Boiler	**Boiler Size (kW)**	154	95.4	183	110	244	170
Airflow	**Total air flow (L/s)**	15,975	13,587	16,860	14,248	18,418	18,419

The results show that if the baseline HVAC plant size is retained for the office building in a future climate, building fabric performance needs to improve between 40% to 50% to minimise the resultant increase in cooling capacity expected due to a warmer future climate. This is illustrated in Figure 42.

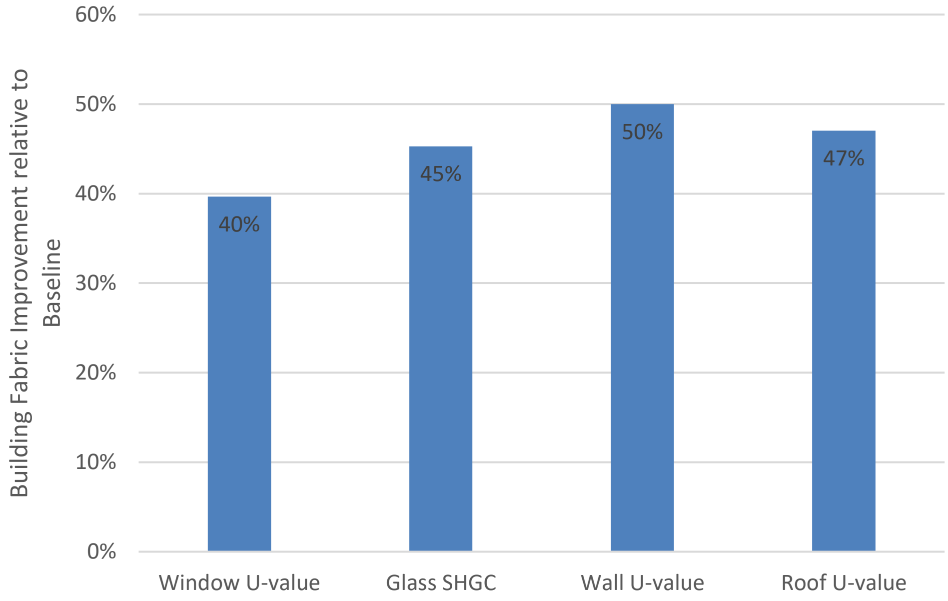

Figure 42. Building fabric improvements required to minimise cooling plant increase in a future 2050 climate - Office

4.3.2 Hotel (Overnight Building)

HVAC CAMEL sizing, using appropriately selected NCC 2019 glazing and wall insulation values, was completed for a hotel building. The hotel building selected is complete with a carpark basement, various commercial tenants on Ground Floor, 9 levels of hotel studios and an office space complete with conference rooms on the top floor. Table 8 shows a summary of the various glazing and insulation values that were used within the CAMEL calculation.

Table 8. Glazing and insulation values used in CAMEL calculation

		Windows		Walls	Roof	Infiltration
	Climate Zones	**U Val**	**Shade Factor**[72]	**U Val**	**U Val**	**ACH**
Brisbane	2	6.75	0.32	0.4	0.27	0.35
Sydney	5	6.75	0.32	0.4	0.27	0.35
Melbourne	6	3.29	0.23	0.36	0.31	0.35

Changes to the required capacities of mechanical units between current-day and 2050 remained consistent between the various climate zones. Results show that in 2050, chiller units will require an increase of approximately 20% of their capacity. Increases in chiller size (kW) ranged between 12% and 24% between climate zones. Boiler units will be able to run on approximately 20% less of their required capacity, with

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[72] Shade factor is defined as the ratio of the Solar Heat Gain for the actual window glass, to Solar Heat Gain for reference glass (taken as 3mm clear glass). In other words, a conversion to shade factor is to divide the window SHGC by 0.88. The window SHGC was determined using the Berkeley Lab WINDOW5 software to calculate total window thermal performance. This window SHGC was used in the energy and thermal comfort modelling (presented in Section 5).

decreases in size (kW) ranging between 18% and 25%. Required total airflow for the hotel building requires a slight capacity increase of approximately 8%, with total airflow (L/s) increases between 5% and 10% in different zones.

Table 9. HVAC plant sizing outcomes – Hotel

	Brisbane		Sydney		Melbourne	
	Current	**2050**	**Current**	**2050**	**Current**	**2050**
Chiller Size (kW)	692	795	616	764	480	536
Boiler Size (kW)	269	201	318	260	327	265
Total air flow (L/s)	26,765	29,013	30,354	33,464	30,544	32,135

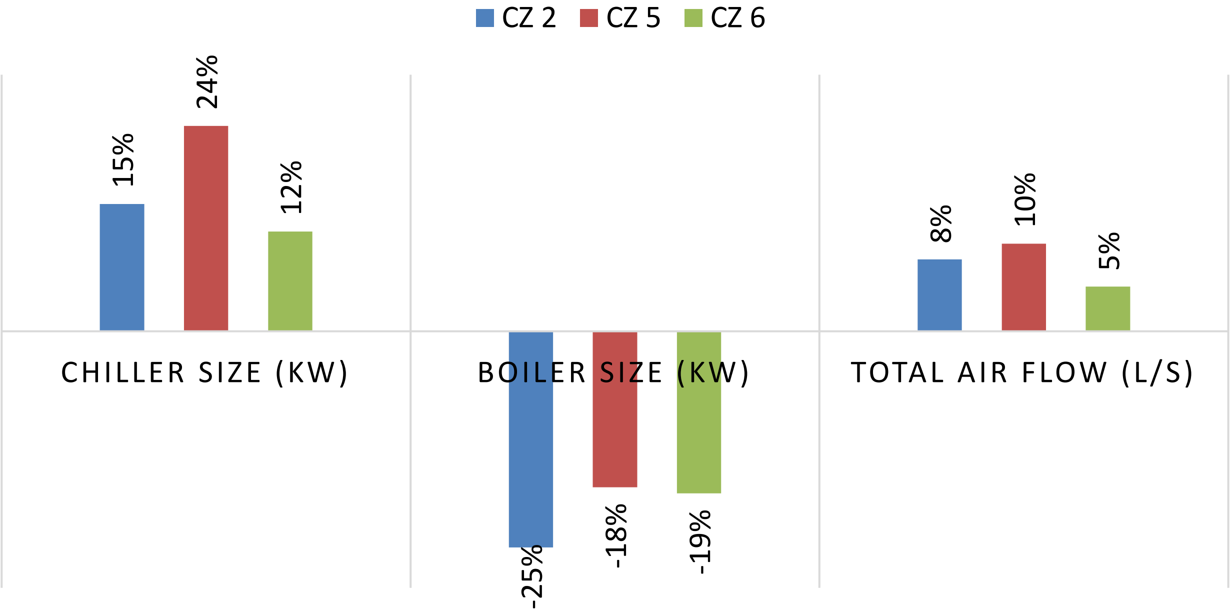

Figure 43. HVAC plant sizing - percentage change in 2050 relative to current climate (Hotel)

A further HVAC plant sizing exercise was conducted using CAMEL to determine the extent of changes required to building fabric in order to keep the HVAC plant size in a future 2050 climate as similar to the baseline HVAC plant size.

Table 10. Building fabric requirements to minimise HVAC plant size changes

		Brisbane		Sydney		Melbourne	
	Parameter	**Current**	**2050 with fabric upgrade**	**Current**	**2050 with fabric upgrade**	**Current**	**2050 with fabric upgrade**
Windows	**U Value**	6.75	1.8	6.75	1.8	6.75	1.8
	Glass Shade Factor	0.32	0.23	0.32	0.23	0.32	0.23
Walls	**U Val**	0.4	0.25	0.4	0.25	0.4	0.25
Roof	**U Val**	0.27	0.143	0.27	0.143	0.27	0.143
Infiltration	**ACH**	0.35	0.35	0.35	0.35	0.35	0.35
Chiller	**Chiller Size (kW)**	692	714	616	665	480	501
Boiler	**Boiler Size (kW)**	269	139	318	180	327	228
Airflow	**Total air flow (L/s)**	26,765	22,532	30,354	25,947	30,544	29,880

The results show that if the baseline HVAC plant size is retained for the hotel building in a future climate, building fabric performance needs to improve between 30% to 73% to minimise the resultant increase in cooling capacity expected due to a warmer future climate. This is illustrated in Figure 44.

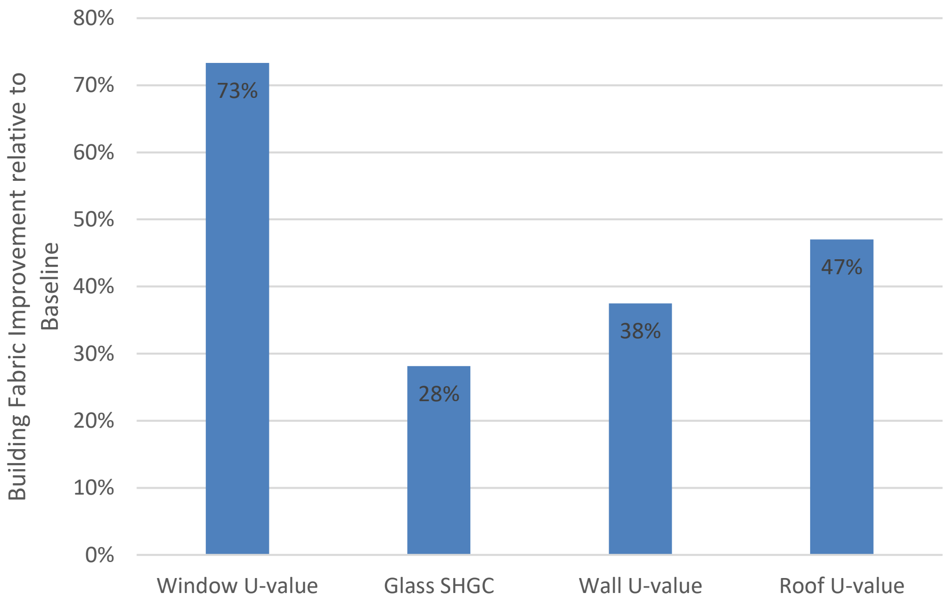

Figure 44. Building fabric improvements required to minimise cooling plant increase in a future 2050 climate - Hotel

4.4 Energy Consumption and Thermal Comfort

For climate zone 2,5 and 7 respectively, seven simulation models per building type was run. The description for each run is shown below. The office building fabric performance and HVAC size are based on CAMEL inputs/outputs in Table 5 and Table 6 above. Hotel building fabric performance and HVAC size are based on CAMEL inputs/outputs shown in Table 8 and Table 9 above.

Run	Climate File	Fabric	HVAC sizing (climate file)
1 (NCC2019 Reference Building)	Baseline	2019 DTS Fabric	Baseline
2 (2050 Future Reference Building)	Future	2019 DTS Fabric	Future
3	Future	2019 DTS Fabric	Baseline
4	Future	2019 DTS Fabric but increase glazing U-value (20%)	Future
5	Baseline	2019 DTS Fabric but increase glazing U-value (20%)	Baseline
6	Future	2019 DTS Fabric but increase glazing SHGC (20%)	Future
7	Baseline	2019 DTS Fabric but increase glazing SHGC (20%)	Baseline

The energy models were used as follows:

Purpose	Comparison
Quantify the impact of changing climate on building energy consumption and occupant thermal comfort.	Run 1 (NCC2019Reference Building) vs. Run 3
Quantify the relative impact on energy and thermal comfort if the designer sacrifices building fabric performance for cost optimisation in the form of thermal transmittance (glazing system U-value) and if it still satisfies JV3 requirements. Quantify if this design cost optimisation decision changes for different climate files.	Run 2 (Future Reference Building) vs. Run 4 Run1 (NCC2019 Reference Building) vs. Run 5
Quantify the relative impact on energy and thermal comfort if the designer sacrifices building fabric for cost optimisation in the form of thermal transmittance (glazing system SHGC) and if it still satisfies JV3 requirements. Quantify if this design cost optimisation decision changes for different climate files.	Run 2 (Future Reference Building) vs. Run 6 Run1 (NCC2019 Reference Building) vs. Run 7
Quantify the relative impact on energy and thermal comfort if the designer sacrifices building fabric for cost optimisation against HVAC efficiency performance to meet JV3 requirements. Quantify if this design cost optimisation decision changes for different climate files.	Run 2 (Future Reference Building) vs. Run 4 Run 2 (Future Reference Building) vs. Run 6 Run1 (NCC2019 Reference Building) vs. Run 5 Run1 (NCC2019 Reference Building) vs. Run 7

4.4.1 Office

The energy and thermal comfort modelling results for the daytime operation (office) building are presented in Table 11, Table 12 and Table 13. Key insights from the results are discussed in Section 5 of this report.

The following tables summarise the details of the run including the weather file and HVAC data used, DTS façade inputs derived from Section J and façade calculators and outputs. The outputs include the internal electrical loads of equipment and lighting, and the HVAC loads for fans, pumps, chillers and boilers (both gas and parasitic electrical loads) as well as a simplified thermal comfort output. Model assumptions and methodology is discussed Appendix A.III.

Note that the thermal comfort values are simplified single value representations of each zone. The *Thermal Comfort Average PMV* value was calculated for each zone by averaging the PMV for each occupied hour over the entire year (compliance level is 98%). These zoned annual averages for each zone are then averaged for all zones to generate a building average value. The *Thermal Comfort Area % Compliant* is the number, represented as a percentage, of zones which comply with the thermal comfort requirements (compliance level is 95%). Compliance for a zone is when the thermal comfort is between -1 ≤ PMV ≤ 1, 98% of the occupied time. Compliance for the building is when 95% of the total floor area complies with this requirement. The results show that none of the scenarios modelled meet the Section J Verification Method thermal comfort requirements, including the baseline Reference Building (Run 1) with the exception of Climate Zone 6 office Run 1. This is a significant finding as it means that adhering to Deemed-to-Satisfy provisions does not guarantee that thermal comfort conditions will be met.

Table 11. Climate Zone 2 Office Energy and Thermal Modelling Results (annual lighting and equipment energy do not vary and are not presented in this table)

Run	Weather File	HVAC	Glazing (Uw/ SHGC)	Ext Walls System R-Value	Roof System R-Value	Floor System R-Value	Heating (Elec) (kWh pa)[73]	Heating (Gas) kWh pa)	Cooling (kWh pa)	Lighting Internal (kWh pa)	Lighting External (kWh pa)	Equipment (kWh pa)	Fans (kWh pa)	Pumps (kWh pa)	Total (kWh pa)	Total tCO2 pa	Thermal Comfort Avg PMV	Thermal Comfort Area % Compliant
1	Baseline	Baseline	5.8/0.46	R2.0	R3.7	R2.0	0.07	392	127,948	150,922	15,806	169,075	21,339	35,167	**520,650**	-	92%	0%
2	Future	Future	5.8/0.46	R2.0	R3.7	R2.0	0.01	63	164,911	150,922	15,806	169,075	22,713	41,967	**565,457**	109%	48%	0%
3	Future	Baseline	5.8/0.46	R2.0	R3.7	R2.0	0.22	1,303	95,891	150,922	15,806	169,075	20,248	32,680	**485,925**	93%	73%	0%
4	Future	Future	7.0/0.46	R2.0	R3.7	R2.0	0.10	453	131,378	150,922	15,806	169,075	21,647	38,816	**528,098**	101%	61%	0%
5	Baseline	Baseline	7.0/0.46	R2.0	R3.7	R2.0	0.07	399	127,853	150,922	15,806	169,075	21,344	35,153	**520,552**	100%	92%	0%
6	Future	Future	5.8/0.55	R2.0	R3.7	R2.0	0.01	43	171,120	150,922	15,806	169,075	24,164	42,364	**573,495**	110%	43%	0%
7	Basline	Baseline	5.8/0.55	R2.0	R3.7	R2.0	0.05	306	134,421	150,922	15,806	169,075	22,764	35,619	**528,913**	102%	89%	0%

Table 12. Climate Zone 5 Office Energy and Thermal Modelling Results

Run	Weather File	HVAC	Glazing (Uw/ SHGC)	Ext Walls System R-Value	Roof System R-Value	Floor System R-Value	Heating (Elec) (kWh pa)	Heating (Gas) kWh pa)	Cooling (kWh pa)	Lighting Internal (kWh pa)	Lighting External (kWh pa)	Equipment (kWh pa)	Fans (kWh pa)	Pumps (kWh pa)	Total (kWh pa)	Total tCO2 pa	Thermal Comfort Avg PMV	Thermal Comfort Area % Compliant
1	Baseline	Baseline	5.8/0.46	R2.0	R3.7	R2.0	0.24	1,659	94,038	150,922	15,824	169,075	20,264	30,415	**482,198**	-	96%	39%
2	Future	Future	5.8/0.46	R2.0	R3.7	R2.0	0.09	495	133,541	150,922	15,824	169,075	22,097	38,464	**530,419**	110%	63%	0%
3	Future	Baseline	5.8/0.46	R2.0	R3.7	R2.0	0.06	444	127,973	150,922	15,824	169,075	22,003	33,209	**519,449**	108%	62%	0%
4	Future	Future	7.0/0.46	R2.0	R3.7	R2.0	0.09	498	133,494	150,922	15,824	169,075	22,104	38,455	**530,372**	110%	63%	0%
5	Baseline	Baseline	7.0/0.46	R2.0	R3.7	R2.0	0.24	1,687	93,938	150,922	15,824	169,075	20,267	30,403	**482,117**	100%	96%	39%
6	Future	Future	5.8/0.55	R2.0	R3.7	R2.0	0.07	405	139,578	150,922	15,824	169,075	23,139	39,030	**537,973**	112%	59%	0%
7	Baseline	Baseline	5.8/0.55	R2.0	R3.7	R2.0	0.20	1,352	99,821	150,922	15,824	169,075	21,188	30,821	**489,003**	101%	95%	17%

Table 13. Climate Zone 6 Office Energy and Thermal Modelling Results

Run	Weather File	HVAC	Glazing (Uw/ SHGC)	Ext Walls System R-Value	Roof System R-Value	Floor System R-Value	Heating (Elec) (kWh pa)	Heating (Gas) kWh pa)	Cooling (kWh pa)	Lighting Internal (kWh pa)	Lighting External (kWh pa)	Equipment (kWh pa)	Fans (kWh pa)	Pumps (kWh pa)	Total (kWh pa)	Total tCO2 pa	Thermal Comfort Avg PMV	Thermal Comfort Area % Compliant
1	Baseline	Baseline	5.8/0.46	R2.0	R3.2	R2.0	1.64	15,174	55,800	150,922	15,821	169,075	19,178	27,026	**452,997**	-	99%	97%
2	Future	Future	5.8/0.46	R2.0	R3.2	R2.0	0.25	1,841	99,847	150,922	15,821	169,075	21,519	32,416	**491,443**	108%	72%	0%
3	Future	Baseline	5.8/0.46	R2.0	R3.2	R2.0	0.17	1,608	96,113	150,922	15,821	169,075	20,440	29,717	**483,698**	107%	72%	0%
4	Future	Future	7.0/0.46	R2.0	R3.2	R2.0	0.26	1,892	99,779	150,922	15,821	169,075	21,521	32,409	**491,419**	108%	72%	0%
5	Baseline	Baseline	7.0/0.46	R2.0	R3.2	R2.0	1.68	15,554	55,688	150,922	15,821	169,075	19,176	27,020	**453,257**	100%	99%	97%
6	Future	Future	5.8/0.55	R2.0	R3.2	R2.0	0.20	1,472	105,891	150,922	15,821	169,075	22,134	32,795	**498,110**	110%	68%	0%
7	Baseline	Baseline	5.8/0.55	R2.0	R3.2	R2.0	1.42	13,155	60,728	150,922	15,821	169,075	19,747	27,332	**456,781**	101%	98%	92%

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[73] Boiler burner fan electrical energy.

