FUTURE PROOFING RESIDENTIAL DEVELOPMENT IN WESTERN SYDNEY

2022

WSROC

TURN DOWN THE HEAT

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The ***Future Proofing Residential Development in Western Sydney*** project works towards delivery of the Turn Down the Heat Strategy and Action Plan (2018). Recommendations for heat-resilient building design will inform future work to improve land use controls and design retrofit programs. The Turn Down the Heat Strategy was developed by 55 organisations across greater Sydney to create cooler, more resilient communities.

This project builds on the ***Future Proofing Residential Development to Climate Change (2021)*** study by Randwick, Woollahra and Waverley councils.

This project is a collaboration between WSROC, WSP and the University of NSW. The project was supported by Blacktown City Council, Hawkesbury City Council, and Liverpool City Council. This project has been assisted by the New South Wales Government and supported by Local Government NSW.

WSROC acknowledges Aboriginal and Torres Strait Islander peoples as the traditional custodians of the lands and waters of this place we now call Metropolitan Sydney. We pay our respect to Elders past, present and future of the Eora, Dharawal (Tharawal), Gundungurra, Dharug (Darug) and Guringai (Kuring-gai) peoples.

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Cars parked in driveways along a Western Sydney residential street.

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ACRONYMS

ABCB	Australian Building Codes Board
BASIX	Building Sustainability Index
AEMO	Australian Energy Market Operator Limited
BoM	Australian Bureau of Meteorology
CIBSE	The Chartered Institution of Building Services Engineers
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DIY	Do-It-Yourself
DTS	Deemed-to-satisfy
EER	Energy Efficiency Ratio
GHG	Greenhouse Gas
ICC	International Code Council
IPCC	Intergovernmental Panel for Climate Change
NatHERS	Nationwide House Energy Rating Scheme
NCC	National Construction Code
NSW	New South Wales
RCP	Representative Concentration Pathways
RMY	Reference Meteorological Year
SHGC	Solar Heat Gain Coefficient
TDTH	Turn Down the Heat
WoH	Whole-of-Home
WSROC	Western Sydney Regional Organisation of Councils

EXECUTIVE SUMMARY

The thermal performance of homes is becoming increasingly important as Australia's climate warms. Improving the thermal performance of residential buildings has been identified as critical both for reducing carbon emissions (NSW Department of Planning, Industry and Environment 2020), and mitigating the impacts of a warming climate to human health, cost of living and infrastructure resilience (Resilient Sydney 2018, Greater Cities Commission 2020, WSROC 2022).

In New South Wales (NSW) the residential sector is responsible for around one third of the state's total electricity consumption (Commonwealth of Australia 2022, NSW Environment Protection Authority 2022). At present, the largest share of household energy is used for air conditioning to maintain a comfortable indoor environment (Pipkorn, Reardon et al. 2021). Energy demand for space cooling is expected to increase if buildings are not designed for the future warming climate. A well-designed building can last for many decades, and it is therefore important that the homes designed and built today are energy efficient and heat resilient now and over their likely lifecycle.

BUILDING REGULATIONS

The NSW Government has regulated energy and water efficiency of residential dwellings, including thermal performance of the building envelope, through Building Sustainability Index (BASIX) since 2004. There are several methods to demonstrate thermal performance in BASIX, however the Nationwide House Energy Rating Scheme (NatHERS) is the most commonly used. NatHERS provides a flexible approach to meet the energy efficiency requirements of both BASIX and the National Construction Code (NCC). It determines building envelope energy efficiency using stars, from 0 – 10, where higher stars mean better thermal performance and lower energy demand to maintain thermal comfort. Post-occupancy energy monitoring however demonstrates that buildings often consume more energy than is estimated at the design stage; representing an energy performance gap (Ambrose MD, James M et al. 2013, Ding, Upadhyay et al. 2019).

To improve the thermal performance of new builds, the Australian Government updated the National Construction Code in 2022 (NCC 2022, effective October 2023). The NCC 2022 includes new NatHERS climate files, and raises the minimum thermal comfort standard for new dwellings to NatHERS 7-star.

Correspondingly, the NSW Government has also increased its BASIX thermal comfort standard to align with the NCC 2022 through *State Environmental Planning Policy (Sustainable Buildings) 2022.*

NCC CHANGES AS ANNOUNCED IN 2022

Current NatHERS. Minimum star rating requirement for new houses and apartments is 6 stars (out of 10). Climate files used in NatHERS software tools, approved for regulatory use until October 2023, are developed using weather data from the period 1967 to 2004.

NCC 2022 (mandatory from October 2023). The minimum requirement for new houses and apartments will increase from 6 to 7 stars. Climate files used in NatHERS software tools are developed using weather data from 1990 to 2015. NCC 2022 is approved for regulatory use from 2022, and will become mandatory from October 2023.

WESTERN SYDNEY'S CHANGING CLIMATE

This study looks at BASIX compliant residential dwellings in Western Sydney (NatHERS climate zone 28) to evaluate whether the current regulations are delivering energy efficiency and heat resilience now and in future. The Western Sydney region is an interesting study for this report for several reasons. First, Western Sydney expects to house more than half of Greater Sydney's total dwellings over the next five years. Secondly, the region already experiences increasingly warm weather, and more extremes compared to Eastern Sydney.

Western Sydney has experienced seasonal shift (i.e., cool periods have shrunk, and warm periods have extended), and the rate of temperature rise in the warm period is significantly higher than the temperature rise in the cool period. As such, it is estimated that the number of hot days (30°C or higher) will increase significantly in the future. At the same time, Western Sydney will continue to witness sub-zero temperatures in winter for around two weeks. The changing climate requires that building design practices be changed and building construction techniques improved.

THIS STUDY

This study is delivered under the Western Sydney Regional Organisation of Councils' Turn Down the Heat Strategy, and is assisted by the New South Wales Government and supported by Local Government NSW. It examines the performance of sample houses (single-storey and double-storey) and multi-unit buildings in a range of scenarios. This includes:

- Examining dwelling energy performance in Western Sydney (Climate Zone 28), based on the following five climate scenarios using a NatHERS accredited tool:
    1. Current NatHERS climate (approved for regulatory use until October 2023)
    2. NCC 2022 climate (approved for regulatory use in 2022, to become mandatory from October 2023)
    3. Current experienced climate (represents the climate scenario of 2020)
    4. Future climate of 2030
    5. Future climate of 2050
- Evaluating indoor temperatures when dwellings are subject to a heatwave scenario; both with air conditioning and in free running mode (without air conditioning).
- Modifying the design of dwellings to meet the higher BASIX standards (as outlined in Sustainable Building SEPP 2022) in the climate of 2050. The future focused designs are then re-evaluated using the current and NCC 2022 NatHERS climate files to check if today's BASIX standards allow designing for the future.

The research methodology for this study broadly aligns with Waverley Council's *Future Proofing Residential Development to Climate Change* study (WSP 2021), which focused on the Sydney Eastern Beaches.

New housing being constructed at Marsden Park, looking towards the Blue Mountains.

FINDINGS

NatHERS climate files are outdated and as a result prioritise dwellings that are efficient to heat.
The climate analysis highlights that both the current and updated (NCC 2022) NatHERS files for Western Sydney are outdated, representing the climatic conditions of pre-1980 and pre-2010 respectively (Figure 1). Importantly, both NatHERS climate files overestimate the cool period and underestimate the warm period of Western Sydney's climate. This is important because assuming a cooler climate will promote dwelling designs that are more efficient to heat than cool. Across the dwellings modelled as part of this study, the average cooling and heating loads are 35% and 65% respectively when modelled using the NCC 2022 NatHERS climate file. In the 2050 scenario, the proportion of energy expended on cooling increases to 70% and heating drops to 30%. This means that dwellings built to current and updated BASIX standards will consume significantly higher amounts of energy for cooling in future. In this case, Australian dwellings would neither be energy efficient nor heat resilient.

Current BASIX-approved dwellings become thermally unsafe during extreme heat if air conditioning is unavailable. The current BASIX complied dwellings were also shown to be thermally unsafe during the extreme weather (2017 heatwave) scenario if they did not have air conditioners, or if the air conditioners were not turned on during the heatwave. On average, indoor temperature in the afternoon remained around 5degreeC less than outdoor temperature, but exceeded 30°C for a few hours when the outdoor temperature hit 40°C. The night-time indoor minimum temperature, aligned with outdoor minimum temperature, exceeding 23°C which can be uncomfortable whilst sleeping.

Homes that perform well in 2050 are not allowed to be built under today's BASIX standards.
This study also presents broad design strategies to assist building designers and builders to design homes to suit future climate conditions, and tests these strategies using future climate files. A future-focused design should address increasingly warm conditions, in addition to the cool period experienced for a few months. Buildings in Western Sydney should be well shaded and insulated to avoid any heat gain during summer but should harness solar exposure to warm up the indoors during the winter months.

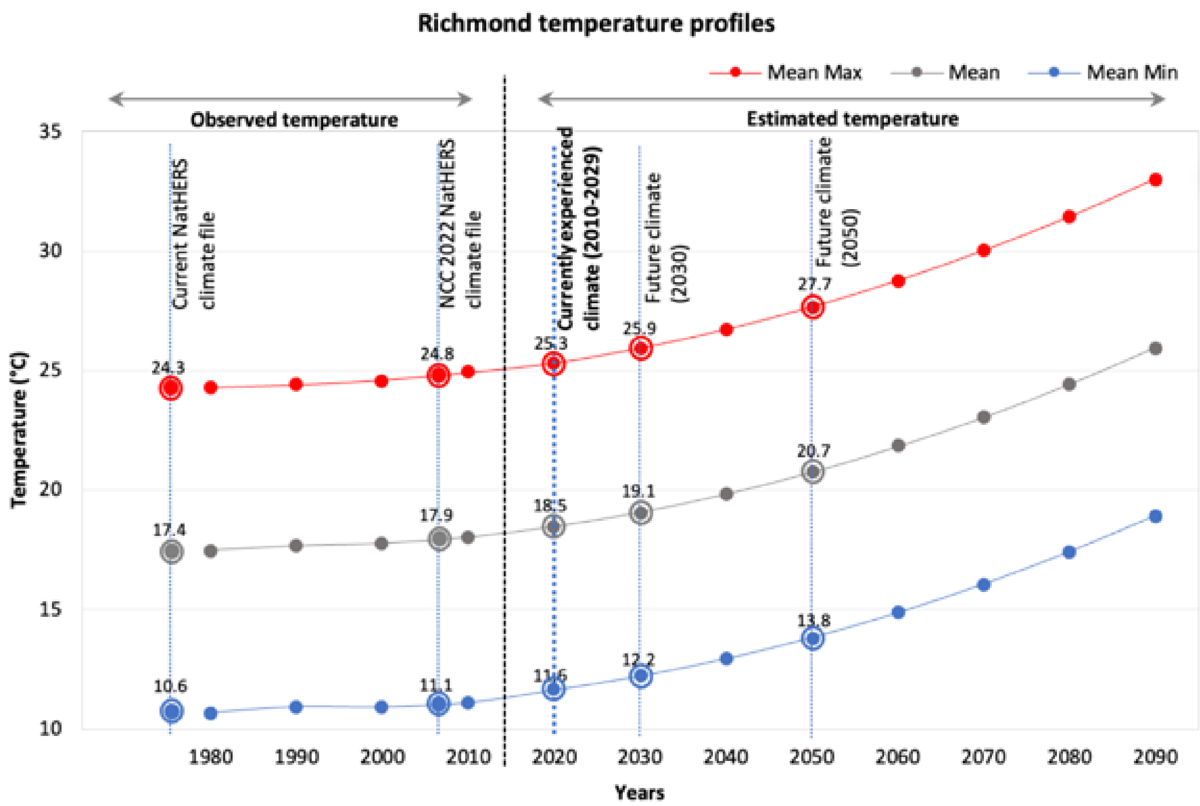

Figure 1: The Western Sydney (Richmond) temperature profile presents observed mean maximum, mean and mean minimum temperatures from 1980 to 2010 and estimated temperatures from 2020 until 2090. Raw yearly temperature data is normalised by taking 20 years of running average, i.e., temperature for 1980 is derived by taking average of 1970 – 1989 (Data source: Commonwealth of Australia 2022)

Some simple design adjustments were made to the selected dwellings to ensure they meet the higher BASIX standards using future (2050) climate scenario.