4.4.2 Hotels

The energy and thermal comfort modelling results for the overnight operation (hotel) building are presented in Table 14, Table 15 and Table 16. Key insights from the results are discussed in Section 5 of this report. Note the U-values shown in Table 8 (CAMEL results) for climate zones 2 and 5 were decreased from 6.75 to 5.83 due to the need to accommodate a 20% increase in U-value in Runs 4 and 5. Applying a 20% increase to 6.75 results in a U-value of 8.1, which is cannot be input in the modelling software, due to an upper limit on input value at 7.0. Model assumptions and methodology is discussed Appendix A.III.

Note that the thermal comfort values are simplified single value representations of each zone. The *Thermal Comfort Average PMV* value was calculated for each zone by averaging the PMV for each occupied hour over the entire year. These zoned annual averages for each zone are then averaged for all zones to generate a building average value. The *Thermal Comfort Area % Compliant* is the number, represented as a percentage, of zones which comply with the thermal comfort requirements. Compliance for a zone is when 98% of the occupied time the thermal comfort is between -1 ≤ PMV ≤ 1. Compliance for the building is when 95% of the total floor area complies with this requirement. The results show that none of the scenarios modelled meet the Section J Verification Method thermal comfort requirements, including the baseline Reference Building (Run 1). This is a significant finding as it means that adhering to Deemed-to-Satisfy provisions does not guarantee that thermal comfort conditions will be met.

Table 14. Climate Zone 2 Hotel Energy and Thermal Modelling Results

Run	Weather File	HVAC	Glazing (Uw/ SHGC)	Ext Walls System R-Value	Roof System R-Value	Floor System R-Value	Heating (Elec) (kWh pa)	Heating (Gas) kWh pa)	Cooling (kWh pa)	Lighting (Internal) (kWh pa)	Equipment (kWh pa)	Fans (kWh pa)	Pumps (kWh pa)	Total (kWh pa)	Total tCO2 pa	Thermal Comfort Avg PMV	Thermal Comfort Area % Compliant
1	Baseline	Baseline	5.83/0.28	R2.49	R3.7	R2.0	16	162,734	76,700	96,863	88,972	47,815	19,940	**493,040**	335	98%	81%
2	Future	Future	5.83/0.28	R2.49	R3.7	R2.0	8	60,347	162,544	96,863	88,972	51,759	44,454	**504,947**	421	88%	0%
3	Future	Baseline	5.83/0.28	R2.49	R3.7	R2.0	6	60,728	163,115	96,863	88,972	47,815	41,122	**498,622**	415	87%	0%
4	Future	Future	7.0/0.28	R2.49	R3.7	R2.0	8	60,427	162,728	96,863	88,972	51,759	44,465	**505,223**	421	88%	0%
5	Baseline	Baseline	7.0/0.28	R2.49	R3.7	R2.0	16	162,912	76,700	96,863	88,972	47,815	19,921	**493,200**	335	98%	81%
6	Future	Future	5.83/0.34	R2.49	R3.7	R2.0	7	56,455	179,496	96,863	88,972	51,759	45,759	**519,312**	437	89%	0%
7	Baseline	Baseline	5.83/0.34	R2.49	R3.7	R2.0	15	155,481	84,971	96,863	88,972	47,815	20,693	**494,810**	342	98%	80%

Table 15. Climate Zone 5 Hotel Energy and Thermal Modelling Results

Run	Weather File	HVAC	Glazing (Uw/ SHGC)	Ext Walls System R-Value	Roof System R-Value	Floor System R-Value	Heating (Elec) (kWh pa)	Heating (Gas) kWh pa)	Cooling (kWh pa)	Lighting (Internal) (kWh pa)	Equipment (kWh pa)	Fans (kWh pa)	Pumps (kWh pa)	Total (kWh pa)	Total tCO2 pa	Thermal Comfort Avg PMV	Thermal Comfort Area % Compliant
1	Baseline	Baseline	5.83/0.28	R2.49	R3.7	R2.0	22	268,179	34,253	96,077	88,054	54,224	8,287	**549,096**	309	99%	91%
2	Future	Future	5.83/0.28	R2.49	R3.7	R2.0	12	121,171	103,079	96,077	88,054	59,677	26,015	**494,325**	366	97%	73%
3	Future	Baseline	5.83/0.28	R2.49	R3.7	R2.0	10	122,441	103,573	96,077	88,054	54,224	22,983	**487,362**	359	97%	65%
4	Future	Future	7.0/0.28	R2.49	R3.7	R2.0	12	121,320	103,161	96,077	88,054	59,677	25,986	**494,505**	366	97%	73%
5	Baseline	Baseline	7.0/0.28	R2.49	R3.7	R2.0	22	268,460	34,245	96,077	88,054	54,224	8,279	**549,361**	309	99%	91%
6	Future	Future	5.83/0.34	R2.49	R3.7	R2.0	12	115,565	112,483	96,077	88,054	59,677	26,356	**497,780**	374	97%	80%
7	Baseline	Baseline	5.83/0.34	R2.49	R3.7	R2.0	21	258,884	38,456	96,077	88,054	54,224	8,681	**544,397**	311	99%	90%

Table 16. Climate Zone 6 Hotel Energy and Thermal Modelling Results

Run	Weather File	HVAC	Glazing (Uw/ SHGC)	Ext Walls System R-Value	Roof System R-Value	Floor System R-Value	Heating (Elec) (kWh pa)	Heating (Gas) kWh pa)	Cooling (kWh pa)	Lighting (Internal) (kWh pa)	Equipment (kWh pa)	Fans (kWh pa)	Pumps (kWh pa)	Total (kWh pa)	Total tCO2 pa	Thermal Comfort Avg PMV	Thermal Comfort Area % Compliant
1	Baseline	Baseline	3.29/0.2	R2.78	R3.2	R2.0	45	562,617	6,532	96,077	88,054	54,593	4,122	**812,039**	394	99%	88%
2	Future	Future	3.29/0.2	R2.78	R3.2	R2.0	55	564,958	6,681	96,077	88,054	57,114	4,404	**817,342**	398	99%	88%
3	Future	Baseline	3.29/0.2	R2.78	R3.2	R2.0	4	53,988	53,288	96,077	88,054	54,593	20,112	**366,117**	373	53%	0%
4	Future	Future	3.95/0.2	R2.78	R3.2	R2.0	57	590,306	6,595	96,077	88,054	57,114	4,439	**842,643**	403	99%	88%
5	Baseline	Baseline	3.95/0.2	R2.78	R3.2	R2.0	47	587,634	6,478	96,077	88,054	54,593	4,172	**837,055**	399	99%	88%
6	Future	Future	3.29/0.24	R2.78	R3.2	R2.0	54	551,237	7,220	96,077	88,054	57,114	4,549	**804,304**	397	99%	88%
7	Baseline	Baseline	3.29/0.24	R2.78	R3.2	R2.0	44	548,999	7,092	96,077	88,054	54,593	4,256	**799,115**	393	99%	88%

5 Discussion

5.1 The Problem Statement

Key Findings:

1. **Current building modelling and HVAC plant sizing practices are not conducive to climate change adaptation. This is because there is no requirement for climate files to consider future climate change, or micro-climate changes such as the urban heat island effect. There is no central depository for Australian future climate files or customised climate files for urban settings.**
2. **Baseline climate files are unsuitable to assess the impacts of climate change on building energy and thermal comfort. The increase in cooling degree days and decrease in heating degree days in the future almost eliminates heating energy consumption and almost doubles cooling energy consumption in a daytime-operation building. The impact of future climate on an overnight operation building is not as substantial. The net impact on whole building energy consumption is around a 10% increase in a daytime building, but around 5% decrease in an overnight building (except climate zone 2).**
3. **Baseline climate files are not suitable for sizing HVAC plant. The use of load estimation software for HVAC plant sizing is not currently regulated, and HVAC plant sizing are conducted using software in-built weather data. The use of HVAC plant sized for baseline climate files from 1990 - 2012 decreases thermal comfort by more than 10% when modelled using future climate files. While designer-added safety factors and client redundancy requirements (N+1 or PCA office quality grade) may alleviate risks of inadequate central thermal plant, there is no redundancy for air handling plant cooling coils. As such, thermal comfort deteriorates or building pump/fan energy increases.**
4. **Updating climate files and mandating their usage through building regulation is the best method to address the problems identified above. As updating climate files will only address buildings seeking to comply under a performance-based approach, the building code should also update its prescriptive-based approach compliance pathway (DTS provisions). DTS provision updates should prioritise stringency improvements to the building fabric, control of air infiltration and cooling equipment efficiency. Future updates to DTS stringency provisions should consider occupant comfort alongside cost-effectiveness.**
5. **The impact of changing greenhouse gas coefficients on design decisions should be assessed. While our analysis shows that the design decision to trade off performance of certain building elements remains unchanged across different climate files, this may not hold true when different greenhouse gas emissions factors are applied. A lower emissions factor for electricity may make it easier to trade off design elements, yet still comply with Code.**

5.1.1 Baseline climate files used for building simulation are unsuitable to address future climate risk

Climate files based on weather data as old as the 1980s[74] are still being used in buildings designed in 2020 and expected to have a lifetime up to 2080. Our climate files analysis in Section 1 shows that future cooling degree days (CDD) may double and heating degree days (HDD) may halve. Figure 45 and Figure 46 show results from the (indirect) emissions end use breakdown and annual energy consumption for HVAC equipment in an office and hotel building. The results show that when future climate files are used to size HVAC equipment and conduct energy modelling, energy consumption for different sub-systems varies substantially, although counteracting effects mean that the net impact on building total energy consumption is more moderate.

From an emissions perspective, the fuel switch from gas-fired heating plant to electric cooling plant leads to a higher net impact on building total emissions footprint, although this analysis assumes that the same grid electricity emissions factor will apply in 2050. When electricity grid decarbonisation with injection of renewable energy generation is used, the emissions impact in a future climate may not be as apparent.

As such, baseline climate files are unsuitable for addressing future climate risk[75]. Similar views were expressed by Cladingboel, R from IES at the November 2017 AIRAH Australasian Building Simulation Conference[76], whose research found energy use intensity increased for a range of commercial buildings across different American climate zones. Cladingboel concluded that building designers should account for climate change in energy simulation (and by extension) the design process and actual building performance.

Supporting data for Figure 45 and Figure 46 are provided in Table 17 of Appendix B.

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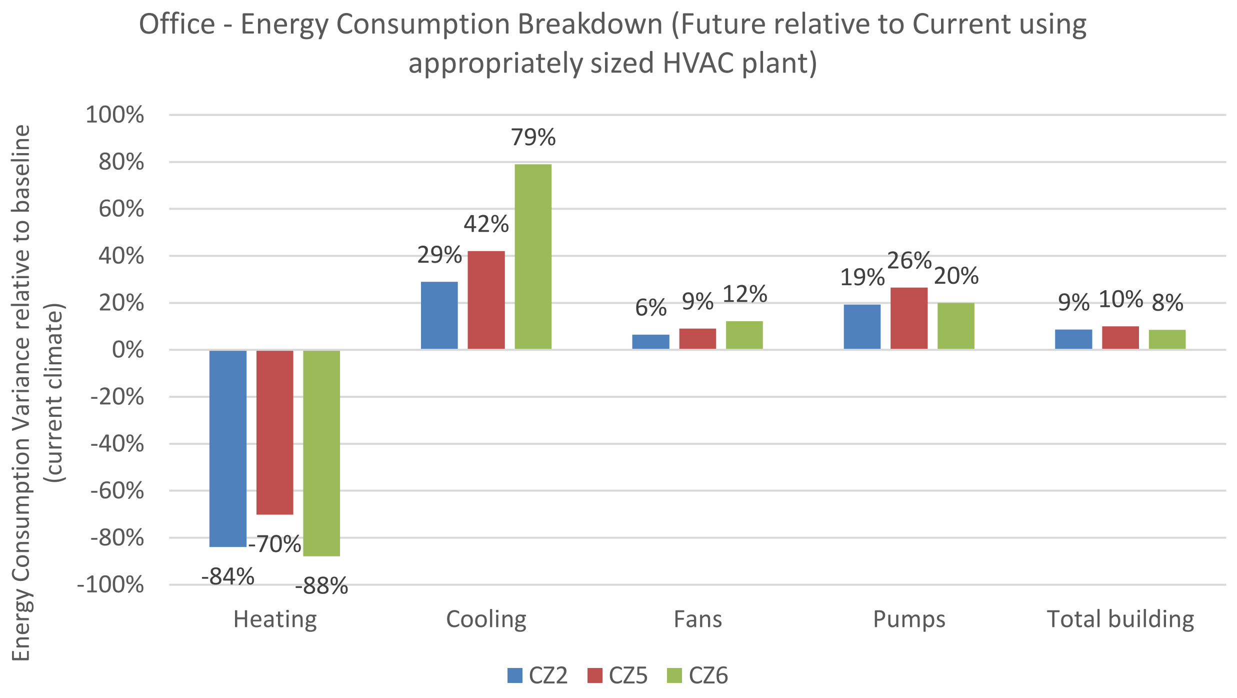
[74] The baseline climate files used in this report as a baseline are IWEC files which is based on 1982-1999 weather data. This is still actively being used in industry despite more recent files being available.

[75] Consider, for instance, the impact that the change in cooling load would have on chiller selection.

[76] https://www.airah.org.au/Content_Files/Conferences/2017/Building-simulation/Presentations/ABSC2017_RogerCladingboel.pdf


Office - Energy Consumption Breakdown (Future relative to Current using appropriately sized HVAC plant)

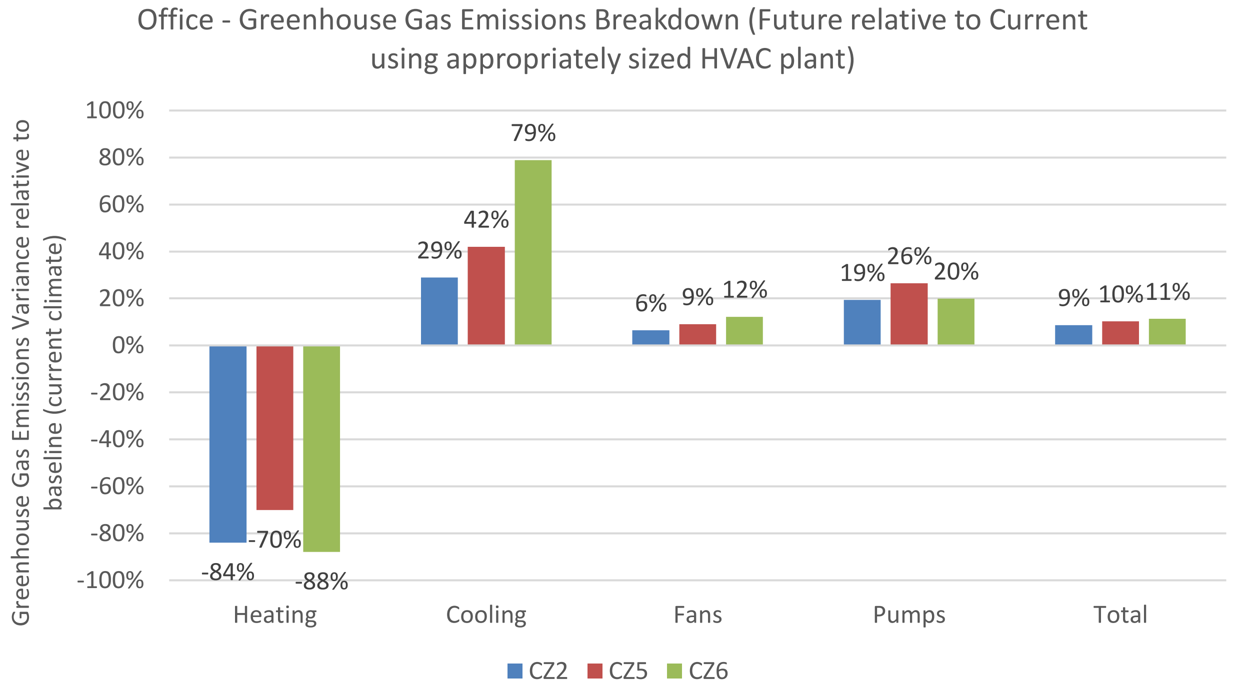

Office - Greenhouse Gas Emissions Breakdown (Future relative to Current using appropriately sized HVAC plant)

Figure 45. Annual energy consumption (top) and greenhouse gas emissions (bottom)in 2050 (highest emissions scenario) relative to baseline using climate-appropriate HVAC plant – daytime building (office).

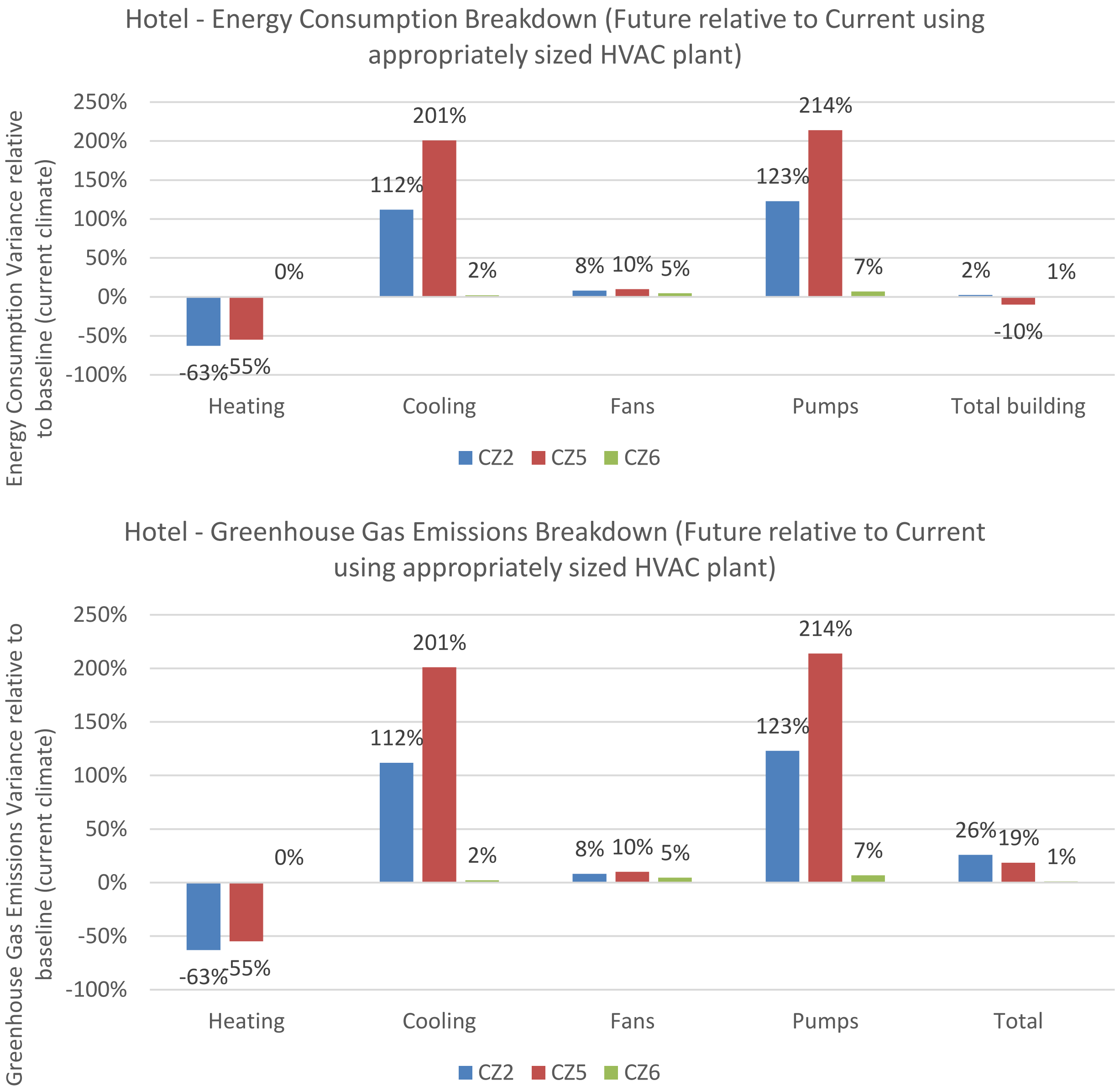


Figure 46. Annual energy consumption (top) and greenhouse gas emissions (bottom)in 2050 (highest emissions scenario) relative to baseline using climate-appropriate HVAC plant – overnight building (hotel).

5.1.2 Baseline climate files used to size HVAC plant are unsuitable to address future climate risk

Climate files used to size air-conditioning plant are not suitable for the potential impacts of a changing climate. It is important to note that climate files used for HVAC plant sizing are not always identical to the climate files used for energy and thermal modelling. The climate file in-built into heat estimation software is often used. In this study the CAMEL in-built weather file covers a period of 1990-2012.

If sized using baseline climate data, cooling equipment would be undersized and heating equipment oversized for future climate. This assertion is based on results from HVAC equipment sized using baseline and future climate files discussed in Section 4.3. In a daytime operation office building, cooling design capacity increases between 8-15% and heating design capacity decreases between 18%-23%. Similar results are found for an overnight operation hotel building, cooling design capacity increases 12-24%, heating design capacity decreases between 18% - 25%. Airflow design capacity increases by 5% to 10%.

However, current industry practice is for mechanical design engineers to include a safety factor ranging between 5% and 30%, to ensure that the HVAC equipment will always be able to handle the building load. The HVAC plant sized using CAMEL in this study had a 5% safety factor for cooling capacity and 20% safety factor for heating capacity. Additionally, some developments have customer-driven central plant redundancy requirements (either PCA Office Quality requirements or N+1 requirements). This means that in some cases, central thermal HVAC equipment sized using baseline climate files inclusive of the safety allowance may be able to handle the increased cooling load introduced by climate change at the central thermal plant level (chillers and boilers). Redundancy and safety factors are not always applied consistently to cooling coils installed at the air handling unit or to air distribution components - the cooling coils and airflow may still be inadequate for adapting to climate change.

The impact of this safety factor design practice appears to be more clearly illustrated in an overnight building as opposed to a daytime operation building. When HVAC equipment is sized using baseline climate files but energy and thermal comfort is modelled in a future climate scenario, Figure 47 shows that thermal comfort is adversely impacted across all climate zones in a daytime only building, but deteriorates ~10% or less in an overnight building in a warm humid (climate zone 2) to warm temperate (climate zone 5) climate. This is not the case for a cool temperate climate like climate zone 6, which sees a severe decrease (almost half) in thermal comfort despite great reductions in building energy consumption.

Supporting data for Figure 47 is provided in Table 18 of Appendix B.

Figure 47. Impact of retaining HVAC plant sized using baseline climate files in a 2050 climate scenario. Daytime building (top) versus overnight building (bottom).

5.1.3 Baseline climate files and modelling do not account for urban heat island effects

In accordance with Section J Specification JVb(3)(iv) and NABERS and Green Star building simulation guidelines, adjacent structures and features (e.g. greenery) are modelled. However, these structures or features are merely assessed for shading impacts. Urban heat island effects are not accounted for. It is not within the remit of the building modelling to assess the building's impact on its surroundings; however, the converse would be possible – in that the surroundings can be considered in building modelling.

The impacts of urban heat island effects on building energy and thermal comfort were not quantified in this body of modelling work. The 2012 City of Melbourne report[77] estimates the UHI effect produces a 0.137 GWh increase in summer electricity demand and 22.0 MVA peak demand increase per °C increase; and 0.17 GWh reduction in winter electricity demand. Published overseas research (discussed in Section 3.4) suggests that the impacts of urban heat island effect on building energy consumption is not substantial, though it may influence design decisions for insulation levels at the extremities of the building (e.g. roof insulation) or roof solar absorptance levels (e.g. light-coloured roof), though those conclusions from overseas may not be applicable within the Australian context.

From a building modelling perspective, the urban heat island effect can be accounted for in two ways:

- One, for the modeller to calculate airflow model impacts using computation fluid dynamic (CFD) and wind tunnel modelling;
- Two, for the modeller to use climate files that have already been corrected for urban heat island effects using weather station or climate data adjustment techniques (discussed in Section 3.4).

The first option is complex and difficult[78], and the learning curve for a typical skilled building simulator would be very steep. Furthermore, it would be very arduous to validate such calculations have been undertaken correctly for each building modelled. This would not be a preferred option as it would preclude a large part of the building simulator workforce from conducting this work in the future without additional investment in professional education. Accurate building data in the area would also be hard to achieve, resulting in large assumptions (most likely pulled from Google Earth for geometry, height etc.)

The second option is very accessible to the building simulator, as it would only involve the use of a climate file that is adjusted for urban heat island effects. This would be a preferred option but would require 'urban' climate files to be developed for direct application by the building simulator. This would be similar to the climate files offered by CIBSE UK (discussed in Section 3.1.2 above).

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[77] https://www.melbourne.vic.gov.au/SiteCollectionDocuments/eco-assessment-of-urban-heat-island-effect.pdf

[78] To do this calculation at local building level, surrounding buildings' make up and data would need to be input or at least assumed, making this highly unpractical for simple assessments such as JV3.

5.2 Do different climate files impact the required building design features?

Key Findings:

1. **Using different climate files within the context of the building code is unlikely to alter design decisions to trade-off building fabric design features.**
2. **As the use of performance Verification Methods to trade-off of HVAC equipment efficiency performance is rare, the use of different climate files is unlikely to alter design decisions to trade-off HVAC equipment design features. If such a situation does eventuate, the use of a future climate file will make it more difficult for a designer to trade-off cooling plant efficiency, and easier to trade-off heating plant efficiency.**
3. **A higher capacity cooling plant is required to ensure regulated thermal comfort conditions are achieved if a future climate file is used for the Verification Methods. While an appropriately sized HVAC plant is important for building resilience and adaptability, this should be accompanied by increased stringency in DTS requirements for HVAC equipment in Part J5, particularly cooling plant and space heaters with better part-load performance (these are generally condensing boilers or electric heat pumps).**

Building modelling is currently a building code requirement in Section J when:

- a certain building feature will not meet deem-to-satisfy (DTS) provisions due to inferior performance or due to design features varying from the norm. It is most commonly used by designers to trade off glazing performance to manage build cost, noting that the building code prevents the designer from using more efficient building services to compensate for the reduction in building fabric thermal performance (except for JV1 which does not use a reference building in the model). It is very rare for designers to use this method to trade off building services performance, largely because the DTS requirements for building services are already cost-effective measures widely adopted in industry[79]. In this case, Verification Method JV3 is used.
- the building is already subject to best practice and committed to a NABERS rating or Green Star Design and As-Built rating. Normally, these buildings are already market leading or designed at a level above building code minimum requirements. The building code allows modelling conducted as part of the NABERS Commitment Agreement and Green Star Design and As-Built rating process to be used for building code compliance. In this case, Verification Methods JV1 or JV2 are used.

In order to comply with the building code, the trade-off in performance (usually a result of construction cost optimisation) must not increase the greenhouse gas emissions of the proposed building relative to the reference building (fully DTS-compliant) and must not breach the minimum thermal comfort levels specified.

The question of whether design decisions concerning building fabric performance change with different climate files was tested by modelling a DTS-compliant reference building and comparing it to a proposed building with poorer building envelope performance. The two proposed buildings either worsen glazing thermal transmittance performance by increasing U-value or solar admittance level by increasing window

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[79] We note that the stringency increase with NCC 2019 Section J requirements may change this.

SHGC from compliant levels by 20%. The ability of the designer to trade-off building energy efficient features in the context of glazing performance was tested separately using current and future climate files. If the relative difference in emissions or thermal comfort is substantially different (e.g. >10%) between the use of a current and future climate file, then we would consider that the design trade-off decision will likely change. However, if the relative difference in emissions or thermal comfort is very small, then we conclude that the design trade-off decision is unlikely to change due to the use of a different climate file.

All values shown in figures in this section are relative values with the DTS-compliant reference building as baseline. For example, a -5% in annual energy consumption means that the proposed building consumes 5% less energy a year compared to the DTS-compliant reference building.

5.2.1 Reducing Performance of Glazing U-Value for Cost Optimisation

Building façade thermal transmittance (U-value) is a building envelope requirement. It is affected by the window U-value, opaque wall thermal resistance values, window-to-wall ratios and, where spandrel panels are used, spandrel panel construction thermal transmittance values. In this case, design decision changes to wall-glazing thermal transmittance has been tested by changing the glazing U-value performance while keeping other variables impacting solar admittance constant.

Figure 48 to Figure 50 show the relative changes to building annual energy consumption, annual greenhouse gas emissions and occupant thermal comfort represented by predicted mean vote (PMV) for climate zones 2, 5 and 6 respectively. A negative value for energy consumption or emissions in the figures mean that the proposed building has produces less emissions and energy consumption compared to the DTS-compliant reference building. A negative value for thermal comfort in the figures means that the proposed building has lower thermal comfort levels than the DTS-compliant reference building. Supporting data for these figures is provided in Table 17 and Table 18.

These are presented for both a daytime (office) and overnight (hotel) building. Building annual energy consumption is shown for interest, but is not a variable considered in the Verification Methods in the 2019 building code Section J.

If the relative difference in emissions or thermal comfort is substantially different (e.g. >10%) between the use of a current and future climate file, then we would consider that the design trade-off decision will likely change. However, if the relative difference in emissions or thermal comfort is very small, then we conclude that the design trade-off decision is unlikely to change due to the use of a different climate file. Insights from the results are as follows:

- In climate zone 2 (Figure 48), the probability of a decision to trade off glazing U-value increases when a future climate file is used. In a daytime building, occupant thermal comfort increases while building emissions decrease. In an overnight building, the GHG emissions and thermal comfort remain relatively unchanged (<0.1%), though occupant thermal comfort improves when using a future climate file instead of a current climate file. Nonetheless, the designer would still likely have made the same decision using a baseline climate file, as neither the proposed daytime or overnight buildings would have been compliant under the current building code thermal comfort requirements (which requires thermal comfort to be achieved in >95% of area >98% of the time).
  Outcome: No change to design decision

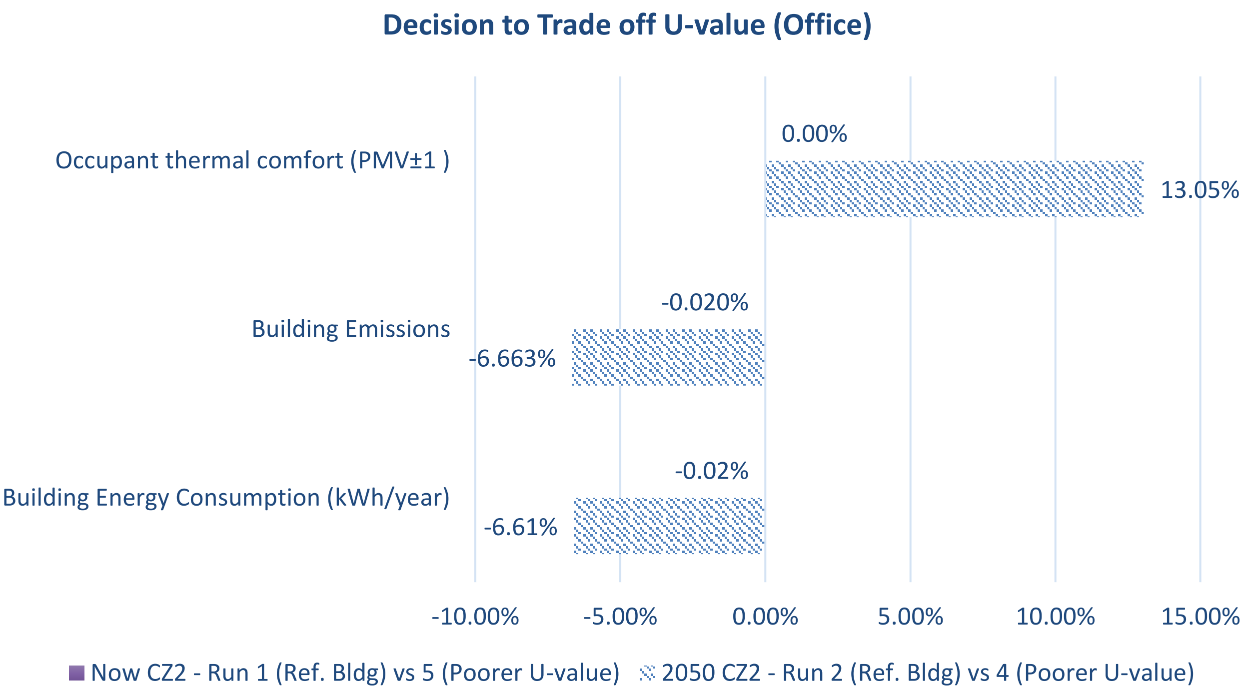
- In <u>climate zone 5 (</u>Figure 49), the probability of a decision to trade off glazing U-value does not change when a future climate file is used. This is because there is no significant difference between the relative change in proposed building's greenhouse gas emissions or thermal comfort when using different climate files (<0.1%).
  Outcome: No change to design decision.
- In <u>climate zone 6 (</u>Figure 50), the probability of a decision to trade off glazing U-value does not change when a future climate file is used. In both overnight and daytime buildings, the designer is just as likely to trade off glazing U-value performance using a baseline climate file, or future climate file. Regardless of climate file used, the proposed designs (with the exception of climate zone 6 daytime building using a current climate file) would not have passed the absolute thermal comfort compliance test (which requires thermal comfort to be achieved in >95% of area >98% of the time).
  Outcome: No change to design decision.