It was observed that the freestanding houses which met the higher BASIX standards using future (2050) climate data file failed to meet the heating cap of the current BASIX standards, and heating and total caps of higher BASIX standards using NatHERS 2022 climate file. This means houses which perform better in future climates are not allowed to be built under NSW's current BASIX standards. However, the apartments in multi-unit dwellings which were optimised for the warmer future climate satisfy the BASIX caps of current and the higher standards. By optimising the design of selected houses and apartments for the future (2050) warmer climate, it was possible to halve the cooling load with NCC 2022 NatHERS climate file.

RECOMMENDATIONS

Future regulatory updates should use more representative climate files to minimise cooling energy consumption and deliver better heat resilience. The recent update of the NatHERS climate file through NCC 2022 failed to acknowledge the climate change already experienced in Australia, and that projected in future. If the issue is not addressed urgently, buildings will continue to be designed for an outdated climate scenario.

Government policies should encourage construction of buildings that are designed for the future climate and provide incentives to do so. Buildings that are optimised for much cooler conditions (the current BASIX complied development) will require excessive energy for cooling, particularly in extreme heat scenarios, putting more stress on the electricity grid. Designing for the future warmer climate (refer Tables 8 and 10 for modifications) will help reduce cooling energy demand now, and reduce pressure on the electricity network, allowing network providers time to meet the additional energy demand in future.

The NSW Government should review thermal comfort targets for low-rise multi-unit buildings to ensure they offer the same level of thermal comfort as houses and apartments in high-rise buildings. The 2022 BASIX review did not increase thermal comfort stringency for multi-unit buildings up to five storeys, therefore in this study, the apartment in a low-rise building had the highest cooling energy load compared with other dwellings. Occupants of apartments in low- rise multi-unit buildings would need to deal with significant heat stress as well as energy shock due to poor thermal performance of their apartments.

Future regulatory updates should address thermal safety to ensure at least part of a dwelling can maintain an acceptable indoor environment during extreme weather events without a mechanical heating and cooling system. Australian buildings are not currently required to demonstrate thermal safety. Thermal safety guarantees occupants' thermal comfort even when air conditioning cannot be run as may be the case in a heatwave-induced blackout, or where energy is unaffordable.

NatHERS should investigate the validity of current thermostat settings, by monitoring houses, to check if the adaptive thermal comfort method is still applicable given the increase in prevalence of ducted air-conditioners. The NatHERS tool uses an adaptive thermal comfort model to determine cooling thermostat settings which regulates the cooling set point temperature. The NCC 2022 NatHERS climate file for Western Sydney (Climate zone 28) has the cooling thermostat setting of 25°C which is 0.5degreeC higher than the cooling thermostat setting used in the current NatHERS climate file. On the other hand, newly introduced NatHERS Whole-of-Home (WoH) tool, specifically focused on energy efficient requirement in the NCC 2022, uses 24°C for cooling thermostat setting for Western Sydney. The different thermostat settings used in NatHERS tools for the same climate zone is confusing.

NatHERS should further investigate the assumed occupancy profile and user behaviour associated with operation of air conditioners. Updates should be informed by monitored empirical data. The home occupancy profile in the NatHERS tool does not reflect a real-life household setting, particularly after the COVID-19 pandemic. NatHERS space occupancy assumes that living spaces are occupied from 7am to midnight and bedrooms are occupied from 4pm to 9am. Outside the assumed occupancy period, NatHERS tool assumes heating/cooling systems will not be used. Since a large portion of the workforce is now working from home, it is likely that bedrooms are being used as workspaces and that air conditioning would be used to cool bedrooms on a hot day. Besides, if the whole house is not cooled from the early morning on a hot day, it is almost impossible to maintain thermal comfort throughout the day due to excessive heat trapped inside the house. Therefore, assumed room occupancy and heating/cooling schedule in the NatHERS tool may contribute to a large energy performance gap in NatHERS rated houses.

THE PROJECT TEAM

UNIVERSITY OF NSW (UNSW)

Since its foundation in 1949, UNSW Sydney has made an ongoing commitment to improve and transform lives in Australia and globally. The Faculty of Arts, Design and Architecture is committed to tackle society's most pressing problems relating to people, place and cultures.

Dr Anir Upadhyay

Dr Upadhyay is a Lecturer at UNSW Built Environment and UNSW Global. Anir is trained as an architect and urban planner. He holds a PhD in Sustainable Design from the University of Sydney. Anir's research mainly interrogates real-world problems related to sustainability and energy efficiency in the built environment. His research explores fundamental issues of sustainable built environment at design and post-occupancy stages by using simple design tools and analysing big data sets. Anir worked closely with the NSW Government to explore post-occupancy energy consumption of BASIX affected dwellings in the Greater Sydney Region.

Anir has developed a simplified climate data analysis method to graphically present climate information to help building designers to develop location specific climate design strategies. Anir co-designed VIHEW which tracks indoor environmental conditions, energy, and water consumption in real-time and recommends occupants various natural/ low energy strategies to make the indoor environment comfortable. VIHEW received Committee for Sydney's Smart City Award (2019) for the best data as an enabler initiative. Anir has published widely in sustainable building design and has presented in conferences nationally and internationally. Anir teaches Building Ecology and Life Cycle Thinking and Energy and the Built Environment courses in Master of Architecture program at UNSW Built Environment.

WSP

WSP is one of the world's leading engineering professional services consulting firms, bringing together approximately 4,500 talented people across 14 offices in Australia. We are technical experts who design and provide strategic advice on sustainable solutions, and future ready engineering projects that will help societies grow for lifetimes to come. We believe that for societies to thrive, we must all hold ourselves accountable for tomorrow. That means creating innovative solutions to the challenges the future will bring. It inspires us to stay curious, act locally, and think internationally.

The research WSP conducted for Waverley Council on the performance of residential dwellings in Eastern Sydney under future climate scenarios highlighted a risk to human health and energy efficiency. This report presents an extension of that investigation, to further develop an understanding of both the climate risks we face, and the measures that we can be putting in place now to improve our resilience to a changing climate.

Katie Fallowfield

Katie is Director of Sustainability at WSP. Katie's extensive experience in sustainable design has led to a thorough understanding of the various options available for thermal comfort and resource efficiency from an individual dwelling to precinct scale applications.
Her previous experience with local government provides an in depth understanding of the planning process and regulatory controls in development. Katie's particular focus is on passive design opportunities and innovative water use reduction strategies.

Katie is a member of the ASBEC Residential Energy Efficiency Advisory Group, a Green Star Accredited Professional, NatHERS Accredited Assessor, LEED Accredited Professional and has a distinct passion for passive design and achieving the best environmental outcome for projects through the simplest and most cost-effective measures.

Nick Asha

Nick is Associate Sustainability at WSP. Nick is a sustainability professional with experience across a breadth of engineering roles including sustainability consulting, infrastructure, industrial automation and engineering design. Nick combines a passionate and pragmatic approach to sustainable building and infrastructure solutions, with technical expertise in a comprehensive suite of analytical techniques. His specialist areas of interest include energy and thermal modelling, daylight and visual comfort assessment, passive design and sustainable waste management.

Nick has worked extensively on projects throughout Australia in the public, industrial, hospitality, commercial, retail and residential sectors.

Patricia Rocha

Patricia is WSP's Senior Sustainability Consultant with over six years of experience working closely with local councils in each Australian State and Territory, successfully delivering Energy Efficiency reports for multiple residential and commercial buildings. She holds a Bachelor's in Architecture and a Masters of Sustainable Development.

Patricia has experience in detailed thermal performance analysis, energy efficiency reports and sustainability management plans. Her key areas of interest include building physics, occupant comfort and façade engineering.

WSROC

Formed in 1973, the Western Sydney Regional organisation of Councils (WSROC) is a membership organisation that represents local councils in the Greater Western Sydney region. With a reputation for considered policy analysis and bipartisan advocacy, WSROC brings a collective voice to those issues which are crucial for Greater Western Sydney's growing population.

WSROC has led work on heat resilience since the release of its Turn Down the Heat Strategy in 2018. Turn Down the Heat has taken a collaborative, multi-sector approach to tackling heat in Western Sydney, with a focus on delivering practical outcomes for communities. Other WSROC-led projects being delivered under the Turn Down the Heat Strategy include:

- **Urban Heat Planning Toolkit:** to help local government strengthen their planning provisions to reduce the impacts of heat.
- **Cool Suburbs:** a rating and assessment tool for building heat resilience in urban planning and development.
- **Heat Smart Western Sydney:** identifies the processes and structures needed for the city to manage to heatwave emergencies, with a focus on how we can support our most vulnerable.
- **Climate Ready Canopy:** Species selection and passive irrigation for a cool urban canopy in a changing climate

Judith Bruinsma

Judith is Project Coordinator at the Western Sydney Regional Organisation of Councils (WSROC). Judith has over 15 years' experience in the local government sector in the Netherlands and Australia, with a particular expertise guiding complex, multi-stakeholder projects on topics including urban heat, climate resilience, emission reduction, and sustainability.

Kelly Gee

Kelly is Policy and Projects Officer at the Western Sydney Regional Organisation of Councils (WSROC). Kelly has a background in public relations and policy development in the local government and private sectors. Kelly has extensive experience working across sectors and industries on heat resilience and heatwave emergency management.

INTRODUCTION

Heat (climate change, urban heat and heatwaves) is widely acknowledged by governments to be a critical challenge for Australia. Impacts are already experienced across human health, cost of living and infrastructure resilience (Blacktown City Council 2018, Resilient Sydney 2018, Greater Cities Commission 2020, Hawkesbury City Council 2021, Penrith City Council 2021, NSW Environment Protection Authority 2022, WSROC 2022). Globally, 2010-2019 was characterised as the warmest decade with frequent heatwaves, lower rainfall, and more extreme weather events (World Meteorological Organization 2021). Similar weather events were observed in Australia (Commonwealth of Australia 2020). Climate change is acknowledged as a key driver for this trend, however, the impact of climate change is not uniform around the globe as some regions/places are more vulnerable than others due to various factors including geography, microclimate and local development-related issues such as heat island impacts.

In NSW, the recent State of the Environment Report (NSW Environment Protection Authority 2022) paints a dire picture of the future if measures to reduce GHG emissions are not introduced soon. Since GHG emissions and global temperature rise are correlated (Intergovernmental Panel for Climate Change 2021), it is critical that global GHG emissions are brought down to net zero by mid-century to limit the global warming well below 2degreeC compared to pre-industrial level (United Nations 2022).

The NSW residential sector accounts for around one third of the state's total electricity consumption (Commonwealth of Australia 2022, NSW Environment Protection Authority 2022) and a correspondingly large share of the state's greenhouse gas (GHG) emissions. As such, addressing residential energy consumption is critical if we are to meet NSW's Net Zero targets (NSW Government 2020, NSW Government 2022).

In addition to climate mitigation via emissions reduction, recent weather events demonstrate that climate adaptation is equally important. This means ensuring residential development is designed to keep people physically safe in a warming climate, and limit financial impacts associated with rising energy use.

THERMAL COMFORT AND BUILDING ENERGY EFFICIENCY IN AUSTRALIAN DWELLINGS

The homes we build today will be in place for many decades to come. It is reasonable to expect that houses built to contemporary standards should offer thermal comfort now, as well as in the foreseeable future, using the least necessary levels of mechanical heating and cooling. The Australian Government has embedded energy efficiency in the National Construction Code, NCC (previously called Building Code of Australia) since 2002. The NCC mandates buildings to meet minimum thermal performance standards through Deemed-to-Satisfy (DTS) provisions or using Nationwide House Energy Rating Scheme (NatHERS) accredited software packages. NatHERS uses a star rating scheme which ranges from 0 to 10, where 0-star represents inability of the design to achieve thermal comfort, and 10-stars represents the least energy needed to mechanically maintain thermal comfort (Figure 2). The NCC 2019 mandates a minimum of 6-stars along with heating and cooling load limits to ensure houses maintain reasonable level of thermal comfort in cool and warm seasons. Recently, Commonwealth, State and Territory building ministers agreed to adopt a minimum standard of 7-stars through NCC 2022 effective from 1st October 2023.

BUILDING SUSTAINABILITY INDEX (BASIX) IN NEW SOUTH WALES

State and territory governments can vary NCC provisions and introduce additional measures. In 2004, the NSW Government introduced the Building Sustainability Index (BASIX). BASIX is a web-based tool that uses design stage information to generate BASIX commitments for sustainable residential buildings. The tool offers multiple options for demonstrating compliance either through Do-It-Yourself (DIY) method or complying with NatHERS pathways or *Passive House* standards (Australian Passive House Association 2022). BASIX regulates water saving measures, and GHG emissions reductions through minimum performance requirements and appliance energy efficiency at the development application stage, for new developments and major renovations. In August 2022, the NSW Government introduced the new *State Environmental Planning Policy (Sustainable Buildings) 2022* which aligns the BASIX thermal performance targets for new dwellings in NSW to NatHERS targets set in NCC 2022, meeting at least NatHERS 7-stars equivalent, except homes in the North Coast climate zones and apartment buildings up to five storeys.

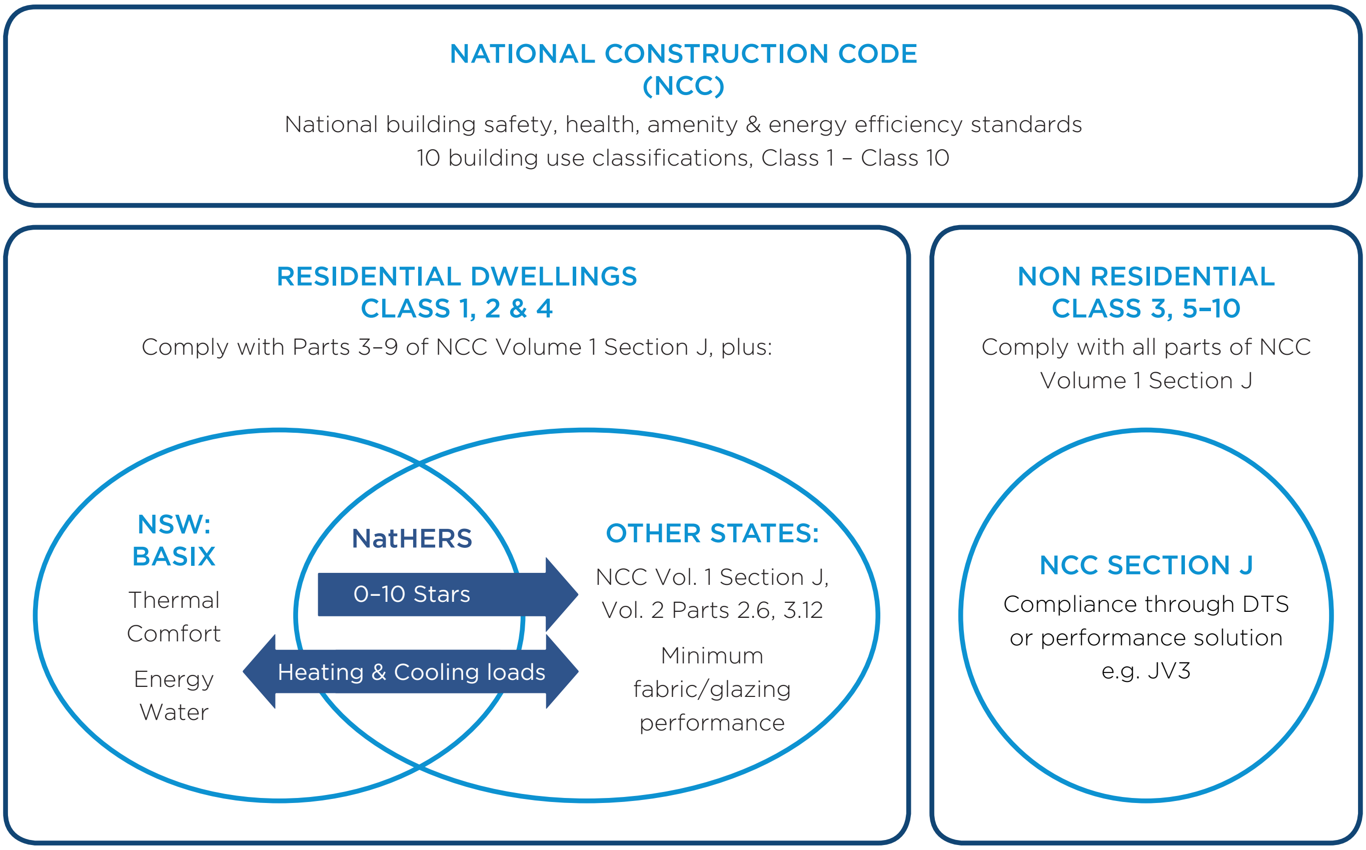

Figure 2: A high-level overview of state and federal policies governing thermal comfort. Outlines relationship between National Construction Code, NatHERS and NSW BASIX State Environmental Planning Policy.

**Note that some additional variances exist in relation to some states/territories or building classes.*

DESIGNING FOR THE FUTURE

It is estimated that energy demand for space conditioning in Australian dwellings, particularly for cooling, will continue to increase due to anticipated warmer climate in the future (Strategy. Policy. Research. 2019). Homeowners are often encouraged to go beyond minimum requirements and achieve a higher star-rating to demonstrate their commitment towards building sustainability. However, the star-rating system assesses thermal performance and building energy efficiency using climate files which portray late last century's climate scenario. As a result, a 9-star house built in 2022, has achieved this rating based on its ability to perform in last century's climate – one that is cooler than we have recently experienced or will be experiencing in future. As a result, these higher star-rated houses may not be thermally safe homes in the future.

THE IMPORTANCE OF THERMALLY SAFE HOMES

Unlike most other building types, homes have a fundamental requirement to provide people safety at all hours and under all circumstances. Thermally safe environments, which maintain an acceptable range of temperatures, are critical to protect the occupants from injury or death resulting from over heating/cooling. Since NatHERS assumes each house is equipped with mechanical heating and cooling systems to meet energy demand, the value of passive solar design is gradually decreasing. As such, reliance on mechanical cooling undermines passive solar design strategies and results in dwelling designs that are less climate responsive (Healy 2008, Mellick Lopes, Arora et al. 2020). These dwellings often become extremely energy intensive and expensive to run during extreme heat or cold periods.

During heat wave events, some people have the option of seeking shelter from heat in cooler public places such as shady parks, swimming pools or natural water bodies, or inside air-conditioned buildings like libraries and shopping malls. But many people, especially the elderly or those with limited mobility have no choice but to remain at home.

Even when people seek refuge in cool locations during the day, most must return home at night when temperatures may still be very high. Extreme heat events with little overnight respite are widely considered to present the biggest health risks for vulnerable people, by prolonging heat exposure (Loughnan, Tapper et al. 2013).

THERMAL AUTONOMY

Thermal autonomy is the aspect of thermal safety that determines whether people will remain safe in their homes without air conditioning during heatwaves (Levitt, M. Ubbelohde et al. 2013). Thermal autonomy is considered a better gauge of a building's resilience to heatwaves. It excludes supplemental air conditioning from the assessment of comfort, so reflects conditions where power is lost as well as the performance of buildings that either have no air conditioning, or where occupants cannot afford to use it.

Australian dwellings are not currently required to demonstrate thermal autonomy (March, Legacy et al. 2021). Further, a recent report highlights that the current BASIX standards for thermal comfort restricts building designers in delivering homes designed for the future warmer climate (Upadhyay, Munsami et al. 2019).

THERMAL AUTONOMY INTERNATIONALLY

Internationally, the UK Government is planning to introduce the Future Homes Standard by 2025 which will include overheating mitigation strategies in new dwellings in England (UK Government 2019). The Chartered Institution of Building Services Engineers (CIBSE) TM59 is used in the UK to assess overheating in residential and non-residential buildings. The TM59 uses adaptive thermal comfort standard (BS EN 15251) to determine upper comfort temperature and mandates that indoor temperatures do not exceed the upper limit more than 3% of occupied summer hours. Further, it requires that the bedroom temperature from 10pm to 7 am cannot exceed 26°C for more than 1% of hours over a full year to ensure night-time thermal comfort in dwellings (CIBSE 2017).

RESILIENCE APPROACH

While climate warming can be mitigated, hot weather and heatwaves can't be eliminated. Therefore, we need to improve buildings' resilience to heat; responding with strategies that minimise the impacts of intense shocks such as heatwaves and the ongoing stress of frequent hot and very hot weather.

A resilience approach involves not only mitigating climate change and reducing urban heat, but also helping people adapt to a hotter climate, and being prepared to respond in extreme events. Buildings designed and built now and in future must ensure thermal comfort, energy and water efficiency, and affordable cooling systems (when required) to ensure everyone has equitable access to a thermally safe home now and in the foreseeable future. The International Code Council (ICC) acknowledges that building codes need to be updated to incorporate future focused climate risk such as heatwaves (International Code Council n.d.).