Table 17. Supporting data for graphs in Section 5.2.1 (Office) – Run 1 vs. 5 and Run 2 vs 4

Climate Zone	Run	Building Energy Consumption (kWh)	Building GHG Emissions (kgCO$_2$)	Thermal Comfort Avg PMV % (target 98%)	Thermal Comfort Area % Compliant (target 95%)
Climate Zone 2	Current Reference	520,650	479,542	92%	0%
	Current Uvalue + 20%	520,552	479,447	92%	0%
Climate Zone 5	Current Reference	482,198	443,172	96%	39%
	Current Uvalue + 20%	482,117	443,077	96%	39%
Climate Zone 6	Current Reference	452,997	511,914	99%	97%
	Current Uvalue + 20%	453,257	511,846	99%	97%
Climate Zone 2	Future Reference	565,457	521,079	48%	0%
	Future Uvalue + 20%	528,098	486,361	61%	0%
Climate Zone 5	Future Reference	530,419	488,469	63%	0%
	Future Uvalue + 20%	530,372	488,424	63%	0%
Climate Zone 6	Future Reference	491,443	569,650	72%	0%
	Future Uvalue + 20%	491,419	569,573	72%	0%

Table 18. Supporting data for graphs in Section 5.2.1 (Hotel)

Climate Zone	Run	Building Energy Consumption (kWh)	Building GHG Emissions (kgCO$_2$)	Thermal Comfort Avg PMV % (target 98%)	Thermal Comfort Area % Compliant (target 95%)
Climate Zone 2	Current Reference	493,040	334,599	98%	81%
	Current Uvalue + 20%	493,200	334,614	98%	81%
Climate Zone 5	Current Reference	549,096	308,642	99%	91%
	Current Uvalue + 20%	549,361	308,680	99%	91%
Climate Zone 6	Current Reference	812,039	394,399	99%	88%
	Current Uvalue + 20%	837,055	399,037	99%	88%
Climate Zone 2	Future Reference	504,947	420,939	88%	0%
	Future Uvalue + 20%	505,223	421,134	88%	0%
Climate Zone 5	Future Reference	494,085	366,155	97%	73%
	Future Uvalue + 20%	494,286	366,232	97%	73%
Climate Zone 6	Future Reference	817,342	398,277	99%	88%
	Future Uvalue + 20%	842,643	402,923	99%	88%



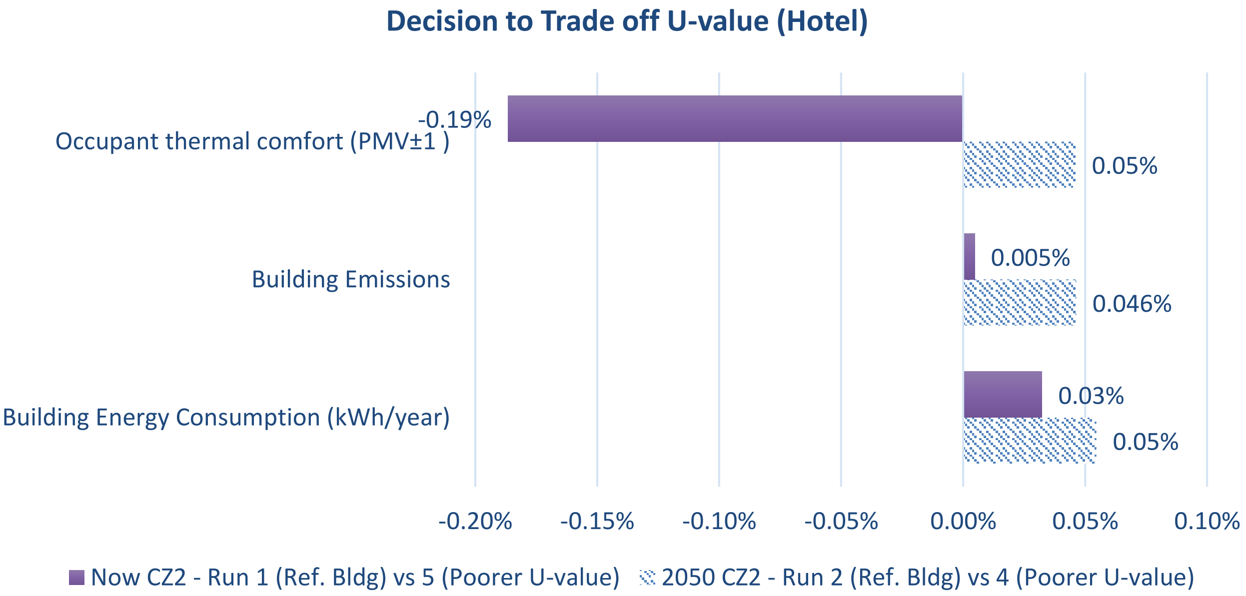
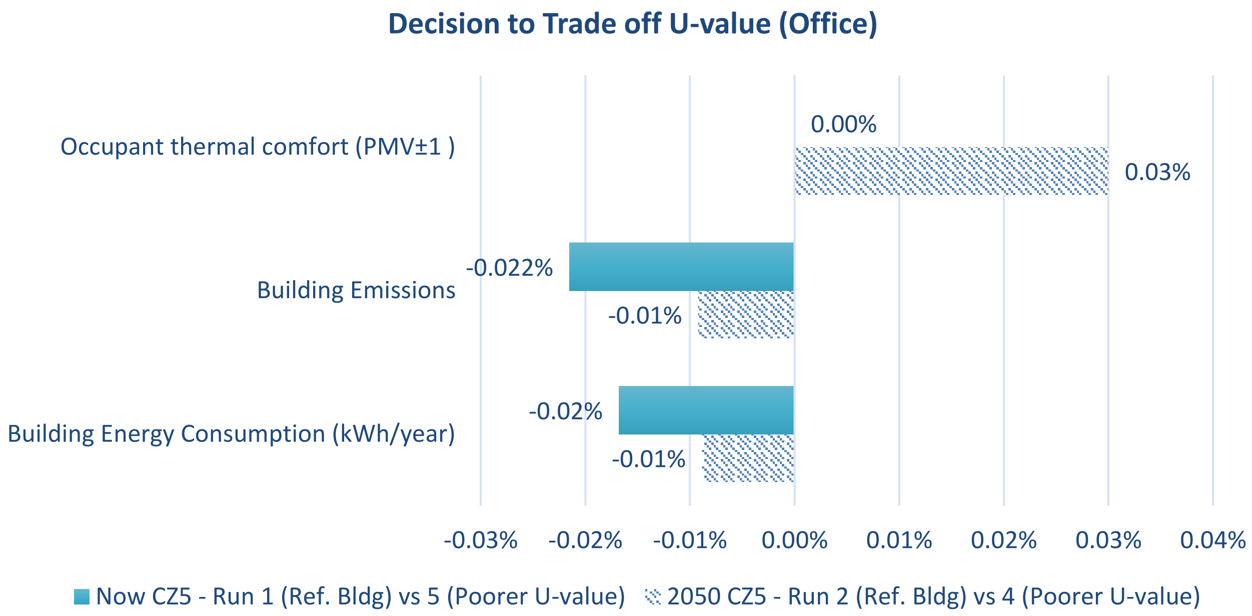


Figure 48. Climate 2 – relative difference of proposed building with inferior glazing U-value performance to reference building, impacts on occupant thermal comfort, building annual emissions and energy consumption.



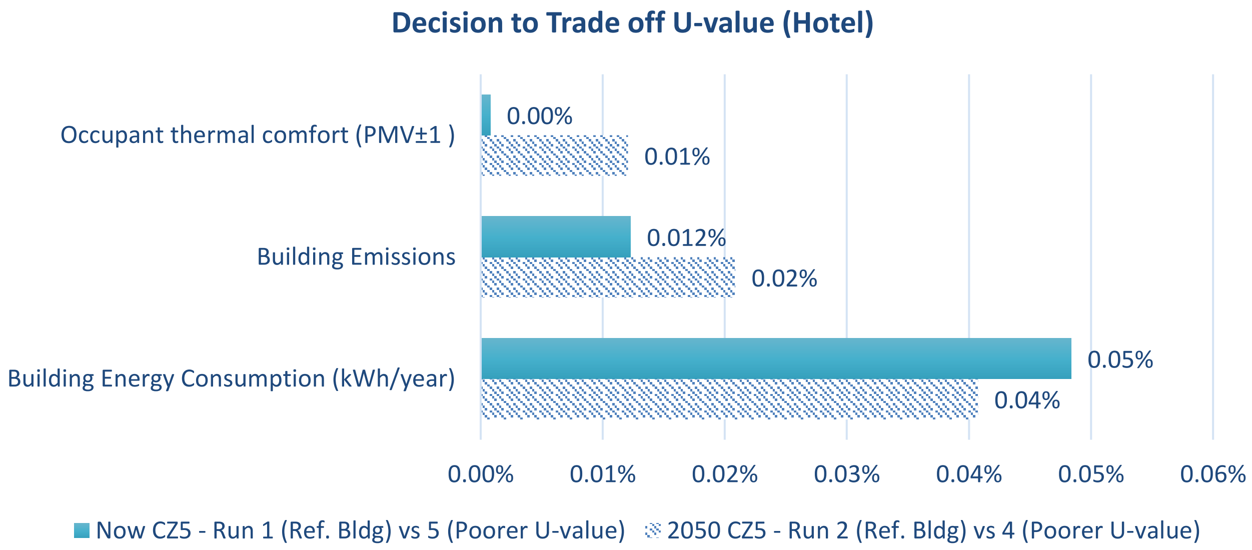
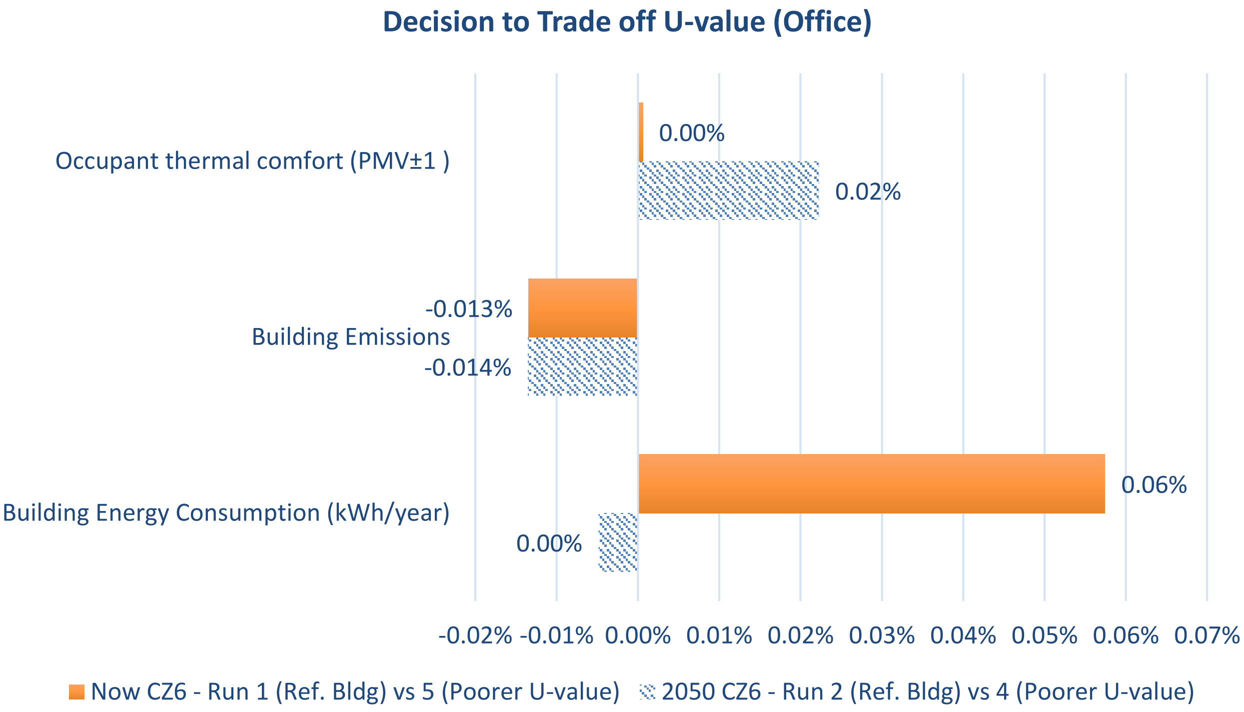


Figure 49. Climate 5 – relative difference of proposed building with inferior glazing U-value performance to reference building, impacts on occupant thermal comfort, building annual emissions and energy consumption. Office Building (top) versus Hotel Building (bottom).



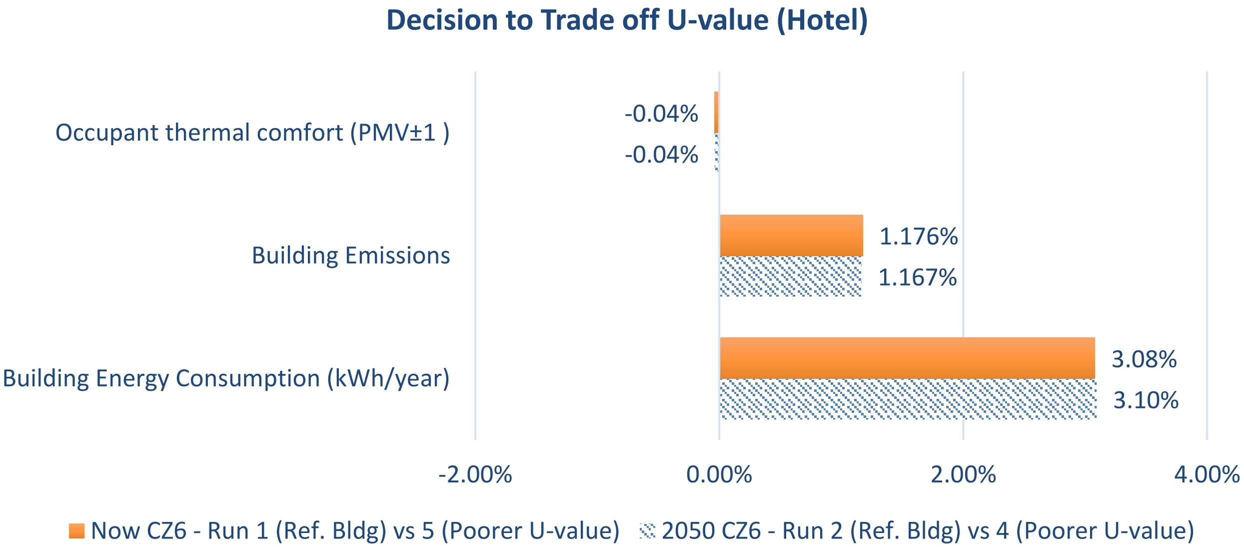


Figure 50. Climate 6 – relative difference of proposed building with inferior glazing U-value performance to reference building, impacts on occupant thermal comfort, building annual emissions and energy consumption. Office Building (top) versus Hotel Building (bottom).

5.2.2 Reducing Performance of Glazing SHGC for Cost Optimisation

Solar admittance is another building envelope requirement. It is affected by the building window-to-wall ratio, shading coefficient (through external shades) and glazing solar heat gain coefficient (SHGC) performance. In this case, design decision changes to solar admittance has been tested by changing the glazing SHGC performance while keeping other variables impacting solar admittance constant.

Figure 51 to Figure 53 show the relative changes to building annual energy consumption, annual greenhouse gas emissions and occupant thermal comfort represented by predicted mean vote (PMV) for climate zones 2, 5 and 6 respectively. A negative value for energy consumption or emissions in the figures mean that the proposed building has produces less emissions and energy consumption compared to the DTS-compliant reference building. A negative value for thermal comfort in the figures means that the proposed building has lower thermal comfort levels than the DTS-compliant reference building. Supporting data for these figures is provided in Table 19 and Table 20.

These are presented for both a daytime (office) and overnight (hotel) building. Building annual energy consumption is shown for interest, but is not a variable considered in the Verification Methods in the 2019 building code Section J.