Beyond individual household requirements, well-performing residential dwellings also deliver broader system benefits including reduced demand on the energy grid and mitigation of urban heat islands, both of which will assist local, state, and federal governments to achieve climate change mitigation targets and commitments.

WESTERN SYDNEY: A HIGH RISK REGION

Greater Sydney extends from coast (in the east) to inland, including Blue Mountains (in the far west). Due to significant topographical variations, local climate varies across Greater Sydney. Coastal Sydney exhibits a relatively small diurnal temperature range with the temperature hovering in between 10°C and 30°C for around 95% of the year. On the other hand, around 50 km away, at the foothills of the Blue Mountains, the temperature range in Western Sydney is larger with early morning temperatures dropping below 5°C (occasionally sub zero) in winter, and afternoon temperatures generally exceeding 30°C in summer. Coastal suburbs usually enjoy a cool breeze on summer afternoons and in the evenings, but this breeze does not reach the western suburbs. Overall, Western Sydney exhibits very different climate characteristics to Eastern Sydney.

Urban heat and heatwaves are significant and growing issues for Western Sydney. Not only is Western Sydney's climate hotter due to local geography, it is also experiencing the impacts of climate change, and a growing urban heat island effect due to rapid and extensive urbanisation. According to the latest *5-year Sydney housing supply forecast (2021/22 – 2025/26)* (NSW Department of Planning and Environment 2022), more than 55% of the total dwellings in Greater Sydney will be built in 12 Western Sydney local councils (Blacktown, Blue Mountains, Camden, Campbelltown, Cumberland, Fairfield, Hawkesbury, Liverpool, Parramatta, Penrith, The Hills Shire and Wollondilly). Urban heat has been identified as a priority issue by the Greater Cities Commission (2020), and the Western Sydney Regional Organisation of Councils (WSROC). Local councils and other organisations are tackling urban heat on multiple fronts to ensure houses are thermally safe.

THIS STUDY: FUTURE PROOFING RESIDENTIAL DEVELOPMENT IN WESTERN SYDNEY

This study is part of a suite of projects being delivered by WSROC under the Turn Down the Heat Strategy (TDTH) which seeks to improve Western Sydney's resilience to heat. All TDTH projects follow a standard resilience framework (see figure 3). This study focuses specifically on helping people adapt to a hotter climate (Step 3). This step can be broken down into two main objectives: enabling people to plan and design for a warmer future climate; and enabling people to develop measures to survive heatwaves, particularly in their homes.

This study evaluates thermal performance of BASIX compliant houses and apartments in Western Sydney (NatHERS climate zone 28) using various climate files, i.e., current NatHERS climate, updated NatHERS climate (endorsed through NCC 2022), currently experienced climate of 2010-2030, immediate future climate (2030) and near future climate (2050).

The study illustrates the changing climate scenarios using the above-mentioned climate files and demonstrates the change in heating and cooling energy loads and level of discomfort conditions experienced in the houses because of warmer climatic conditions. The study then modifies a sample of dwellings to satisfy the higher BASIX standards for thermal comfort (endorsed from October 2023) using future climate of 2050. The future focused designs are then re-evaluated using the current NatHERS climate file and NCC 2022 NatHERS climate file to check if the BASIX allows designing for future.

Figure 3: Western Sydney's resilience framework to combat heat

STUDY AIMS

This study aims to:

1. Analyse the climate data files which represent current NatHERS climate, NCC 2022 NatHERS climate, currently experienced climate of 2020 (represents 2010-2029 climate), and future climate of 2030 and 2050
2. Analyse and evaluate the impact of climate on the thermal performance of dwellings
3. Evaluate the thermal performance of dwellings during extreme weather (i.e., heatwaves) events
4. Outline broad design strategies for future climate
5. Develop BASIX-compliant houses and residential flats using future climate scenarios and test whether current and proposed higher BASIX standards regulations would allow such developments
6. Recommend policy directions to encourage designing for the future warmer climate.

METHODOLOGY

This study uses detached (single and double storeys) and multi-unit buildings to explore the thermal performance of dwellings in various climate scenarios.

CLIMATE DATA AND CLIMATE FILES USED IN THE STUDY

- Long-term global, national, regional, and local temperature anomaly data set is sourced from the Bureau of Meteorology's website.
- Mean monthly maximum and minimum temperature data for Richmond from 1970 to 2021 is sourced from the Bureau of Meteorology's databank.
- Australia Reference Meteorological Year (RMY) climate files representing the current NatHERS climate, and NCC 2022 NatHERS climate are in-built in NatHERS accredited software packages.
- Future climate (RCP8.5) scenarios representing 2030 and 2050 are sourced from the CSIRO database (CSIRO 2022).
- Currently experienced climate representing the 2020 scenario is prepared by Dr. Anir Upadhyay, UNSW.
- For the heatwave scenario, the 2017 weather file from Richmond, prepared by Exemplary Energy, is used.

Aerial view of terrace and apartment housing at Thornton Estate, Penrith.

CLIMATE ANALYSIS

Comfort based climate analysis (Upadhyay 2018) is used to determine warm, cool, and intermediate periods and allow comparing them to communicate the change in climatic conditions across five climate scenarios.

THERMAL PERFORMANCE SIMULATION TOOLS

- The current NatHERS accredited software package, FirstRate5 v5.3.2b (3.21), developed by Sustainability Victoria is used to assess the thermal comfort requirement of the current BASIX standards.
- FirstRate5 v5.4.1a (3.21) beta version, which contains the NCC 2022 NatHERS climate file, is used for testing the thermal performance of buildings for the higher BASIX standards. The same simulation tool is used to simulate buildings using currently experienced and future climate scenarios.
- NatHERS climate zone 28 is used for thermal performance simulation
- Modelling was performed in accordance with the current version of NatHERS Technical Note (Version June 2019) and BASIX thermal comfort protocol (2020)

BASIX STANDARDS

NSW BASIX standards are developed in accordance with the National Construction Code (NCC) which uses NatHERS climate files and star rating to set and assess thermal comfort requirements.

Current BASIX

In accordance with the NCC, current NSW BASIX standards draw on NatHERS climate files (1967 - 2004) and require a NatHERS 5.5 to 6-star rating.

Higher BASIX (effective October 2023)

The revision of the NCC in 2022 included updates to NatHERs climate files (1990 – 2015), and increased star rating to NatHERs 7-stars. BASIX standards have been updated accordingly through *NSW State Environmental Planning Policy (Sustainable Buildings) 2022.*

This study uses higher BASIX thermal comfort standards (NCC 2022) to check compliance when buildings are modelled using all climate files except the current NatHERS climate file.

SAMPLE DWELLINGS

Four sample dwellings were chosen for this study which include houses and multi-unit buildings. Dwellings were selected to reflect the most common housing typologies currently being constructed in Western Sydney, whilst ensuring a variety of dwelling types to allow thermal performance to be explored across different urban forms.

Houses exhibit thermal stress differently than apartments in multi-unit buildings and therefore, design responses to develop thermally safe houses and apartments will be different. The sample dwellings are retrieved from multiple sources as indicated below.

Table 1: Sample dwelling types and design source

DWELLING TYPES	DWELLINGS (PER BUILDING)	DESIGN SOURCES
Detached (single storey)	1	Blacktown City Council
Detached (double storey)	1	
Low-rise (3 storeys)	9	*Future proofing residential development to climate change 2021* (adapted for Western Sydney)
High-rise (12 storeys)	120	

BUILDING FABRIC

The sample buildings complied with the current BASIX thermal comfort standard (NSW DP&E 2020). Thermal and physical properties of building fabric is outlined below:

Table 2: Sample buildings' thermal and physical properties

BUILDING FABRIC ELEMENT	HOUSE (SINGLE STOREY)	HOUSE (DOUBLE STOREY)	LOW-RISE MULTI-UNIT BUILDING (THREE STOREYS)	HIGH-RISE MULTI-UNIT BUILDING (TWELVE STOREYS)
External wall insulation	R1.5 insulation	R2.5 insulation	R1.5 insulation	R-values vary from R1.0 to R3.0
External ceiling / Roof insulation	R2.5 ceiling insulation + R1.3 roof insulation	R4.0 ceiling insulation + a layer of Anti-glare foil	R2.8 ceiling insulation R2.5 ceiling insulation to glazed common area	R4.0 ceiling insulation (Top Level)
Roof colour	0.5 (Medium)	0.7 (Dark)	0.5 (Medium)	0.5 (Medium)
Floors above unconditioned / External spaces insulation	No added insulation	R2.0 insulation	R1.0 insulation	R2.0 insulation (Level 1)
Corridor wall insulation	No added insulation R1.5 to bedroom wall adjoining the Garage	No added insulation R2.5 to walls adjoining the Garage	R1.0 insulation to Units 2, 5 & 8 R1.5 insulation to all remaining apartments	R-values vary from R1.0 to R2.0
Adjoining wall between apartments insulation	No added insulation	No added insulation	No added insulation	R3.0 insulation (mainly for noise control)
Glazing	Typical single glazing in aluminium frame: U-value 6.70 and SHGC 0.70	Typical single glazing in aluminium frame (applied to Dining sliding windows) Low- E single glazing in aluminium frame: U-value 5.40 and SHGC 0.58 (applied to all remaining windows)	Double glazing to Dining windows on Unit 5 Single glazing to all remaining windows U-values and SHGC values vary	Double glazing & Single glazing U-values and SHGC values vary
Openability	Casement windows to facade: 45% Casement windows to Alfresco: 30%	W.06 Sliding windows: 60% All remaining sliding windows/doors: 45%	Varies for each type, please refer to plans and models	Varies for each type, please refer to plans and models
Internal blinds	Yes, to all bedrooms and living rooms (default modelling protocol of holland blinds)	Yes, to all bedrooms and living rooms (default modelling protocol of holland blinds)	Yes, to all bedrooms and living rooms (default modelling protocol of holland blinds)	Yes, to all bedrooms and living rooms (default modelling protocol of holland blinds)
Screening/shading	Overhangs from roof as per drawings	Overhangs from level above and roof as per drawings	Overhangs from level above as per drawings	Overhangs from level above as per drawings

CLIMATE DESIGN STRATEGIES FOR THE FUTURE CLIMATE

Broad climate design strategies are adopted from *Improving the thermal performance of dwellings for carbon positive and healthy homes* (Upadhyay, Munsami et al. 2019) to inform designing for the future (2050) climate scenario. A list of practical modifications, without changing building layout, is prepared to guide modifications of selected dwellings to meet higher BASIX thermal comfort standards using a future (2050) climate scenario.

LIMITATIONS

This study relies on secondary data from various agencies as identified in the report. The project team analysed the data to answer the research questions using various techniques which aligns with the industry best practice and academic excellence. The findings in the study are largely drawn from the results obtained from the NatHERS simulations.

Light coloured home situated in a housing estate with dark coloured roofs.

THE CHANGING CLIMATE

Climate change is an ongoing phenomenon. Earth's surface temperature is influenced by natural variabilities (e.g., solar variations, volcanoes and aerosols) and human anthropogenic greenhouse gas emissions (Swanson, Sugihara et al. 2009). Climate scientists have confirmed that human influence is playing a greater role in the recent temperature rise (Intergovernmental Panel for Climate Change 2021). Figure 4 illustrates global annual mean temperature anomaly from 1850 to 2019.

This figure shows a modest temperature increase from late 19th century until early 20th century. By late 20th century, global annual temperature increased by around 0.4degreeC compared to the temperature observed around 100 years ago. The rate of temperature rise is unprecedented since 1980s and an average of 0.5degreeC increase was observed during the last two decades (2000-2019) with reference to 1961-1990 base temperature. The trendline shows that the global temperature will further increase by 0.3degreeC by 2025 with reference to 2010 (i.e., 2000-2019 average) climate.

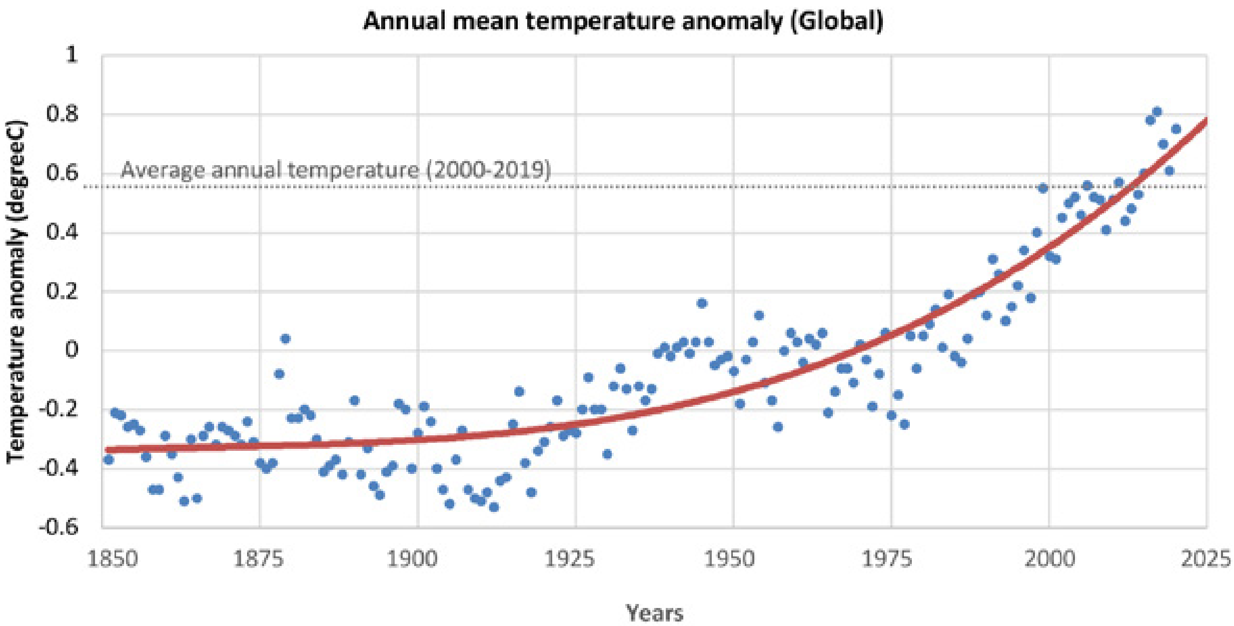

Figure 4: Global annual mean temperature anomaly (based on 30-year climatology; 1961-1990) from 1850 to 2019. The thick red line represents a polynomial trend line with R^2 = 0.84. (Data source: Commonwealth of Australia 2022)

HISTORICAL TEMPERATURE TREND IN AUSTRALIA, NEW SOUTH WALES AND WESTERN SYDNEY (RICHMOND)

Historical annual mean temperature anomaly for Australia, New South Wales (NSW) and Richmond is presented in Figure 3. Australia has experienced consistently rising temperatures since 1980, but the highest temperature increase was observed in the last decade (2010-19), particularly since 2013. New South Wales and Richmond also followed a similar trend in temperature rise since 1980. Australia witnessed the warmest year on record in 2019 accompanied by frequent heatwaves. Historically, the magnitude of temperature rise in NSW has been consistently higher than the national average, particularly in the last decade where mean maximum temperature was around 0.2degreeC higher than the national average. Richmond exhibited an overall slightly lower temperature rise than the NSW average. From 2017 to 2019, Australia experienced three of the consecutive warmest years on record. The average annual temperature anomaly for 2017-2019 in NSW was 1.7degreeC higher than the reference period (1961-90) whereas, it was 1.3degreeC higher in Richmond.

Eastern Australia has been experiencing La Niña from late 2020 and Bureau of Meteorology (2022) forecasts it will continue until later this year (i.e. 2022). Therefore, an abrupt temperature drop was observed in 2020 and 2021 compared to the previous years. Due to the recent La Niña event, Richmond experienced the coolest year in 2021 since 2008.

Figure 5 shows increased mean temperature from the start of 21st century, however year to year variability makes it difficult to understand the actual trend of the climate change. Therefore, it is important to take a long-term running average to understand temperature rise and resultant climate change impact at the local level.

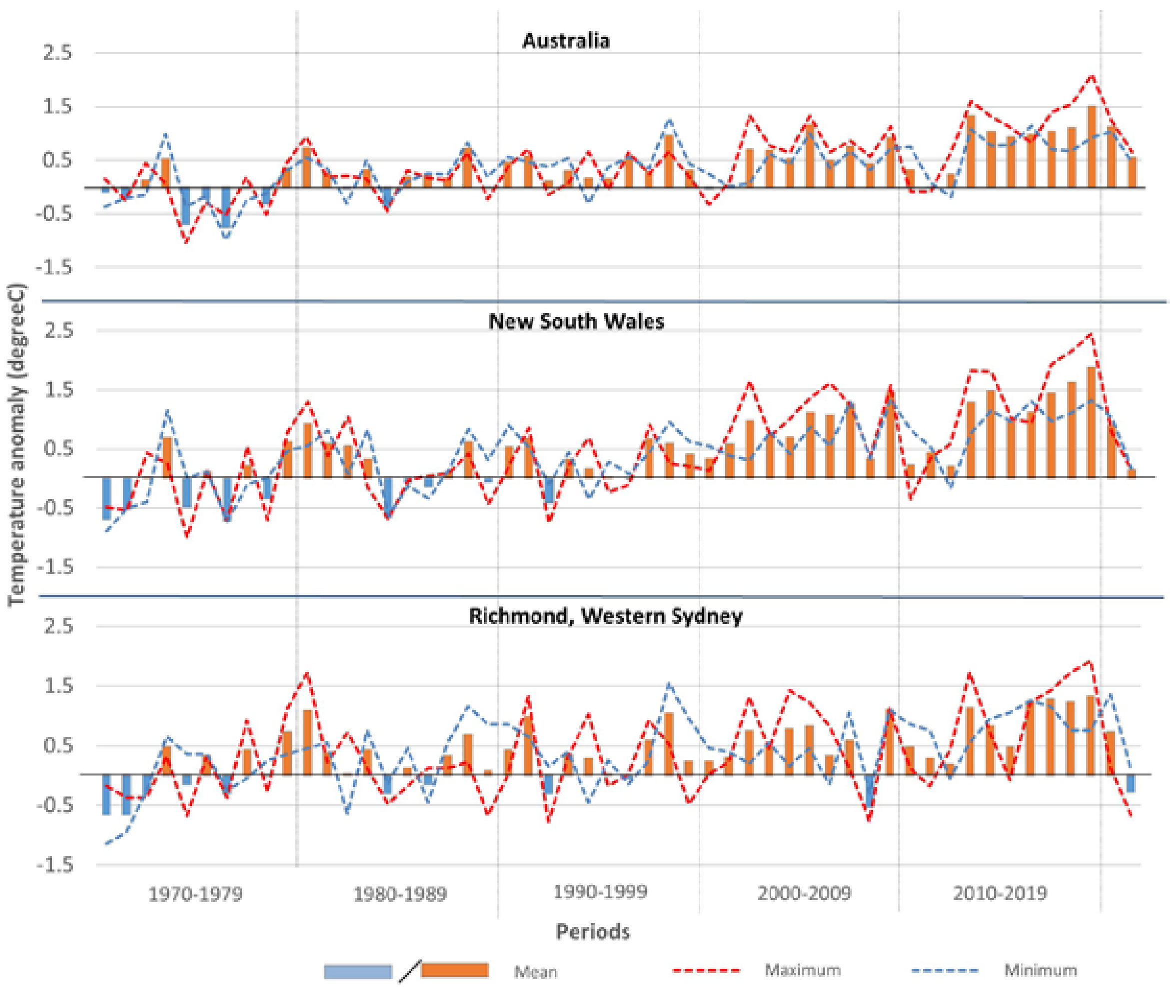

Figure 5: Annual maximum, mean and minimum temperature anomaly (based on 30-year climatology; 1961-1990) for Australia, New South Wales and Richmond from 1970 to 2021. (Data source: Commonwealth of Australia 2022)

THE CHANGING CLIMATE OF WESTERN SYDNEY

Western Sydney has experienced consistent rise in temperature for the last 40 years. Figure 4 illustrates the temperature profile for Richmond which is the representative weather station for Western Sydney (NatHERS climate zone 28). This graph has utilised measured mean maximum and mean minimum temperature from 1970 to 2021 and internal variability of the weather is normalised by taking 20 years of running average, i.e., temperature for 1980 is derived by taking average of 1970 – 1989. The observed data shows that the mean temperature in the last 30 years (1980 – 2009) increased by 0.5degreeC and the temperature increase in the last decade (2010-19) was 0.4degreeC.

The rate of temperature rise in this decade (2020 to 2029) is projected to be much higher (i.e., 0.6degreeC) than what we have experienced so far.

Figure 6 also shows that the current NatHERS climate file portrays pre-1980 climate scenario and the updated NatHERS climate file represents pre-2010 climate. However, the current climate of 2020 (representing 2010 – 2029 scenario) is 1.1degreeC warmer than the current NatHERS climate file and 0.6degreeC warmer than the updated NatHERS climate file.

> Western Sydney's 2020 climate is 1.1 degreeC warmer than the current NatHERS climate file, and 0.6degreeC warmer than the updated NatHERS climate file due to come into effect October 2023.