If the relative difference in emissions or thermal comfort is substantially different (e.g. >10%) between the use of a current and future climate file, then we would consider that the design trade-off decision will likely change. However, if the relative difference in emissions or thermal comfort is very small, then we conclude that the design trade-off decision is unlikely to change due to the use of a different climate file. Insights from the results are as follows:

- In climate zone 2 (Figure 51), the probability of a decision to trade off glazing SHGC increases in an overnight building but decreases in a daytime building. This is because when a future climate file is modelled, the thermal comfort in the overnight building improves but deteriorates in the daytime building. From a building emissions perspective, annual emissions are relatively unchanged in a daytime building but increases in an overnight building when a future climate file is used. The designer may elect to use on-site renewable energy to offset the additional emissions incurred in the proposed design with poorer building fabric. Nonetheless, irrespective of climate file used, the designer would not be able to trade off glazing SHGC performance without changing other building fabric elements[80].
  Outcome: No change to design decision.
- In climate zone 5 (Figure 52), the probability of a decision to trade off glazing SHGC decreases when a future climate file is used. Irrespective of climate files used, thermal comfort is adversely impacted and building emissions increase when glazing SHGC performance is compromised. A similar trend is observed across daytime and overnight buildings. A designer would not trade off glazing SHGC performance without improving other building fabric elements to improve thermal comfort and reduce building emissions. It is however arguable that a greater improvement in other building elements is required when a future climate file is used to comply with Verification Methods thermal

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[80] The absolute thermal comfort requirement being met in 95% of occupied zones, 98% of the time is not met. Improvements could be in the form of reducing window-to-wall ratio or introducing external shades to reduce solar admittance, or reducing building façade thermal transmittance.

comfort requirements. Nonetheless, irrespective of climate file used, the designer would not be able to trade off glazing SHGC performance without changing other building fabric elements.
Outcome: No change to design decision.

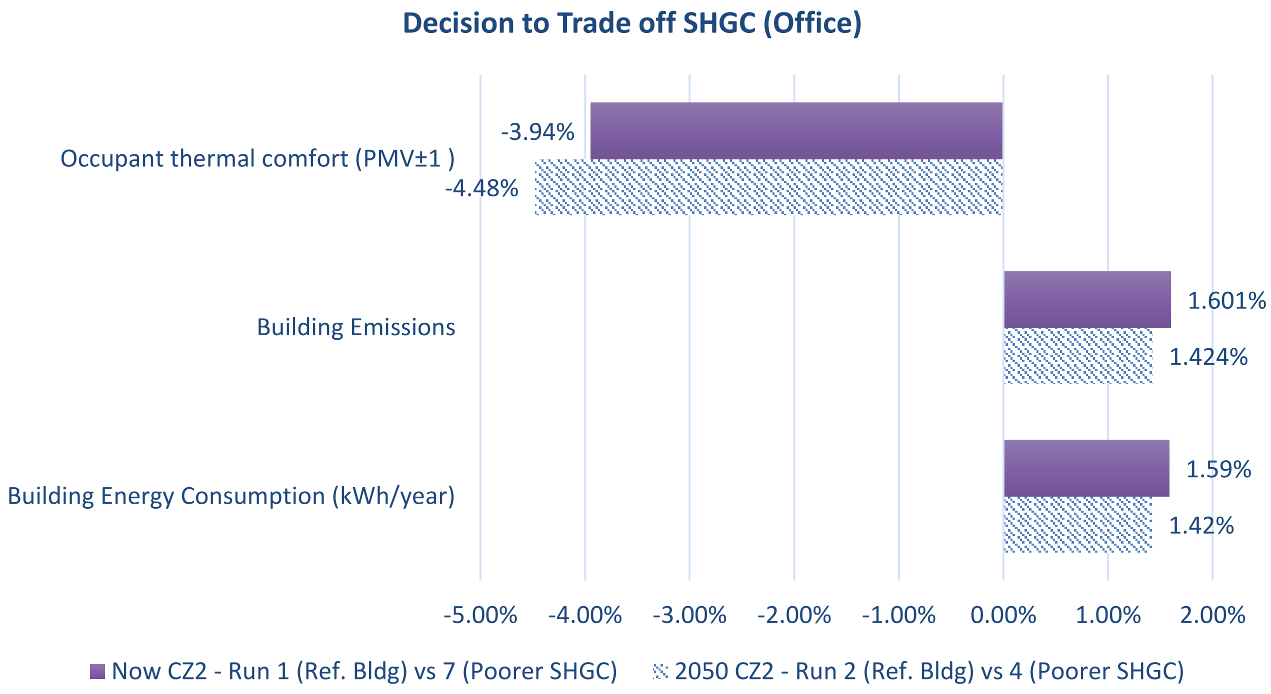
- In climate zone 6 (Figure 53), the probability of a decision to trade off glazing SHGC is less likely to occur in a daytime building when a future climate file is used; whereas this trade-off decision is likely unchanged when different climate files are used in an overnight building. In a daytime building, regardless of climate file used, the designer would not trade off glazing SHGC performance without improving thermal performance of other building elements; however, the relative improvement required in other building elements to facilitate this trade-off is greater when using a future climate file. In an overnight building, the designer is just as likely to trade off SHGC performance regardless of climate file used.
  Outcome: No change to design decision.

Table 19. Supporting data for graphs in Section 5.2.2 (Office)

Climate Zone	Run	Building Energy Consumption (kWh)	Building GHG Emissions ($kgCO_2$)	Thermal Comfort Avg PMV % (target 98%)	Thermal Comfort Area % Compliant (target 95%)
Climate Zone 2	Current Reference	520,650	479,542	92%	0%
	Current SHGC + 20%	528,913	487,221	89%	0%
Climate Zone 5	Current Reference	482,198	443,172	96%	39%
	Current SHGC + 20%	489,003	449,670	95%	17%
Climate Zone 6	Current Reference	452,997	511,916	99%	97%
	Current SHGC + 20%	456,781	518,288	98%	92%
Climate Zone 2	Future Reference	565,457	521,079	48%	0%
	Current SHGC + 20%	573,495	528,501	43%	0%
Climate Zone 5	Future Reference	482,117	443,077	63%	0%
	Current SHGC + 20%	537,973	495,497	59%	0%
Climate Zone 6	Future Reference	491,443	511,846	72%	0%
	Current SHGC + 20%	498,110	577,763	68%	0%

Table 20. Supporting data for graphs in Section 5.2.2 (Hotel)

Climate Zone	Run	Building Energy Consumption (kWh)	Building GHG Emissions ($kgCO_2$)	Thermal Comfort Avg PMV % (target 98%)	Thermal Comfort Area % Compliant (target 95%)
Climate Zone 2	Current Reference	493,040	334,599	98%	81%
	Current SHGC + 20%	494,810	341,568	98%	80%
Climate Zone 5	Current Reference	549,096	308,642	99%	91%
	Current SHGC + 20%	544,397	311,154	99%	90%
Climate Zone 6	Current Reference	812,039	394,399	99%	88%
	Current SHGC + 20%	799,115	392,679	99%	88%
Climate Zone 2	Future Reference	504,947	420,939	88%	0%
	Current SHGC + 20%	519,312	437,042	89%	0%
Climate Zone 5	Future Reference	494,085	366,155	97%	73%
	Current SHGC + 20%	498,222	374,095	97%	80%
Climate Zone 6	Future Reference	817,342	398,277	99%	88%
	Current SHGC + 20%	804,304	396,525	99%	88%



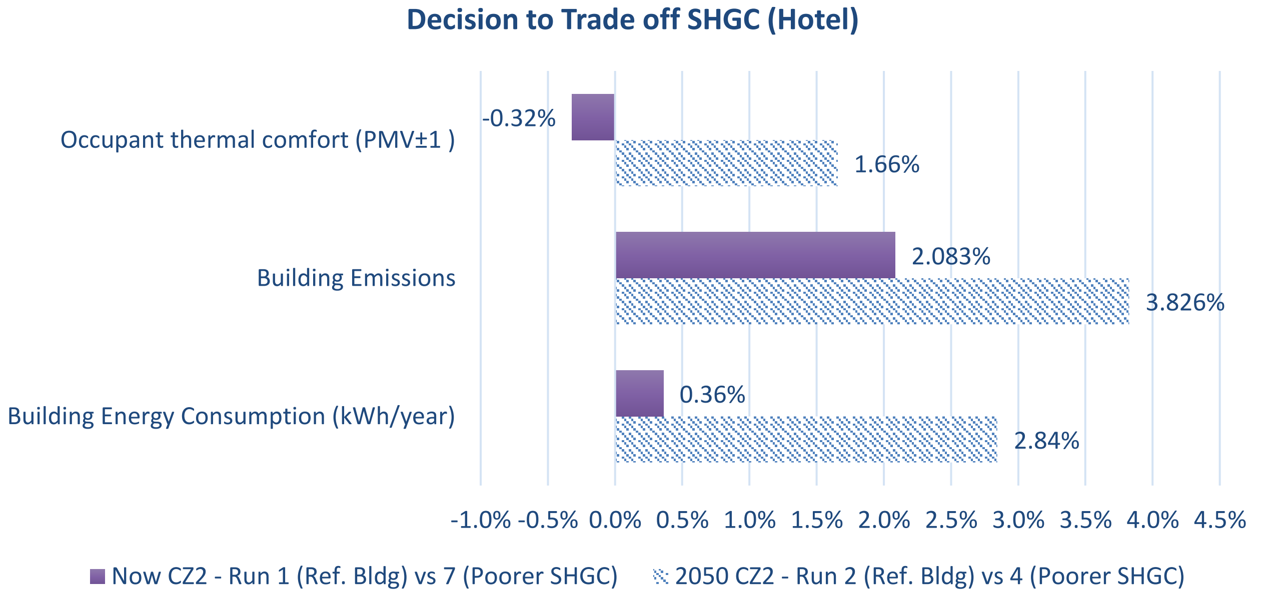
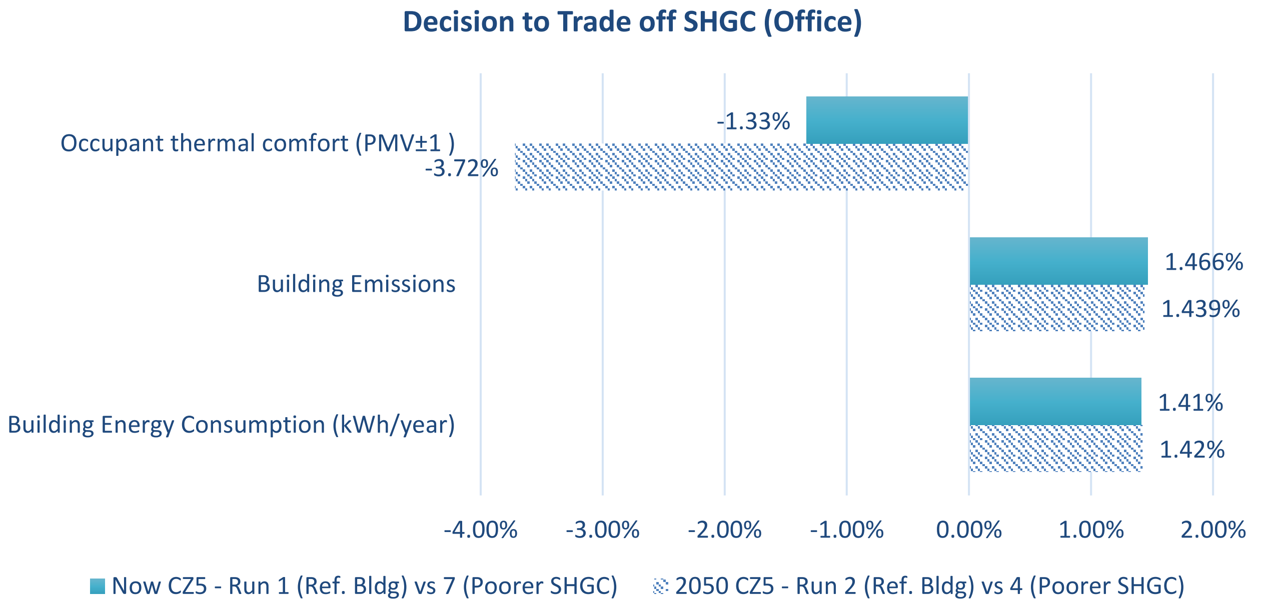


Figure 51. Climate 2 – relative difference of proposed building with inferior glazing SHGC performance to reference building, impacts on occupant thermal comfort, building annual emissions and energy consumption. Office Building (top) versus Hotel Building (bottom).



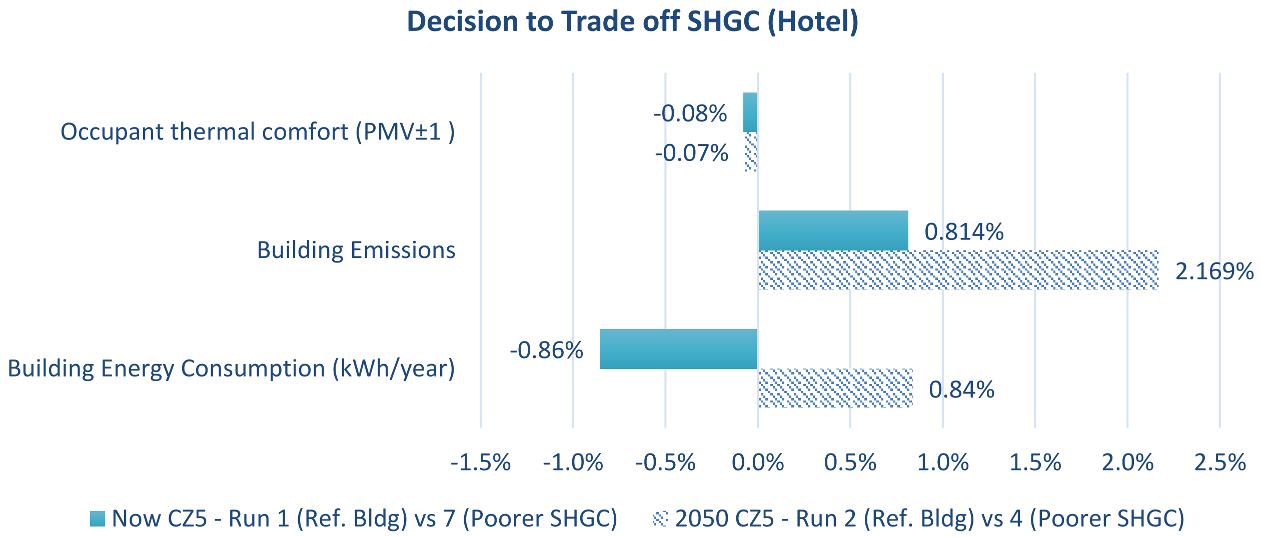


Figure 52. Climate 5 – relative difference of proposed building with inferior glazing SHGC performance to reference building, impacts on occupant thermal comfort, building annual emissions and energy consumption. Office Building (top) versus Hotel Building (bottom).

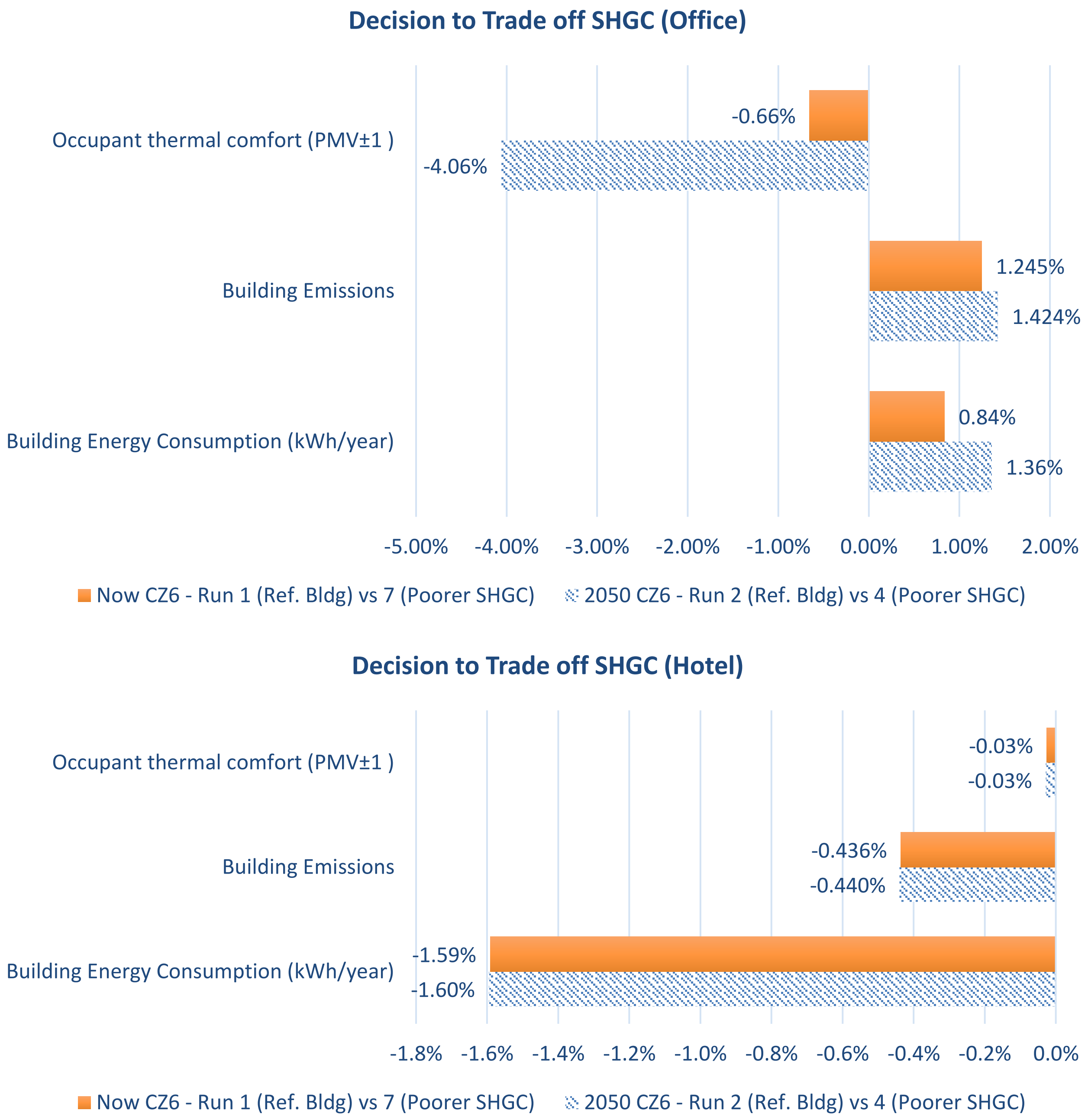


Figure 53. Climate 6 – relative difference of proposed building with inferior glazing SHGC performance to reference building, impacts on occupant thermal comfort, building annual emissions and energy consumption. Office Building (top) versus Hotel Building (bottom).