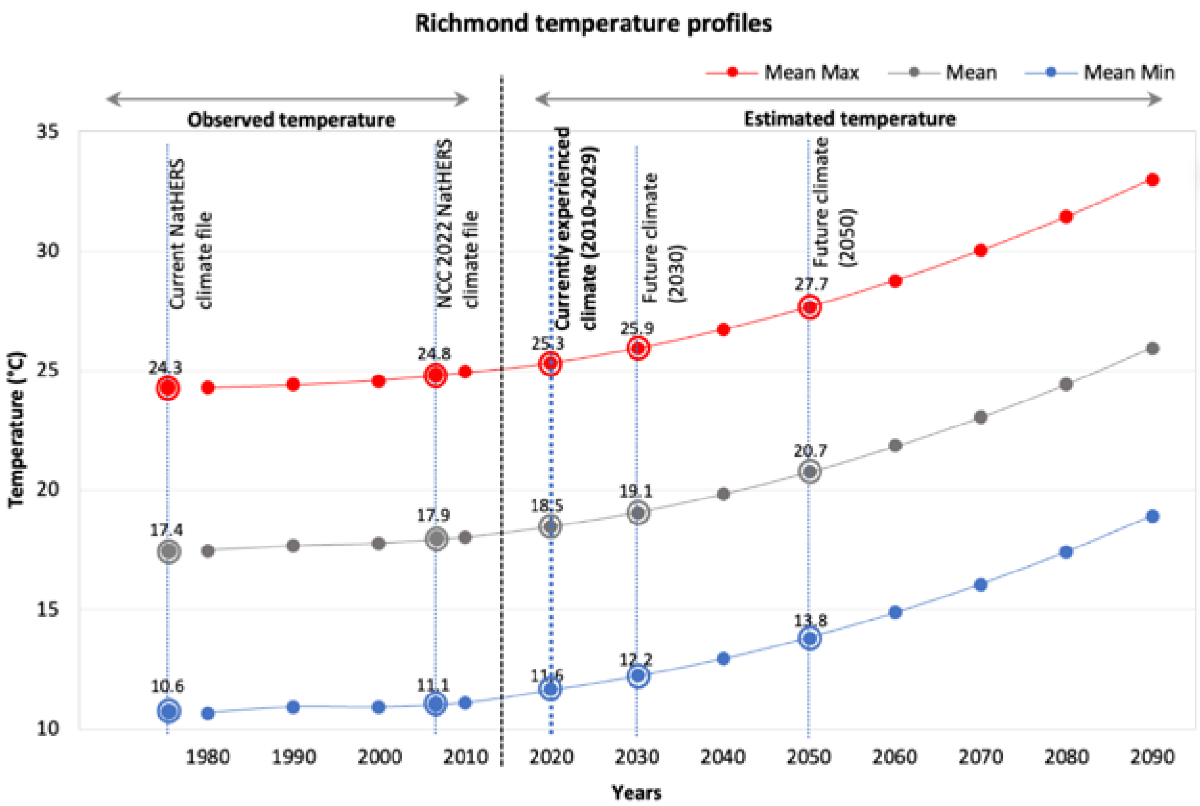

Figure 6: Richmond temperature profile presents observed mean maximum, mean and mean minimum temperatures from 1980 to 2010 and estimated temperatures from 2020 until 2090. Raw yearly temperature data is normalised by taking 20 years of running average, i.e., temperature for 1980 is derived by taking average of 1970 – 1989 (Data source: Commonwealth of Australia 2022)

Figure 7 illustrates the inter-decadal average number of hot and cold days in Western Sydney. It is estimated that in future, the number of hot days (30°C or higher) will increase rapidly but there will not be a similar decrease in the number of cold days. The trend line suggests that Western Sydney will continue to witness sub zero temperature in winter for around 10 – 14 days in the future too.

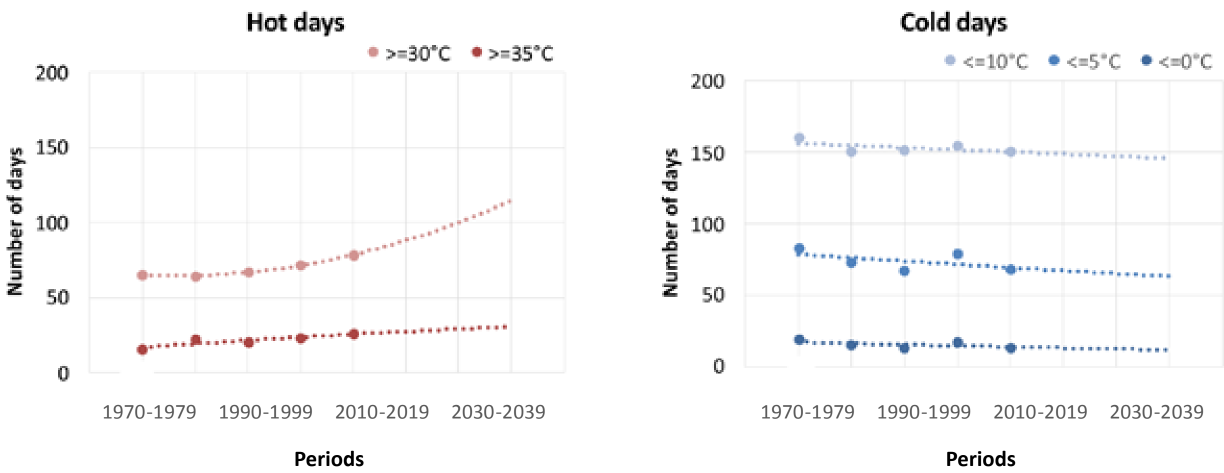

Figure 7: Observed number of hot and cold days in the last five decades and estimated for the next three decades (Data source: Commonwealth of Australia 2022)

THE IMPLICATION OF THE WARMING CLIMATE IN BUILDING DESIGN

The temperature analysis presented in Figure 6 informs that the houses currently (in 2022) designed and built in Western Sydney are optimised for the pre-1980 climate scenario which is 1.1degreeC cooler than the current climate (2010-2029). Current regulations (both National Construction Code and NSW BASIX) enforce designers to develop designs to address predominantly 'heating dominated' historical climate of the past. The buildings which are designed and built now may not perform well in today's balanced (i.e., equal periods with heating and cooling demand) climate let alone the future 'cooling dominated' climate.

> Houses designed and built in Western Sydney to October 2023 are optimised for a pre-1980 climate scenario.

The current NatHERS climate file, which represents a climatic scenario more than 40 years old, is used to develop current building energy efficiency provisions. In 2022, the NCC endorsed updated climate files in NatHERS software packages which will come into effect from October 2023. However, these updated climate files are already outdated, representing a pre-2010 climate scenario. This means the new energy efficiency provisions based on these files will encourage designs that are better suited for temperatures 0.5degreeC cooler than what has been experienced recently in Western Sydney.

Buildings designed and built today are expected to last 50 years or more; therefore, it is necessary to understand the changing climatic context and design buildings considering the next 20 – 30 years. Designing for the future climate will help future proofing buildings until the next renovation provides opportunities for adaptation.

Timber frame of a new home.

CLIMATE DATA ANALYSIS

In this section, the five Western Sydney climate scenarios are further explored using a comfort-based climate analysis (Upadhyay 2018) to highlight week-by-week conditions across the calendar year. These include:

- Current NatHERS climate (in use until September 2023)
- NCC 2022 climate (to become mandatory from October 2023)
- Current experienced climate (represents the climate scenario of 2020)
- Future climate of 2030
- Future climate of 2050

CURRENT NATHERS CLIMATE SCENARIO

The current NatHERS climate scenario is developed by using average weather data from the period 1967 to 2004. It is used for analysing building energy efficiency of residential buildings in Australia using NatHERS accredited software packages. Figure 8 outlines outdoor thermal comfort conditions using hourly temperature and humidity on a weekly basis. The size of the squares for each comfort category represents the frequency of its occurrence weekly. A higher frequency of occurrence is represented with the larger squares and vice versa. The sum of occurrences for all the comfort conditions should be 100% for each week.

The current NatHERS climate file (in use until September 2023) is developed using average weather data from the period 1967 to 2004.

Figure 8 also identifies weeks with dominant discomfort due to heat and cold which is labelled as warm and cool periods respectively. Intermediate periods which separate two major periods (i.e., warm and cool) often experience low heat discomfort to low cold discomfort conditions, including comfortable condition.

The current NatHERS climate scenario portrays Western Sydney as having a seven-month cool period, starting from early April (week 17) and ending in October (week 44). According to this scenario, Western Sydney's climate requires more heating than cooling. According to this climate file, the warm period prevails for less than two months, from mid-January until first week of March. The severity of discomfort in the warm period can extend up to extremely severe discomfort for few hours in weeks 3 and 4. The dominant level of heat discomfort hovers around low to moderate level of discomfort during the warm period. In the cool period, severe discomfort due to low temperatures can be experienced for a few hours for around seven weeks when outdoor never attains comfortable conditions. At the start and towards the end of the cool period, morning and night-time temperatures remain in the cold discomfort range but day-time temperature often hovers within comfortable to low discomfort conditions.

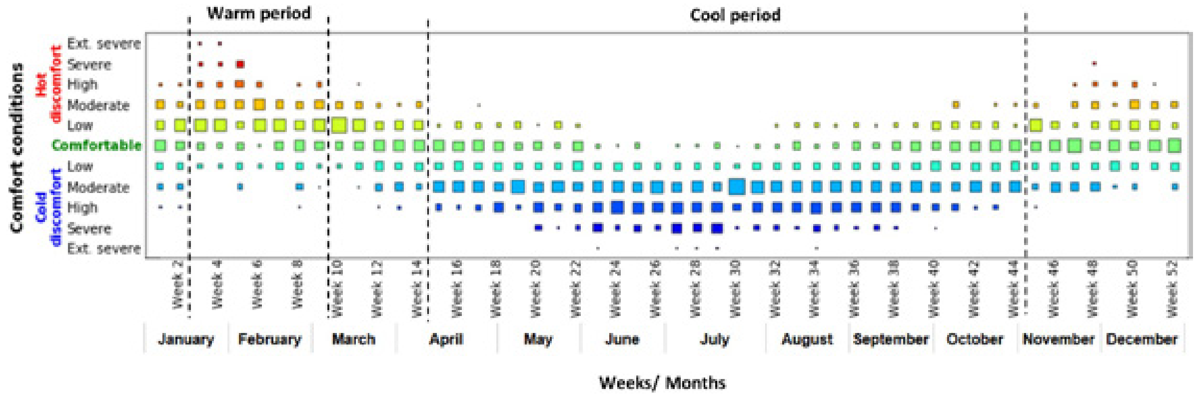

Figure 8: Outdoor thermal comfort conditions (using hourly temperature and humidity) portrayed by the current NatHERS climate file for Richmond which represents an average climate of 1967 - 2004 (Source: Dr Anir Upadhyay)

NCC 2022 NATHERS CLIMATE SCENARIO

The NCC 2022 NatHERS climate scenario is developed by using weather data from 1990 to 2015. This climate scenario also portrays Western Sydney as needing more heating than cooling (Figure 2). However, the warm period has extended significantly in this climate scenario compared to the current NatHERS climate scenario (Figure 8). The warm period prevails for around four months, starting from mid-November to early March for around 16 weeks. The cool period has shrunk by a month in this climate scenario compared with the current NatHERS climate scenario. The intermediate period which separates cool to warm period has also shrunk significantly.

The NCC 2022 NatHERS climate file (in effect from October 2023) is developed using average weather data from 1990 to 2015.

CURRENTLY EXPERIENCED CLIMATE OF 2020 (2010 – 2029)

The currently experienced climate used in this study, is derived by using measured mean maximum and mean minimum temperature from 1970 to 2021. The mean maximum and minimum temperatures are estimated by using fitting trend lines for each month. The climate file representing 2020 was compiled by selecting relevant monthly weather data from the weather data bank (Exemplary Energy Partners 2022) as informed by the projected mean maximum and minimum temperatures.

As illustrated in Figure 10, current climate of Western Sydney is balanced, i.e., almost equal duration of warm and cool periods. The warm period starts from early November until March (21 weeks long) and cool period starts from May until mid-September (19 weeks long). Early warm period is often milder as discomfort due to heat rarely exceeds high discomfort conditions. The heat discomfort increases significantly from late December until February when high level of discomfort is often experienced during the afternoons. It is not uncommon to occasionally experience severe heat discomfort during the warm period due to heatwaves.

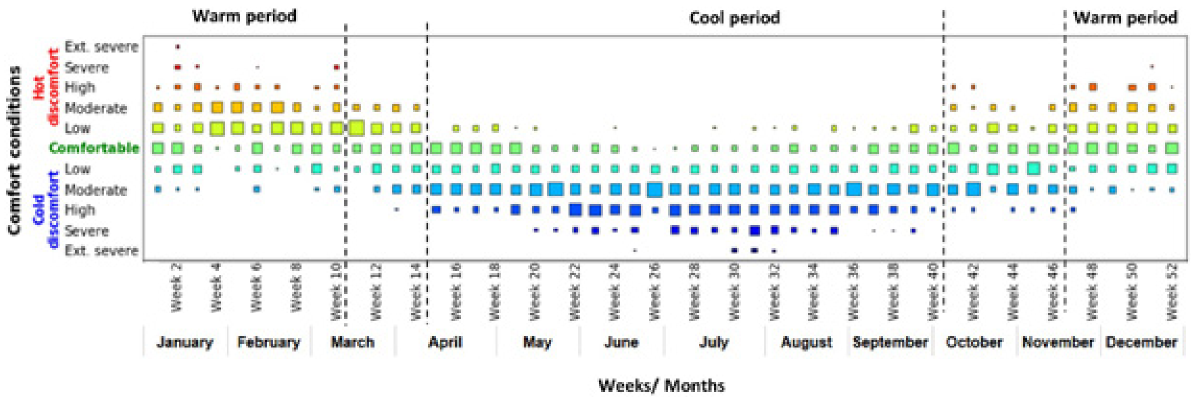

Figure 9: Outdoor thermal comfort conditions (using hourly temperature and humidity) portrayed by the NCC 2022 NatHERS climate file for Richmond which represents an average climate of 1990 - 2015 (Source: Dr Anir Upadhyay)

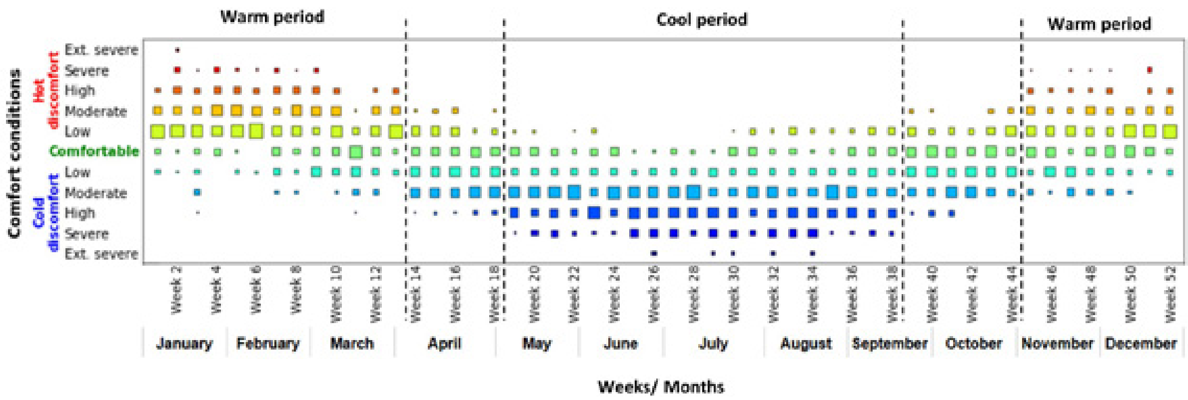

Figure 10: Outdoor thermal comfort conditions (using hourly temperature and humidity) portrayed by the currently experienced climate for Richmond which represents 2010-2029 climate scenario (Source: Dr Anir Upadhyay)

2030 AND 2050 FUTURE CLIMATE OUTLOOK

The future climate scenarios for all NatHERS climate zones are prepared by the CSIRO and made publicly available (CSIRO 2022). CSIRO prepared three sets of climate files to represent different greenhouse gas concentration trajectories adopted by the IPCC which is commonly known as Representative Concentration Pathways (RCPs). The recent IPCC report concluded that temperature rise will be approximately 1.5degreeC in 2030 irrespective of greenhouse gas emissions reductions strategies adopted now. Therefore, the worst-case (RCP 8.5) future climate scenarios are adopted for this study. Figure 11 illustrates the 2030 climate scenario for Western Sydney. This climate scenario also presents a balanced climate outlook. According to this climate file, Western Sydney will experience a warm period for 20 weeks starting from mid-November until early April. The severity of discomfort due to heat will increase from January until mid-March when moderate to high discomfort conditions will prevail majority of the time. The cool period in Western Sydney will start from early May until September for 22 weeks.

The CSIRO prepared the future climate files using a morphing technique by taking the NCC 2022 NatHERS climate file as a baseline year. Therefore, a gradual upward shift in comfort conditions (i.e., from cold discomfort to heat discomfort) can be observed in Figures 9, 11 and 12. The 2050 climate file also exhibits a balanced climate outlook similar to the 2030 scenario (Figure 12) with subtle changes in comfort conditions. An increased frequency of high discomfort conditions due to heat can be observed in the warm period and a reduction of occurrences of severe discomfort due to cold in the cool period.

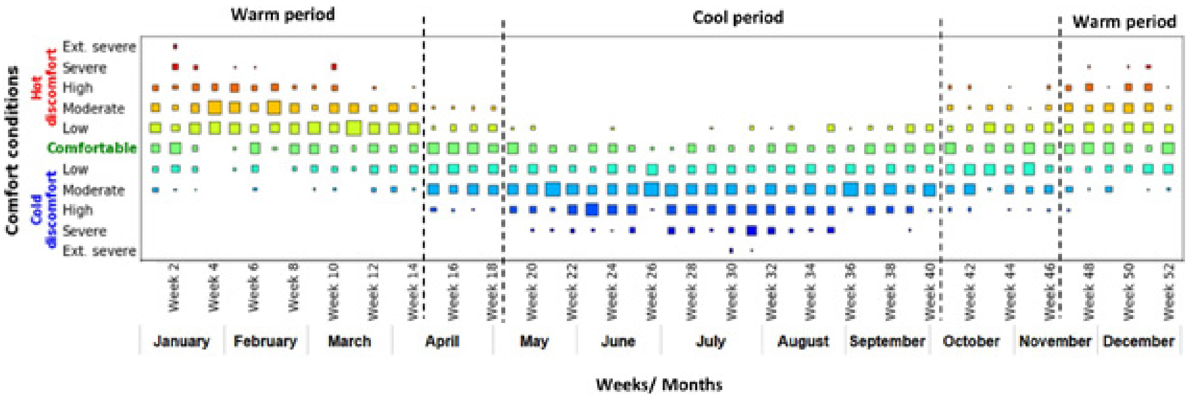

Figure 11: Outdoor thermal comfort conditions (using hourly temperature and humidity) portrayed by the future climate file for Richmond which represents 2030 climate scenario (RCP8.5) (Source: Dr Anir Upadhyay)

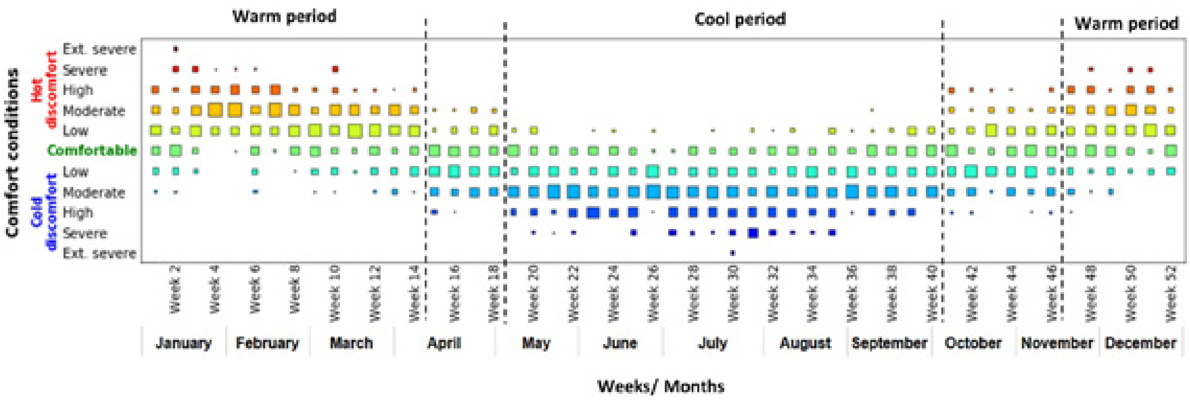

Figure 12: Outdoor thermal comfort conditions (using hourly temperature and humidity) portrayed by the future climate file for Richmond which represents 2050 climate scenario (RCP8.5) (Source: Dr Anir Upadhyay)

VARIATION IN CLIMATE PARAMETERS IN DIFFERENT CLIMATE SCENARIOS

Table 3 illustrates changes in climatic parameters in different climate scenarios in Western Sydney. An overall warming effect is clearly demonstrated as average hourly temperature has been consistently increased from the current NatHERS climate scenario to future climate of 2050. The current NatHERS climate file, in effect until September 2023, takes into consideration a much lower temperature than currently experienced (i.e., in 2020) in Western Sydney. More importantly, the NCC 2022 NatHERS climate file which will come into effect from October 2023 also portrays a cooler climate than is currently experienced.

It is evident that the number of days with temperature higher than 35°C will increase and number of days with temperature less than 10°C will decrease in future. The currently used and NCC 2022 NatHERS climate files significantly under-estimate days with warmer conditions and over-estimate days with cooler conditions.

"… the currently used and NCC 2022 NatHERS climate files under-estimate days with warmer conditions, and over-estimate days with cooler conditions.

Table 3: Variation in temperature and humidity during various climate scenarios in Richmond

CLIMATIC PARAMETERS	CLIMATE SCENARIOS				
	Current NatHERS climate	NCC 2022 NatHERS climate	Currently experienced climate of 2020	Future climate (2030)	Future climate (2050)
Average hourly temperature (°C)	16.7	17.0	17.4	18.2	18.8
Number of days with temperature >=35°C	9	15	16	25	26
Average hourly temperature (°C) when temperature >=35°C	37.2	37.1	37.6	37.3	37.4
Number of days with temperature <=10°C	151	144	129	126	107
Average hourly temperature (°C) when temperature <=10°C	6.7	6.7	6.2	6.9	7.0
Average diurnal temperature range (degreeC)	12.4	12.6	12.3	12.5	12.4

Aerial view of housing estate employing urban heat mitigation measures.

ISSUES WITH THE NATHERS CLIMATE FILES

NatHERS climate files currently being used to demonstrate building energy efficiency portray a climate of the late last century. Recently, the Australian Building Codes Board (ABCB) has announced a significant change of the National Construction Code and introduced updated climate files (i.e., NCC 2022 NatHERS climate files) which will be effective from 2023. However, the newly introduced climate file for Western Sydney is already outdated as it under-estimates hours with warmer conditions, and over-estimate hours with cooler conditions when compared to the currently experienced climate of 2020.