5.2.3 Impacts on Mechanical Design

As discussed in Section 4.3, using a future climate file shows that cooling capacity and airflow requirements of the mechanical plant increase, with a corresponding decrease in heating capacity required. Within the context of the use of climate files and energy modelling in the current building code (in Verification Method JV3):

- Trading off building services performance[81].
    - Referencing Figure 41 and Figure 43, it will be more difficult for a building designer to trade off HVAC equipment efficiency that affects cooling capacity when a future climate file is used. This is because the cooling equipment such as chillers, chilled water pumps or heat rejection equipment can be reasonably expected to operate for longer hours or at higher capacity under a future climate scenario. The designer would need to increase efficiency of other equipment substantially or increase building fabric thermal performance to ensure that building code annual greenhouse gas emissions requirements are met.
    - It will be easier for a building design to trade off efficiency performance of heating equipment when a future climate file is used. A stop gap should be placed by reviewing Section J DTS stringency for heating plant efficiency to ensure that heating plant specified operate efficiency at part load operation. This is described in Section 6.2.3.
- Plant selection
    - The largest impact from using different climate files to size building HVAC equipment is design cooling and heating capacity. Simply put, a designer using a future climate file might select a larger cooling plant and either retain the current heating plant capacity or select a smaller heating plant. The designer will also increase fan size (ductwork increase)[82] or increase cooling coil capacity (pipework increase). However, the building code does not currently regulate how HVAC plant is sized, it merely requires the designer to consider impacts on annual greenhouse gas emissions if Verification Methods are used, and if a DTS solution is used, for equipment to be selected with a minimum level of efficiency[83]. From this perspective, specifying different climate files within the current building code would not impact the required mechanical design features. It may be possible to sidestep this issue by assessing thermal comfort impacts in addition to cost effectiveness when the ABCB undertakes work to determine stringency change to Section J DTS provisions.
    - However, in a situation where the building designer is using a Verification Method to trade off building fabric performance, it would not be possible for the proposed building to meet building code thermal comfort performance requirements unless an adequately-sized HVAC plant is specified[84]. This is shown in the modelling results in Figure 47 where a DTS-compliant building is modelled in a future climate scenario using HVAC plant sized for current climate. It can be seen that relative to the baseline (DTS-compliant building modelled using baseline

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[81] For reasons discussed above in Section 5.2, it is uncommon for building services performance to be traded off. However, the scenario of mechanical equipment efficiency design trade-off is discussed here for completeness.

[82] Generally, it is preferable for plant cooling capacity to be increased using thermal plant rather than increased airflow. Cubic fan laws mean that fan energy increases exponentially as airflow increases.

[83] Independent of regulated climate files selection and no energy modelling required.

[84] The only means for the designer to improve absolute thermal comfort conditions in the building is by improving building façade thermal performance or increasing HVAC equipment capacity. Given building façade thermal performance is being traded off, the only option for the designer is to increase HVAC equipment capacity.

climate file), up to a 40% decline in thermal comfort (climate zone dependent) may occur. Hence, the need to update baseline climate files to future files so that this thermal comfort loss is captured within the simulation. The exception to this is climate zone 6 (Melbourne), where the future climate seems to be beneficial for an overnight-operation building operating with HVAC equipment sized using current climate data – thermal comfort improves, energy consumption decreases and no change to greenhouse gas emissions is observed.

  - The use of a future climate file is expected to increase building annual energy consumption, and potentially annual greenhouse gas emissions (if electricity emissions factors remain unchanged). This signals the need for DTS efficiency requirements for HVAC equipment in Part J5 of the building code to be made more stringent to avoid increases in building annual greenhouse gas emissions[85].

5.2.4 Impacts on Building Fabric Design

Building fabric improvements include control of thermal transmittance window, roof and wall U-values (thermal transmittance) as well as control of window solar admittance (through the use of glazing with low solar heat gain coefficients, use of external shading or reducing window).

As discussed in Section 4.3 and illustrated using Figure 42 and Figure 44, in order to roughly retain baseline HVAC plant size for an overnight building (hotel) in a future climate, building fabric performance needs to improve between 30% to 73% to minimise the resultant increase in cooling capacity expected due to a warmer future climate. In a daytime building such as an office building, the required building fabric improvements are between 40% to 50%.

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[85] In a JV3 scenario, the proposed building and reference building are modelled with the same DTS-compliant building services and their resultant annual greenhouse gas emissions compared to ensure parity performance or better.

6 Building Code Response and Recommendations

Key Recommendations:

1. **Update Section J Performance Requirements to reference the full life span of the building and systems.**
2. **At present, Section J Specification JVb does not stipulate the use of specific climate files beyond requiring the proposed and reference building to be modelled using the same location where climatic data is available. Introduce the requirement for the climatic data used for energy and thermal comfort modelling to be a future climate file (nominally 10-15 years into the future, or 2030) in Specification JVb(3)(a)(iii). In order to ensure alignment between the Verification Methods JV1, JV2 and JV3, the ABCB should coordinate with NABERS and the GBCA to update their NABERS Commitment Agreement handbook and Green Star Design & As Built v1.3 Energy Consumption and Greenhouse Gas Emissions Calculation Guide to specify future climate modelling must occur.**
3. **To avoid increase in building annual greenhouse gas emissions due to increased HVAC plant size, the stringency of Section J Deemed-to-Satisfy (DTS) provisions should be reviewed against updated cost-benefit analysis using future climate files, and increased where beneficial, particularly for requirements related to cooling equipment. Thermal comfort should also be included as an assessment criterion when reviewing changes to DTS provisions.**
4. **The ABCB or nominated government body should manage and host a centrally available database of 'accredited' climate files. Climate files should be reviewed and updated at minimum once every decade to account for changes in climate and projection values. At time of writing, current options for future climate files include the Ersatz climate files developed by Exemplary Energy Partners. CSIRO's recently-updated NatHERS climate files (up to 2016) and associated future climate files may also be suitable options although these are not publicly available at time of writing. As the CSIRO Electricity Sector Climate Information (ESCI) work is projected to be completed by 2022, we recommend that a review of the central database of climate files be scheduled in the next two years to coincide with this.**
5. **Commission research and development of future climate files for each climate zone incorporating impacts of urban heat island effects. Buildings within an urbanised environment should use an 'urban' climate file instead of a regional climate file such as the airport which is not representative of the localised climate where the building is located. It may be beneficial to commission case studies on mitigating urban heat island effects using trees or green-walls (evaporative effects) within the energy model, which is currently only capable of incorporating external shading impacts (easily) at time of writing).**
6. **Introduce the requirement to conduct a risk assessment for extreme weather events (extreme heat, wind and floods) and the ability of the building to adapt to or mitigate those risks. Extreme risks such as the occurrence of hail may also need to be considered especially for buildings where rooftop solar panels are used to achieve NCC compliance. This requirement may not be directly applicable within the Section J Energy Efficiency section of the Code, and may require a new Building Resilience requirement to be created if this was adopted. This would require future Extreme Weather Files to be created for this assessment.**
7. **The impact of changing greenhouse gas coefficients on design decisions should be assessed. While our analysis shows that the design decision to trade off performance of certain building elements remains unchanged across different climate files, this may not hold true when different greenhouse gas emissions factors are applied. A lower emissions factors for electricity may make it easier to trade off design elements, yet still comply with Code.**

6.1 Potential solutions

The discussion in Section 5 indicates that climate files should account for future climate projections and extreme weather events. The Government's response to the issue needs to consider two traits for assets within the building:

- The building shell's lifetime is generally upwards of 50 years. The building façade is generally static and is very difficult to retrofit once installed. The ability of the building to adapt to climate change from a building façade perspective needs to be addressed now due to the timeframes for asset lifecycle renewal. The building façade can be described as illiquid.
- Building services such as HVAC equipment have a renewal cycle of about 15 to 25 years. The impact of climate change on building services can be reviewed and major plant equipment replaced based on the new requirement. Relative to building façade, HVAC plant is more liquid as an asset.

As such, from the perspective of ensuring building resilience and adaptability to climate change, it is far more important to ensure that building façade performance is assured and not traded off.

The literature review found a range of approaches adopted by other jurisdictions that can be categorised as:

- Regular updates of climate files supplied by government (or government-sponsored) embedded into simulation engines so that consistent files are used to demonstrate compliance to building regulation.
    - California provides weather data current till 2017 to reflect climate change within the Building Energy Code Compliance (CBECC) software. This is updated on a regular basis. Designers use this to select measure trade-offs. Green schemes such as ASHRAE is focussed on updating climate data more regularly instead of creating future climate files.
- A centralised source for climate files sponsored by government for both current and future projections available for purchase through an accredited organisation.
    - The Greater London Authority (GLA) requires buildings to be modelled and assessed[86] using two sets of climate files supplied by CIBSE. CIBSE provides climate data current till 2013 for assessment of energy consumption and thermal comfort; and future projected climate data to assess building overheating risk. Future climate data incorporates impact of urban heat island effects and climate change – designers can select the region (urban, suburban and rural) to reflect this.

To ensure that the impact of climate change on heating and cooling loads is managed, the building code should adopt a two-pronged approach:

- One that is performance-based, by requiring designers to model the proposed building using a future climate file, so that the impact on energy consumption, thermal comfort and greenhouse gas emissions can be quantified. The climate file may also need to be adjusted to account for micro-climate changes, particularly the urban heat island effect.
- A second that is prescriptive-based, by updating the Deemed-to-Satisfy requirements in the building code. The focus should be on identifying suitable stringency levels for passive building elements

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[86] Discussion regarding the GLA requirement is provided in Section 3.1.2.

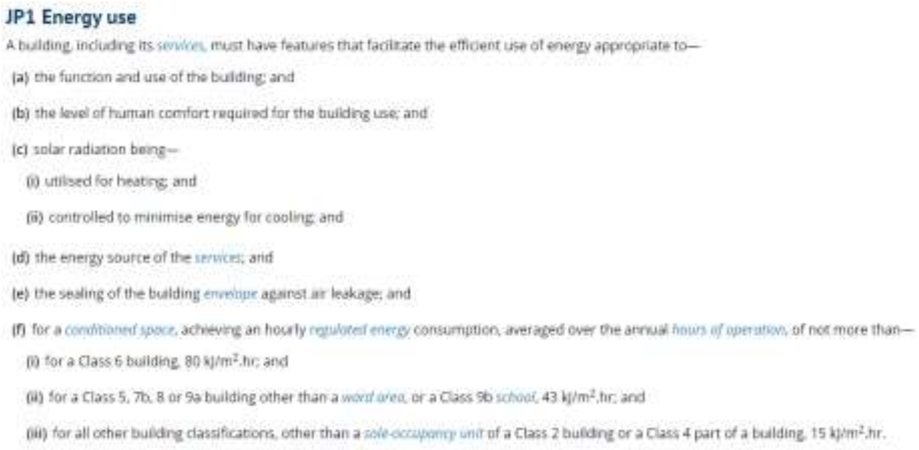
(building envelope improvements), control of air infiltration and HVAC equipment efficiency improvements (particularly cooling equipment).

Detailed recommendations for proposed changes to the building code are described in subsequent sections.

6.2 Changes to Section J of the Building Code of Australia

6.2.1 Performance Requirement

JP1 currently bears no explicit reference to building resilience based on future climates.



JP1 Energy use

A building, including its *services*, must have features that facilitate the efficient use of energy appropriate to—

(a) the function and use of the building; and

(b) the level of human comfort required for the building use; and

(c) solar radiation being—

(i) utilised for heating; and

(ii) controlled to minimise energy for cooling; and

(d) the energy source of the *services*; and

(e) the sealing of the building *envelope* against air leakage; and

(f) for a *conditioned space*, achieving an hourly *regulated energy* consumption, averaged over the annual *hours of operation*, of not more than—

(i) for a Class 6 building, 80 kJ/m².hr; and

(ii) for a Class 5, 7b, 8 or 9a building other than a *ward area*, or a Class 9b *school*, 43 kJ/m².hr; and

(iii) for all other building classifications, other than a *sole-occupancy unit* of a Class 2 building or a Class 4 part of a building, 15 kJ/m².hr.

Figure 54. NCC 2019 Volume 1 Amendment 1 Extract - JP1

The building code Section J Performance Requirement should be amended to reference the full life span of the building and its systems, such that it encompasses impacts of climate change. A simple amendment to the text will account for the different life spans of building fabric and HVAC equipment.

Recommendation

- *Amend wording to include reference to the full life span of the buildings and its systems. This is likely to take the form of an additional requirement JP1(f):*
    - *JP1(f) hourly regulated energy consumption (kJ/m^2.hr) requirements should be reviewed in the context of future climate.*

6.2.2 Verification Methods JV1, JV2 and JV3

JV1, JV2 and JV3 are verification methods, each with their own set of modelling requirements that loosely speaking, also allow cross-utilisation of modelling parameters from each other's modelling guidelines for the purposes of building code compliance.

JV1 is the NABERS Commitment Agreement pathway, which uses the *NABERS Commitment Agreement Handbook for Estimating Ratings v1.2* for its modelling requirements. It requires weather data used to be for a reference year dataset for a local weather station representative of the local area, with a relatively broad definition of allowable data sources. Sources include the ACADS-BSG/CSIRO nominated TRY[87], a TMY, variants of WYEC, IWEC or other standard weather year data. It also allows the modeller to use any alternative methodology justifiable as weather data.

JV2 is the Green Star Design & As-Built pathway, which uses the *Energy Consumption and Greenhouse Gas Emissions Calculation Guide v1.3* for its modelling requirements. It requires climate files to be taken from the following options in order of preference – a RMY location within 50 km of the building in the same climate

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[87] The ACADS-BSG administers the Australian Climatic Data Bank (ACDB)

zone, TRY location within 50km of the building in the same climate zone, an actual year of recorded weather data from a location within 50 km of the project location for the same climate zone, or, interpolated data based upon 3 points within 250 km of the project location.

JV3 is the Verification Using a Reference Building pathway, which references Specification JVb and Specification JVc. There is no reference to climate files.

The building code Section J Verification Methods and the corresponding Specifications should be expanded to reference accredited future climate files from a centralised source. Ideally, the use of climate data with a measurement period ending more than 20 years from the time of design should be banned[88]. The ‘future’ climate file should be selected to be approximately 10-20 years ahead (nominally 2030 projections for the current code). Several implementation methods were considered including the option to mimic the London method, where multiple simulations using different climate files are modelled, and the option where climate files are updated regularly by the government to reflect actual changes in climate. While it was agreed that these methods can be adopted, it would lead to substantial increase in costs to the developer in the first option (due to the need for multiple models), and in the second, substantial costs from the Government to maintain the current climate files database.

Recommendation

- *Add requirement in Specification JVb Modelling Parameters(3)(a) for a future climate file (nominally 2030) under an appropriate RCP pathway to be used. A list of accredited sources or climate files criteria should be listed. Ideally, the climate file should be hosted within the ABCB or nominated government body database.*
- *Liaise with NABERS and GBCA to update the NABERS Commitment Agreement Handbook for Estimators and Green Star Design & As-Built Energy Consumption and Greenhouse Gas Emissions Calculation Guide to ensure alignment.*
- *Commission additional work to determine if it is feasible to change Specification JVb(2)(d) from a simple representation of air infiltration rates in ACH (bears no relation to changes in wind speed and wind pressure in its current form) to a more complex single/multi-zone infiltration model that requires some knowledge of crack coefficients in the building. These are generally unknown by the modeller, and therefore default values referenced from other sources such as CIBSE Guide A or as developed within Australia would need to be provided. This also needs to be accompanied by provision of appropriate training to upskill Australian modellers to use the more complex method to account for infiltration.*

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[88] For example, IWEC data which is based on measurement period 1982-1999 would be banned from use as the measurement end date is 21 years from time of writing. In this case, the designer would use the more recent IWEC2 file (period 1983-2008).

6.2.3 Deemed-to-Satisfy Provisions

Part J0 to Part J8 were reviewed to ascertain provisions that may be impacted by climate change, and therefore require changing. Stringency changes should be assessed using a future climate file, with the assessment criterion expanded to thermal comfort (in addition to cost effectiveness).

Recommendation

Ref.	Item	Description	Amendment Required
Part J0.2	Sole-occupancy units for Class 2 building or Class 4 part of building	Heating & cooling loads currently reference NatHERS ratings and requirements. Heating & cooling limits must be complied with separately.	Liaise with NatHERS for requirement to model a future climate file embedded within NatHERS guidelines. CSIRO has recently updated NatHERS climate files current to 2016.
Part J0.4	Roof thermal breaks	Thermal break R-value >= R0.2 between metal sheet roofing and supporting metal purlins, rafters, or battens.	Thermal break R-values may require adjustment to counter climate change. Additional work is required to determine appropriate stringency levels, if required.
Part J0.5	Wall thermal breaks	Thermal break R-value >= R0.2 between external cladding and metal frame.	Thermal break R-values may require adjustment to counter climate change. Additional work is required to determine appropriate stringency levels, if required.
Part J1.3	Roof and ceiling construction	Roof and ceiling insulation R-values, particularly for climate zones with downward direction of heat flow.	R-values for all climate zones may require adjustment – additional work is required to determine appropriate change to stringency levels if required. Particular attention should be paid to the cooler climate zones 7 and 8 which currently have upward direction of heat flow as they may shift to downward direction of heat flow under a climate change scenario).
Part J1.6	Floors	Floor insulation R-values may also require adjustment due to higher ground temperatures.	Floor R-values may require adjustment – additional work is required to determine appropriate change to stringency levels if required. Particular attention should be paid to climate zone 8 (currently most stringent) which may shift into the same category as climate zones 4 to 7.
Part J1.5	Walls & glazing	Total U-values and SHGC may require adjustment.	Additional work is required to determine appropriate change to stringency levels for U-values, opaque wall component R-values and solar admittance. The modelling work in this study for the limited climate zones suggest that control of solar admittance becomes increasingly important to manage thermal comfort and minimise greenhouse gas emissions.
Part J5.2(a)(iii)	Economy cycle conditions	Table J5.2 economy cycle requirements and benefits may reduce due to less mild conditions and increased wet bulb temperatures.	The cost-benefit for total airflow rates requiring economy cycle for each climate zone may change, and adjustment required.

Ref.	Item	Description	Amendment Required
			A new requirement in Part J5.2(a) to install outside air temperature and dew point temperature sensors for economy cycle enthalpy/dew point control is required.
Part J5.3 - Table J5.3	Mechanical ventilation system controls	Climate zones where outdoor air flow treatment is required may change.	The required measure for outdoor air treatment in each climate zone may change. For example, climate zones 1 to 3 which previously did not have an option for heat recovery may now require heat recovery systems to 'reject' heat into the building exhaust stream. Additional work is required to determine how each variable should change, including the level at which outdoor air flow (L/s) requires outdoor air treatment.
Part J5.10	Refrigerant chillers	Minimum EERs for refrigerant chillers (COP / IPLV) may need to be increased to counter increased building energy consumption associated with higher cooling load & reduced economy cycle operation.	Minimum chiller performance, in particular IPLV requirements, should be increased. The exact stringency level will require updated cost benefit analysis. The appropriateness of using IPLV should also be investigated, as IPLV is based on AHRI design ambient temperatures that may not align to the increased design temperatures with climate change.
Part J5.10 (d)	Gas water heaters	Boilers with good part load performance or modular design need to be specified to counter increased operation at part load due associated with a warming climate.	Technical requirements incorporating modular heating plant design to facilitate increased part load operation should be introduced, and/or boilers with poor part load performance (e.g. non-condensing boilers) should not be allowed. The exact stringency levels will require updated cost benefit analysis.
Part J5.11(a)	Unitary air-conditioning equipment	Currently has minimum EER cooling performance when tested in accordance with AS/NZS 3823.1.2 at test condition T1 which is based on ambient DB 35°C/WB 24°C. Increased temperatures will require Test Condition T1 to be reviewed.	Reconsider suitability of the use of test condition T1, as ambient design conditions may no longer be appropriate[89]. Separately, as HVAC equipment capacity is expected to increase to address overheating risk, the use of SEER instead of EER should be investigated. This is aligned with MEPS for air conditioners <65kWr which will adopt the SEER standard.[90] As it was for IPLV, the appropriateness of the underlying basis for SEER (design temperatures) should also be reviewed in the context of climate change.

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[89] Design ambient temperatures calculated for a future climate scenario exceeds 35°C DB in climate zones 5 and 6 exceeds the 25°C WB in climate zone 5.

[90] https://www.energyrating.gov.au/news/air-conditioner-determination-signed

Ref.	Item	Description	Amendment Required
Part J5.12	Heat rejection equipment	Higher heat rejection loads may allow lower maximum fan motor input power (W/kWrej) figures.	Review heat rejection equipment industry data and determine if stringency can be increased due to higher heat rejection thermal loads. Additionally, the existing provision in Table J5.12 suggest no correlation between heat rejection energy and climate zone. This relationship may have changed with climate change and should be reviewed.

6.3 Climate Files Database and Development

There is currently no centralised or accredited climate files database in Australia available for public access. Energy modellers generally use in-built weather files from simulation engines (e.g. IWEC) or seek TRY files from the ACDB. Specifically, for future climate files, validated versions are currently not widely available or known.

Additionally, localised weather effects such as the urban heat island effect cannot be modelled unless the modeller modifies variables in the climate files to mimic the urban heat island effect. While there has been a fair amount of work done on appropriate methodologies to modify/reconstruct climate files, this has largely been within a niche research community of climate experts. The quality, accuracy and consistency of modified climate files will be impossible to be regulated through the building code, not to mention preventing the people from gaming the system.

At present, the building code does not regulate how HVAC plant is sized, it merely requires the designer to consider impacts on annual greenhouse gas emissions if Verification Methods are used, and if a DTS solution is used, for equipment to be selected with a minimum level of efficiency. There is opportunity for the centralised climate files database to include multi-year weather data used for HVAC plant sizing, though this would be subject to detailed discussions with a load estimation software developer such as ACADS-BSG.

Our recommendation for a centralised climate files database combined with a regular update cycle is aligned with the PCA's submission to the Royal Commission into National Natural Disaster Arrangements dated 28 April 2020. In Recommendation 7 of the PCA submission, it calls for the Commonwealth to establish a 'one stop shop' climate change mitigation and adaptation web portal that is freely available, including information on national climate change data, allowing built environment professionals and communities to understand the predicted impacts of climate change for their local areas and take appropriate action to enhance building resilience. In Recommendation 8 of the PCA submission, it calls for the ABCB to regularly review the potential impacts of climate change on different building types and specific attributes and systems within buildings for code adaptation; and work with agencies like CSIRO and the Bureau of Meteorology (BOM) to incorporate current and fit-for-purpose weather files for building performance simulation, as well as files to simulate a projected worst case physical risk against an agreed RCP as defined by IPCC and endorsed by Australian financial regulators in consultation with industry.

Recommendation

- *Establish a centralised database for accredited climate files (baseline and/or future) that can be used for Verification Methods. This could be set up in similar fashion to the London approach, where the climate files are administered by an industry body like CIBSE instead of the government. The database administrator will be responsible for vetting climate files and ensuring that climate files are updated on a regular cycle to account for changes in climate and updated future projections (at minimum once every 10 years). As the CSIRO Electricity Sector Climate Information (ESCI) work is projected to be completed by 2022, we recommend that a review of the central database of climate files be scheduled in the next two years to coincide with this. Currently, an appropriate climate files source is the Ersatz Future Metrological Year (EFMY) Weather Data developed by Exemplary Energy Partners.*
- *Commission a gap analysis for locations that are located within an urban area but only have access to regional (generally, airport) weather stations. Climate files for these urban areas should be updated to incorporate the urban heat island effect. This can be conducted by climate experts using morphing techniques (cf. Ren, 2012) or through installation of additional weather stations. This should ultimately present similar options to those available through CIBSE-UK where users have the option to select urban, sub-urban or regional climate files for the climate zone locale.*
- *Discuss the possibility of hosting future weather data files within the central database of 'accredited' climate files for HVAC plant sizing with developers of load estimation software (e.g. ACADS-BSG, CAMEL software developers). Note that we do not recommend that the HVAC plant being sized solely based on 'future' climate files to avoid the risk of the resultant heating plant being inadequate to service existing heating loads in the building. It is more important that modular heating plant design be specified (see recommendation for gas water heater DTS changes in Section 6.2.3 above)*

6.4 Other Recommendations

The climate files used for energy and thermal comfort modelling are based on one year of hourly data that best represents median weather conditions over a multiyear period. In this way, the building is designed to 'typical' rather than extreme conditions, which avoids the risk of 'over-engineered' buildings. As discussed in Section 1.1, CSIRO predicts that extreme events such as extreme heat, wind and floods will increase in the future. The occurrences of extreme events were not observed within the climate files analysis in Section 2 of this report as the climate files are 'typical' files rather than extreme weather files. To fully ensure building resilience to climate change, it may be beneficial for the Building Code to introduce a qualitative risk assessment requirement for extreme weather events, though this is likely to be most suitably introduced in a new section of the building code addressing '*Building Resilience*'.

Recommendation

- Consider introducing the requirement to conduct a risk assessment for extreme weather events (extreme heat, wind and floods) and the ability of the building to adapt to or mitigate those risks. Extreme risks such as the occurrence of hail may also need to be considered especially for buildings where rooftop solar panels are used to achieve NCC compliance. This requirement may not be directly applicable within the Section J Energy Efficiency section of the Code, and may require a new Building Resilience requirement to be created if this was adopted. This would require future Extreme Weather Files to be created for this assessment.

6.5 Alternative Methods

At this stage, we consider that building regulation is the best mechanism to ensure building adaptability and resilience to climate change. While beyond-code green schemes such as the Green Star rating scheme and NABERS commitment agreement are already considering how building resilience can be incorporated within their respective schemes, we note that the target audience for beyond-code schemes and the building code are ultimately a different subset. This is because subscribers to beyond-code schemes are generally early adopters that are already market-leading in energy efficiency and sustainability. It is the role of the building code is to set minimum requirements to uplift the standard of the whole built environment market, largely affecting buildings that would not proactively invest in such measures without a driver like regulatory compliance.

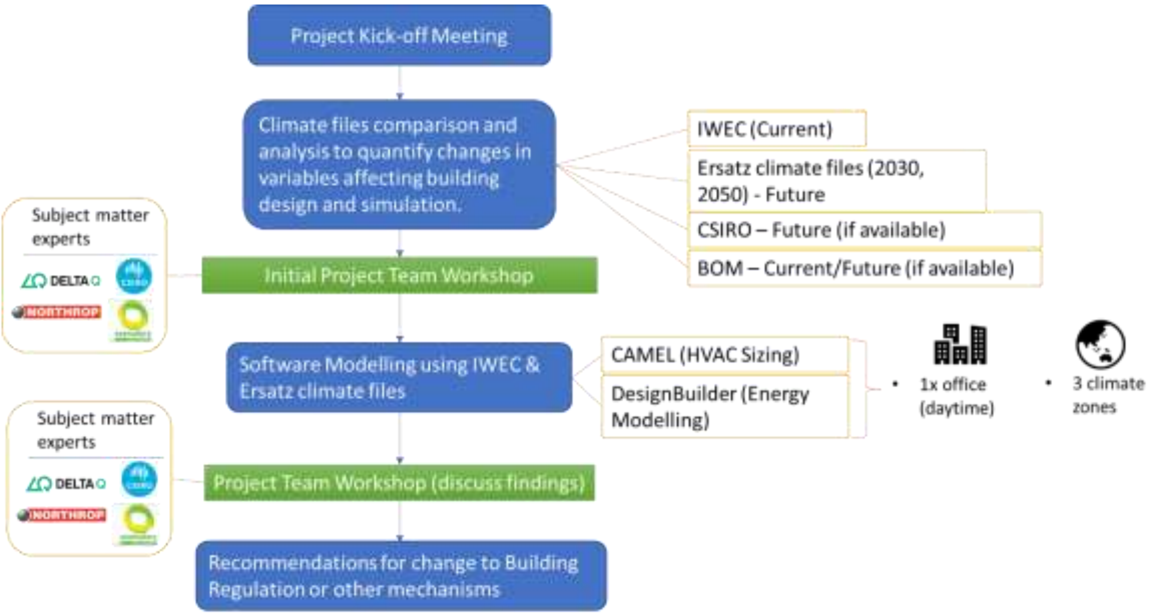
6.6 Additional Work

The work in this report was conducted for a limited number of climate zones and climate files. There is opportunity to expand on the findings in this report through additional work, including:

1. The HVAC plant sizing and energy and thermal comfort modelling in this report have been conducted based on 2050 climate data generated for the highest-emissions scenario. This was done to assess the worst-case climate impact on building energy and design. We recommend that the analysis in this report be repeated using 2030 climate data on an emissions pathway that is agreed as a most-likely scenario (a scenario between IPCC RCP2.6 and RCP8.5). 2030 is also a useful point of analysis as it coincides with the 10- to 20-year HVAC plant end-of-life replacement cycle. A 2030 analysis would useful to validate the findings and recommendations of this report, including the impact of under-sizing HVAC plant (for future climate) within the lifetime of the equipment.
2. The analysis in this report has been conducted for three climate zones that represent the most densely populated areas in Australia. Climate zones 2, 5 and 6 effectively covers the major capital cities including Brisbane, Sydney, Perth, Adelaide and Melbourne. However, the findings may or may not be consistent across the other climate zones 1, 3, 4, 7 and 8 (Darwin, Hobart and Canberra). Climate change may lead to cooler climates resembling a warmer climate zone, or more extreme weather in warm and very humid climates. We recommend that the analysis in this report be repeated for other Australia climate zones to confirm this or otherwise.
3. Energy and thermal comfort modelling in this report revealed that a DTS 2019 compliant building does not necessarily achieve the thermal comfort requirements specified in JV1(a)(ii)(B), JV2(a)(iii) and JV3(a)(ii). For context, the thermal comfort requirement specified for the Section J Verification Method requires evidence that the Predicted Mean Vote (PMV) of ±1 is achieved not less than 95% floor area of occupied zones, for more than 98% of the annual hours of operation. Future work to update DTS provisions (Part J1 to J8) should consider thermal comfort in addition to cost effectiveness.
4. It may be helpful to reassess the appropriateness of 8 climate zones, and whether the various locations should still be classified within the same climate zone. For example, while Perth, Adelaide and Sydney are in the same climate zone 5 currently, climate data observations may reveal that Perth may no longer belong in the same climate zone as Sydney. Similarly, a city like Canberra or Hobart may more resemble climate zones 6 or 7 (instead of the existing 7 and 8).

Appendix A Methodology

The following methodology was adopted.



Appendix A.I Project kick off

The project kick-off meeting was held on 11 March 2020 with the Department and project team members. It was agreed that the methodology reflected in this project plan will be adopted, with the following clarifications:

- Climate zones 2 (Brisbane), 5 (Sydney/Perth/Adelaide) and 6 (Melbourne) will be included within the scope of this research.
    - Climate zone 2 - warm humid summer, mild winter
    - Climate zone 5 - warm temperate
    - Climate zone 6 – mild temperate
- Two sets of climate files will be modelled for the purposes of this project.
    - *Current climate files used for desktop analysis and energy/thermal modelling:* IWEC[91] files developed by the US Department of Energy (1982-1999), available in EnergyPlus .epw file format.
    - *Current climate data used to size HVAC plant:* In-built function in CAMEL[92] using post-1990s (1990-2012) design condition data sets, for the *comfort* conditions scenario.
    - *Future climate files for year 2050 projection under the highest carbon emissions/warmest scenario*:[93] Ersatz climate files developed by Exemplary Energy Partners using underlying data owned by Bureau of Meteorology (BoM) and applying Projected Change Values provided by CSIRO for that purpose.

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[91] International Weather Energy Consumption (IWEC)

[92] CAMEL is a load estimation software used to size HVAC plant.

[93] The climate file for year 2030 projection under the highest emissions scenario provided by Exemplary Energy Partners will also be analysed; however, only the year 2050 climate file will be used for HVAC load estimation, energy and thermal modelling in CAMEL and EnergyPlus.

- An office building with building fabric and services compliant to the National Construction Code (NCC) 2019 Section J Deemed-to-Satisfy (DTS) provisions will be used to model thermal comfort and annual energy consumption impacts.
    - The office building is a L-shaped two-storey building of approximately 3,700m^2 area.
    - Gas boilers will be modelled for space heating purposes, along with compressor chillers for cooling.
    - Synthesis of energy and thermal comfort modelling results will reflect the extent of HVAC plant over-sizing under current practice, including if the recommendation of using climate files accounting for a warming climate will lead to continued and excessive HVAC plant sizing for redundancy purposes.

Appendix A.II Desktop Review and Internal Project Team Workshop 1

We analysed current climate files, future climate files provided by Exemplary Energy Partners and climate files provided by CSIRO for the following climate variables:

- Mean daytime (6am to 9pm) and overnight (6pm through 9am) temperatures reported on a monthly basis for January to December, including:
    - Dry bulb temperature
    - Wet bulb temperature
    - Wind speed
- Maximum and minimum dry bulb temperature and corresponding wind speed, as well as wet bulb temperature and corresponding wind speed reported on a seasonal basis:
    - Summer – December to February
    - Autumn – March to May
    - Winter – June to August
    - Spring – September to November
- Frequency of days and hours with extreme weather events:
    - where the dry bulb temperature exceed 40°C.
    - where wind gusts exceed 90km/h.

Literature review was conducted to research the following items:

- Research future climate files that are available or under development in the market by various organisation.
- Research how other countries such as the US, UK, Europe and select Asian countries (where language permits) are approaching the issue of climate change and its impacts on commercial building HVAC and fabric design.
- Identify provisions in the NCC Volume One Section J that are affected by changing climate, climate file usage or change in building design.

Appendix A.III HVAC Sizing and Simulation Model

Appendix A.III.I Initial Set Up - Building Geometry and Services

Daytime Operation Building (Class 5 Office)

A representative office building was designed and modelled to meet 2019 Section J DTS requirements. Specifically, initial modelling parameters including modelling profiles for the building will be in accordance with Specification JVb and JVc modelling parameters. This includes:

- Occupancy profile; and,
- Operation profiles for artificial lighting (4.5 W/m^2), appliances and equipment and air-conditioning; and,
- Internal sensible heat gains for equipment
- Occupant internal heat gains

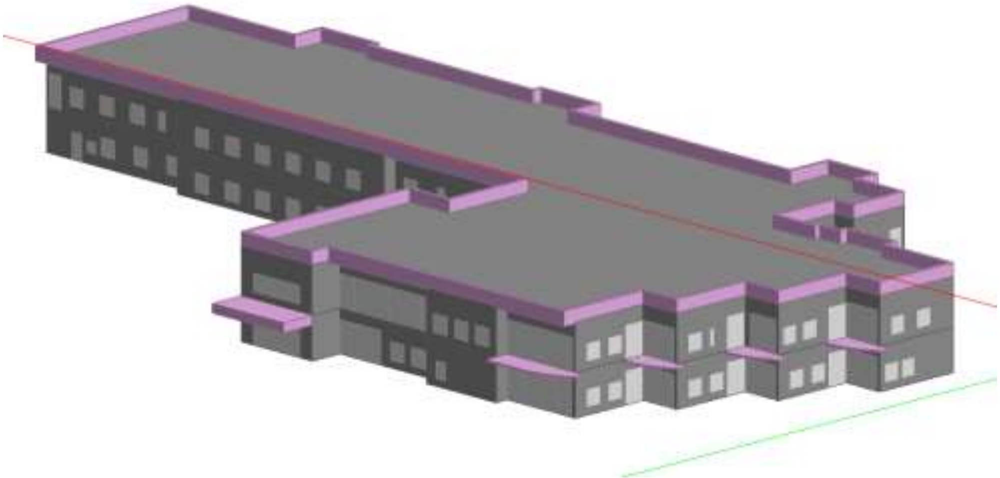
The modelling in CAMEL and EnergyPlus will be repeated for climate zones 2, 5 and 6.

The chosen building is a two-storey building in an "L" shape. Both levels comprise of open plan office space, meeting rooms, quiet rooms, utility rooms and communal space.

The wall construction is primarily brick with internal insulation behind plasterboard, and an insulated metal deck roof.

HVAC services comprised central chilled and heating hot water plant, including gas-fired boilers and air-cooled chillers serving centralised AHUs with zoned VAV units. Chillers and boilers were set up in a N+1 configuration, with 100% redundancy with equal sized chillers/boilers.

Infiltration to the mode was applied using a Delta T and Wind Speed Coefficients Crack Template, assuming 'Medium' cracks as defined by DesignBuilder.



Overnight Operation Building (Class 3 Hotel)

A representative hotel will be designed and modelled to meet 2019 Section J DTS requirements. Specifically, initial modelling parameters including modelling profiles for the building will be in accordance with Specification JVb and JVc modelling parameters. This includes:

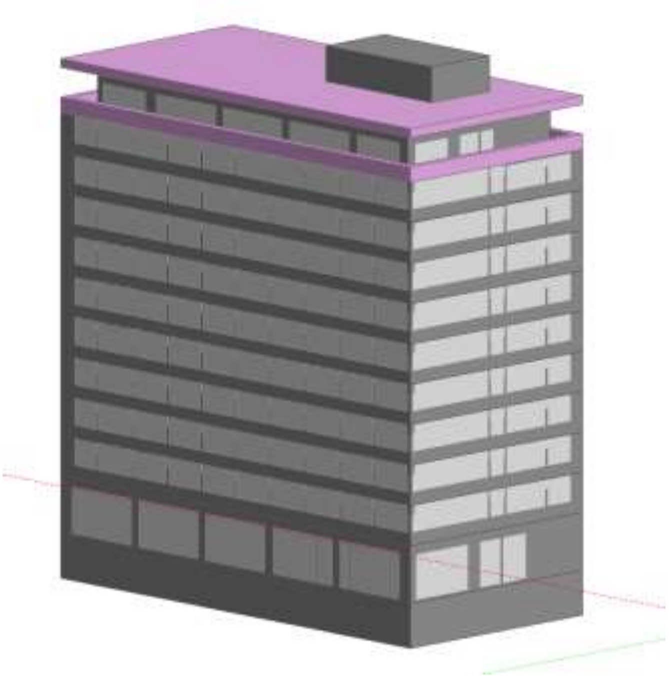
- Occupancy profile; and,
- Operation profiles for artificial lighting (3 W/m^2 for hotel and 14W/m^2 for ground retail), appliances and equipment and air-conditioning; and,

- Internal sensible heat gains for equipment
- Occupant internal heat gains

The modelling in CAMEL and EnergyPlus will be repeated for climate zones 2, 5 and 6. The chosen building is a 10-storey hotel which has been adaptively reused from an old stock office building. The Ground Floor includes retail and offices, Levels 1 to 9 are typical hotel rooms and Level 10 is an office space.

The wall construction is primarily precast panel or brick with internal insulation behind plasterboard, and an insulated metal deck roof. HVAC services comprised centralised chillers and boilers with zoned FCUs. Zones are 1 per hotel room, the café, restaurant, reception etc on ground and on Level 10 perimeter zones and 2x centre zones, with meeting rooms separate.

Infiltration to the mode was applied as per the NCC 2019 JVb Modelling Parameters of 0.7 air changes per hour when there is no mechanically supplied outside air, and 0.35 air changes per hour at all other times.



Appendix A.III.II HVAC Plant Sizing

CAMEL was be used as a load estimation tool to size HVAC plant. Within CAMEL, 'comfort' design conditions will be used to size HVAC plant in CAMEL. The definition of 'comfort' design conditions is based on the AIRAH Comfort and Critical Design Conditions – Air Conditioning Load Estimation.

- The summer "comfort" design conditions are the non-coincident dry-bulb and wet-bulb 3pm temperatures that are individually exceeded on 10 days per year (inclusive of one standard deviation).
- The winter "comfort" design condition is the 8am dry-bulb temperature that is not exceeded on 10 days per year (inclusive of one standard deviation).

The CAMEL models are tabulated below:

Run	Weather File	Fabric	HVAC
HVCR1	Current climate file – *using CAMEL in-built function*	2019 DTS Fabric	HVAC Plant as sized by CAMEL Run 1
HVCR2	Future climate file	2019 DTS Fabric	HVAC Plant as sized by CAMEL Run 2
HVCR3	Future climate file	Adjusted to reduce HVAC size	HVAC Plant sizing to match CAMEL Run 1 as closely as possible

At this point, we compared the HVAC plant sizing between HVCR1 and HVCR2 to determine the impact of using different climate files on design. This result was cross-referenced against thermal comfort modelling results below (specifically thermal comfort outputs from Run 3), to determine if there is a genuine need for an increase/decrease in HVAC plant sizing, or, if the change merely reflects an increase in design contingency.

HVCR 3 was used to assess the extent of design/stringency change in building fabric required in order for HVAC plant sizing to remain unchanged between different climate files.

Appendix A.IV Internal Project Team Workshops

The first internal project team workshop discussed the following items:

- How input variables from climate files are used by building designers for sizing HVAC plant and used within building energy modelling, particularly climate variables identified in the climate data analysis to vary substantially. At minimum, we will discuss the usage and impact of these variables:
    - Dry bulb temperature – maximum, minimum, mean, frequency of occurrence.
    - Wet bulb temperature - maximum, minimum, mean, frequency of occurrence.
    - Wind speed
- How urban heat island effects are accounted for in climate files and simulation software
- Any work on climate file projections by various organisations, not already identified through the literature review.
- Alternative methods besides updating climate files, such that the impact of climate change on building energy consumption and thermal comfort can be addressed.
- Preliminary discussions regarding whether practices in other countries is applicable within the Australian context, and, the provisions within the NCC Section J (JV2, JV3 and DTS) that require consideration or changes.

The second internal project team workshop was held via videoconference to discuss results from the modelling exercise. Internal project team workshop participants included climate experts (Exemplary Energy Partners and CSIRO who have indicated in-principle support) and design engineers (Northrop Consulting Engineers). The workshop discussed and validate the following points:

- Sections of the building code that may require changing, based on the relative magnitude of change in energy or thermal comfort, as identified in the energy modelling;
- Impact of different files on how design trade-offs between HVAC and building fabric (modelled above as poorer glazing performance) are considered; and,

- In-principle changes that may be required to the 2019 NCC Volume One Section J DTS, JV2 or JV3, if any, to avoid adverse outcomes from design trade-offs to overall building greenhouse gas emissions.

Appendix B Supporting Data

Appendix B.I Supporting Data for Section 5.1

Table 21. (Run 1 vs Run 2) Greenhouse gas emissions (kgCO_2) for graphs in Section 5.1.1 – Change in emissions using climate-appropriate HVAC plant (resizing HVAC plant according to climate)

Building Type	Climate Zone	Climate	Heating	Cooling	Fans	Pumps	Others	Total
Office	Climate Zone 2	Current	393	127,948	21,339	35,167	335,803	520,650
		2050	63	164,911	22,713	41,967	335,803	565,457
	Climate Zone 5	Current	1,659	94,038	20,264	30,415	335,821	482,198
		2050	495	133,541	22,097	38,464	335,821	530,419
	Climate Zone 6	Current	15,175	55,800	19,178	27,026	335,818	452,997
		2050	1,842	99,847	21,519	32,416	335,818	491,443
Hotel	Climate Zone 2	Current	162,750	76,700	47,815	19,940	185,835	493,040
		2050	60,354	162,544	51,759	44,454	185,835	504,947
	Climate Zone 5	Current	268,201	34,253	54,224	8,287	184,131	549,096
		2050	121,184	103,079	59,677	26,015	184,131	494,085
	Climate Zone 6	Current	562,661	6,532	54,593	4,122	184,131	812,039
		2050	565,012	6,681	57,114	4,404	184,131	817,342

Table 22. Run 1 vs. Run 3 for graphs in Section 5.1.2 – Change in emissions without climate-appropriate HVAC plant (use baseline HVAC plant to service future climate)

Building Type	Climate Zone	Run	Building Energy Consumption (kWh)	Building GHG Emissions (kgCO_2)	Thermal Comfort Avg PMV (%)
Office	Climate Zone 2	Current	520,650	479,542	92%
		2050	485,925	446,869	73%
	Climate Zone 5	Current	482,198	443,172	96%
		2050	519,449	478,397	62%
	Climate Zone 6	Current	452,997	511,914	99%
		2050	483,698	560,872	72%
Hotel	Climate Zone 2	Current	493,040	334,599	98%
		2050	498,622	414,829	87%
	Climate Zone 5	Current	549,096	308,642	99%
		2050	487,362	359,025	97%
	Climate Zone 6	Current	812,039	394,399	99%
		2050	366,117	372,958	53%

Appendix B.II Supporting Data for Section 5.2.1 (Trading off U-Value)

Table 23. Supporting data for graphs in Section 5.2.1 (Office) – Run 1 vs. 5 and Run 2 vs 4

Building Type	Climate Zone	Run	Building Energy Consumption (kWh)	Building GHG Emissions (kgCO$_2$)	Thermal Comfort Avg PMV % (target 98%)	Thermal Comfort Area % Compliant (target 95%)
Office	Climate Zone 2	Current Reference	520,650	479,542	92%	0%
		Current Uvalue + 20%	520,552	479,447	92%	0%
	Climate Zone 5	Current Reference	482,198	443,172	96%	39%
		Current Uvalue + 20%	482,117	443,077	96%	39%
	Climate Zone 6	Current Reference	452,997	511,914	99%	97%
		Current Uvalue + 20%	453,257	511,846	99%	97%
Office	Climate Zone 2	Future Reference	565,457	521,079	48%	0%
		Future Uvalue + 20%	528,098	486,361	61%	0%
	Climate Zone 5	Future Reference	530,419	488,469	63%	0%
		Future Uvalue + 20%	530,372	488,424	63%	0%
	Climate Zone 6	Future Reference	491,443	569,650	72%	0%
		Future Uvalue + 20%	491,419	569,573	72%	0%

Table 24. Supporting data for graph is in Section 5.2.1 (Office) - Proposed Building vs. Reference Building

		Building Energy Consumption (Proposed vs. Reference)	**Building GHG Emissions** (Proposed vs. Reference)	**Thermal Comfort Avg PMV** (Proposed vs. Reference)
Trade off U-value now	Now CZ2	-0.02%	-0.020%	0.00%
	Now CZ5	-0.02%	-0.022%	0.00%
	Now CZ6	0.06%	-0.013%	0.00%
Trade off U-value in 2050	2050 CZ2	-6.61%	-6.663%	13.05%
	2050 CZ5	-0.01%	-0.01%	0.03%
	2050 CZ6	0.00%	-0.014%	0.02%

Table 25. Supporting data for graphs in Section 5.2.1 (Hotel)

Building Type	Climate Zone	Run	Building Energy Consumption (kWh)	Building GHG Emissions (kgCO$_2$)	Thermal Comfort Avg PMV (%)	Thermal Comfort Area % Compliant
Hotel	Climate Zone 2	Current Reference	493,040	334,599	98%	81%
		Current Uvalue + 20%	493,200	334,614	98%	81%
	Climate Zone 5	Current Reference	549,096	308,642	99%	91%
		Current Uvalue + 20%	549,361	308,680	99%	91%
	Climate Zone 6	Current Reference	812,039	394,399	99%	88%
		Current Uvalue + 20%	837,055	399,037	99%	88%
Hotel	Climate Zone 2	Future Reference	504,947	420,939	88%	0%
		Future Uvalue + 20%	505,223	421,134	88%	0%
	Climate Zone 5	Future Reference	494,085	366,155	97%	73%
		Future Uvalue + 20%	494,286	366,232	97%	73%
	Climate Zone 6	Future Reference	817,342	398,277	99%	88%

		Future Uvalue + 20%	842,643	402,923	99%	88%

Table 26. Supporting data for graph is in Section 5.2.1 (Hotel) - Proposed Building vs. Reference Building

		Building Energy Consumption (Proposed vs. Reference)	**Building GHG Emissions** (Proposed vs. Reference)	**Thermal Comfort Avg PMV** (%)
Trade off U-value now	Now CZ2	0.05%	0.046%	0.05%
	Now CZ5	0.04%	0.02%	0.01%
	Now CZ6	3.10%	1.167%	-0.04%
Trade off U-value in 2050	2050 CZ2	0.03%	0.005%	-0.19%
	2050 CZ5	0.05%	0.012%	0.00%
	2050 CZ6	3.08%	1.176%	-0.04%

Appendix B.III Supporting Data for Section 5.2.2 (Trading off SHGC)

Table 27. Supporting data for graphs in Section 5.2.2 (Office)

Building Type	Climate Zone	Run	Building Energy Consumption (kWh)	Building GHG Emissions ($kgCO_2$)	Thermal Comfort Avg PMV (%)	Thermal Comfort Area % Compliant
Office	Climate Zone 2	Current Reference	520,650	479,542	92%	0%
		Current SHGC + 20%	528,913	487,221	89%	0%
	Climate Zone 5	Current Reference	482,198	443,172	96%	39%
		Current SHGC + 20%	489,003	449,670	95%	17%
	Climate Zone 6	Current Reference	452,997	511,916	99%	97%
		Current SHGC + 20%	456,781	518,288	98%	92%
Office	Climate Zone 2	Future Reference	565,457	521,079	48%	0%
		Current SHGC + 20%	573,495	528,501	43%	0%
	Climate Zone 5	Future Reference	482,117	443,077	63%	0%
		Current SHGC + 20%	537,973	495,497	59%	0%
	Climate Zone 6	Future Reference	491,443	511,846	72%	0%
		Current SHGC + 20%	498,110	577,763	68%	0%

Table 28. Supporting data for graphs in Section 5.2.2 (Office) - Proposed Building vs. Reference Building

		Building Energy Consumption (Proposed vs. Reference)	**Building GHG Emissions** (Proposed vs. Reference)	**Thermal Comfort Avg PMV** (Proposed vs. Reference)
Trade off SHGC now	Now CZ2	1.59%	1.601%	-3.94%
	Now CZ5	1.41%	1.466%	-1.33%
	Now CZ6	0.84%	1.245%	-0.66%
Trade off SHGC in 2050	2050 CZ2	1.42%	1.424%	-4.48%
	2050 CZ5	1.42%	1.439%	-3.72%
	2050 CZ6	1.36%	1.424%	-4.06%

Table 29. Supporting data for graphs in Section 5.2.2 (Hotel)

Building Type	Climate Zone	Run	Building Energy Consumption (kWh)	Building GHG Emissions (kgCO$_2$)	Thermal Comfort Avg PMV (%)	Thermal Comfort Area % Compliant
Hotel	Climate Zone 2	Current Reference	493,040	334,599	98%	81%
		Current SHGC + 20%	494,810	341,568	98%	80%
	Climate Zone 5	Current Reference	549,096	308,642	99%	91%
		Current SHGC + 20%	544,397	311,154	99%	90%
	Climate Zone 6	Current Reference	812,039	394,399	99%	88%
		Current SHGC + 20%	799,115	392,679	99%	88%
Hotel	Climate Zone 2	Future Reference	504,947	420,939	88%	0%
		Current SHGC + 20%	519,312	437,042	89%	0%
	Climate Zone 5	Future Reference	494,085	366,155	97%	73%
		Current SHGC + 20%	498,222	374,095	97%	80%
	Climate Zone 6	Future Reference	817,342	398,277	99%	88%
		Current SHGC + 20%	804,304	396,525	99%	88%

Table 30. Supporting data for graphs in Section 5.2.2 (Hotel) - Proposed Building vs. Reference Building

		Building Energy Consumption (Proposed vs. Reference)	**Building GHG Emissions** (Proposed vs. Reference)	**Thermal Comfort Avg PMV** (%)
Trade off SHGC now	Now CZ2	0.36%	2.083%	-0.32%
	Now CZ5	-0.86%	0.814%	-0.08%
	Now CZ6	-1.59%	-0.436%	-0.03%
Trade off SHGC in 2050	2050 CZ2	2.84%	3.826%	1.66%
	2050 CZ5	0.84%	2.169%	-0.07%
	2050 CZ6	-1.60%	-0.440%	-0.03%