The 2020 Western Sydney climate is balanced with almost equal duration of warm and cool periods. This phenomenon will be more prominent in the future as people will experience increased hours of heat discomfort during the warm period. The number of hours with temperature exceeding 35°C in 2050 will increase by 70% compared with the NCC 2022 NatHERS climate file. Similarly, the number of hours with temperature lower than 10°C will decrease by 40% in 2050 with respect to the NCC 2022 NatHERS climate file.

In the next section, the impact of various climate scenarios on the thermal performance of buildings is explored.

IMPACT OF CLIMATE ON THERMAL PERFORMANCE OF BUILDINGS

In Australia, one method of demonstrating the thermal performance of buildings is the NatHERS software package which reports heating and cooling loads to show the design response in cool and warm seasons. Total load, which is the sum of heating and cooling loads, is used to infer the overall yearly thermal performance of a building. Total load is used to determine the NatHERS star rating. The Australian Building Codes Board recently increased the minimum thermal performance requirement for houses to NatHERS 7-star through NCC 2022. The New South Wales Government also increased the thermal performance of houses through the *State Environmental Planning Policy (Sustainable Buildings) 2022* to align with NCC 2022.

In this section, the impact of climate on the thermal performance of sample buildings is presented. As outlined in Table 1, the sample dwellings used for this study include houses (single-storey and double-storey) and selected apartments in multi-unit buildings. Each sample dwelling was assessed under five different climate scenarios. The base case, which complied with the current BASIX thermal comfort standards, is simulated using the current NatHERS tool with the current NatHERS climate file. The same building is modelled for all other climate scenarios (i.e., NCC 2022 updated NatHERS climate, currently experienced climate (2010-2029), future climate 2030 and future climate 2050) using the beta version of the NatHERS tool.

THERMAL PERFORMANCE OF HOUSES

The thermal performance of single and double storeyed houses under various climate scenarios are presented in Table 4. Both houses, which comply with current BASIX requirements, will fail to meet higher BASIX standards (effective from October 2023) when modelled using the NCC 2022, currently experienced, and future climate files.

The single-storey house fails to comply with BASIX total cap when NCC 2022 NatHERS and currently experienced climate files are used. In future climate scenarios, the house exceeds both cooling and total caps set by BASIX.

The double-storey house also fails to comply with BASIX total cap when the NCC 2022 NatHERS climate file is used. The house exceeds both cooling and total caps set by the BASIX for currently experienced, and future climate scenarios.

Table 4: Thermal performance of houses determined by various climate scenarios

CLIMATE SCENARIO	BASIX CAPS (MJ/m^2)			SIMULATION RESULTS – LOADS (MJ/m^2)			BASIX status
	Heating	Cooling	Total	Heating	Cooling	Total	
Single-storey house							
Current NatHERS climate	55.8	56.2	–	52.3	30.6*	–	Pass
NCC 2022 NatHERS climate	56	37.5	60	53.4	22.2	**75.6**	**Fail**
Currently experienced climate of 2020	56	37.5	60	43	35.7	**78.7**	**Fail**
Future climate (2030)	56	37.5	60	30.4	**38.3**	**68.7**	**Fail**
Future climate (2050)	56	37.5	60	23.1	**51.9**	**75**	**Fail**
Double-storey house							
Current NatHERS climate	55.8	56.2	–	43.9	52.2*	–	Pass
NCC 2022 NatHERS climate	56	37.5	60	49.6	31.1	**80.7**	**Fail**
Currently experienced climate of 2020	56	37.5	60	42.6	**43.9**	**86.5**	**Fail**
Future climate (2030)	56	37.5	60	30.6	**49.7**	**80.3**	**Fail**
Future climate (2050)	56	37.5	60	24.2	**60.1**	**84.3**	**Fail**

*Higher cooling load is associated with lower cooling thermostat setting in the current NatHERS accredited tools which is 24.5°C. It is increased to 25°C in the beta version of NatHERS tool which is used for NCC 2022 NatHERS climate file, currently experienced and future climates.

THERMAL PERFORMANCE OF A HIGH-RISE BUILDING AND SELECTED APARTMENTS

The high-rise building, which currently complies with BASIX requirements, will fail to meet higher BASIX standards when modelled using the beta version of the NatHERS tool with NCC 2022 NatHERS and future climate files. This building has 117 apartments and the thermal performance of individual apartments varies due to various factors such as orientation, location within the building and glazing area. Table 5 illustrates the average heating, cooling, and total loads across all apartments within the sample high-rise building. Standard deviation is used to indicate the dispersion of loads between apartments relative to the average loads.

Table 5: Thermal performance of a high-rise building and selected (worst and best performing) apartments determined by various climate scenarios

CLIMATE SCENARIO	BASIX CAPS (MJ/m²)			SIMULATION RESULTS – LOADS (MJ/m²)			BASIX status
	Heating	Cooling	Total	Heating	Cooling	Total	
High-rise (12 storeys) building (117 apartments)							
Current NatHERS climate	55.8	56.2	–	24.1	28.4	–	Pass
NCC 2022 NatHERS climate	58	45	60	31.5 ±13.8	20.8 ±10.4	**52.2 ±20.9**	**Fail** (20 apartments fail)
Currently experienced climate of 2020							
Future climate (2030)	58	45	60	17.3 ±9.9	**35.6 ±13.2**	**52.9 ±19.6**	**Fail** (21 apartments fail)
Future climate (2050)	58	45	60	12.8 ±8.2	**47.4 ±14.8**	**60.2 ±19.1**	**Fail** (36 apartments fail)
Worst performing apartment in high-rise building (12.10)							
Current NatHERS climate	63.3	63.7	–	37.7	45.2	–	Pass
NCC 2022 NatHERS climate	65.1	50.6	79	58.9	46.2	**105.1**	**Fail**
Currently experienced climate of 2020	65.1	50.6	79	48.6	**56.7**	**105.3**	**Fail**
Future climate (2030)	65.1	50.6	79	37.3	**67.2**	**104.5**	**Fail**
Future climate (2050)	65.1	50.6	79	29.7	**82**	**111.7**	**Fail**
Best performing apartment in high-rise building (7.08)							
Current NatHERS climate	63.3	63.7	–	32.9	16	–	Pass
NCC 2022 NatHERS climate	65.1	50.6	79	39.3	5.2	44.5	Pass
Currently experienced climate of 2020	65.1	50.6	79	35.3	16.1	51.4	Pass
Future climate (2030)	65.1	50.6	79	23.2	15.8	39	Pass
Future climate (2050)	65.1	50.6	79	17.7	23.3	41	Pass

This building fails to comply with BASIX total cap when the NCC 2022 NatHERS climate file is used. In the future climate of 2030, 17 apartments (15%) exceed the cooling cap, and 20 apartments (17%) exceed the total cap set by BASIX. When the building is simulated using the future climate of 2050, the number of apartments that failed to meet the cooling cap increased to 36 (31%), and 23 apartments (20%) exceeded the total cap set by BASIX.

Two extreme cases are presented here to demonstrate the wide range of thermal comfort variations in multi-unit buildings. The worst performing apartment is located at level 12 (top level), facing north-west orientation with three sides exposed. Window to floor area ratio for this apartment is 50% with around half of the windows facing west. This apartment fails to comply with BASIX total cap when the NCC 2022 NatHERS climate file is used. It exceeds both cooling and total caps set by BASIX for currently experienced and future climate scenarios.

The best performing apartment is located at level 7, facing the west orientation with a narrow side exposed. A small balcony is located on the western side which protects the bedroom from solar heat gain. The window to floor area ratio for this apartment is 34% with slightly more than half of the windows facing west. This apartment meets the BASIX requirements for all the climate scenarios tested in this study.

THERMAL PERFORMANCE OF A LOW-RISE BUILDING AND SELECTED APARTMENTS

The low-rise 3 storey building, which currently complies with the BASIX requirements, will meet BASIX standards when modelled using the beta version of NatHERS tool with the NCC 2022 NatHERS climate file. BASIX thermal performance and energy standards for multi-unit buildings up to 5 storeys remain unchanged in the *Sustainable Building SEPP* which means these buildings do not need to meet NatHERS 7-star requirement. The BASIX heating and cooling caps are set to deliver NatHERS 5.5 to 6-star buildings.

This building has nine apartments, and they exhibit variation in thermal performance due to multiple factors such as orientation, location within the building and glazing area. Table 6 illustrates the average heating, cooling and total loads along with standard deviation to indicate the dispersion of loads between apartments relative to the average loads. In the future climate of 2030, five apartments (56%) exceed the cooling cap and an additional three apartments (i.e., a total of eight apartments, 89%) exceed the cooling cap when modelled using the future climate of 2050.

Table 6: Thermal performance of the low-rise building and selected (worst and best performing) apartments determined by various climate scenarios

CLIMATE SCENARIO	BASIX CAPS (MJ/m²)			SIMULATION RESULTS – LOADS (MJ/m²)			BASIX status
	Heating	Cooling	Total	Heating	Cooling	Total	
Low-rise (3 storeys) building (9 apartments)							
Current NatHERS climate	55.8	56.2	–	43.6	44.4	–	Pass
NCC 2022 NatHERS climate	63.6	49.3	–	46.8 ±14.4	31.7 ±8.3	–	Pass
Currently experienced climate (2010-2029)							
Future climate (2030)	63.6	49.3	–	26.5 ±9.8	**52.3 ±10.9**	–	**Fail** (5 apartments fail)
Future climate (2050)	63.6	49.3	–	20.1 ±7.9	**69.1 ±12.2**	–	**Fail** (8 apartments fail)
Worst performing apartment in low-rise building (1.09)							
Current NatHERS climate	63.3	63.7	–	31.1	58.4	–	Pass
NCC 2022 NatHERS climate	69.7	54.2	–	35.6	44.4	–	Pass
Currently experienced climate (2010-2029)	69.7	54.2	–	26.2	**63**	–	**Fail**
Future climate (2030)	69.7	54.2	–	19.9	**70.4**	–	**Fail**
Future climate (2050)	69.7	54.2	–	15.3	**88.5**	–	**Fail**
Best performing apartment in low-rise building (1.04)							
Current NatHERS climate	63.3	63.7	–	42.4	33	–	Pass
NCC 2022 NatHERS climate	69.7	54.2	–	46.6	22	–	Pass
Currently experienced climate (2010-2029)	69.7	54.2	–	40.7	35.9	–	Pass
Future climate (2030)	69.7	54.2	–	27.2	36.8	–	Pass
Future climate (2050)	69.7	54.2	–	20.6	51.1	–	Pass

The worst performing apartment is located on level 3 (top level), facing north with three sides exposed. Window to floor area ratio for this apartment is 48% with slightly less than half of the windows facing west. This apartment fails to comply with BASIX cooling caps for currently experienced and future climate scenarios.

The best performing apartment is located on level 2 (mid-level), facing south with three sides exposed. Window to floor area ratio for this apartment is 48%. Large windows located on the south and west orientations comprised 80% of the total window area. This apartment meets the BASIX requirements for all the climate scenarios tested in this study.

PERFORMANCE OF DWELLINGS IN CURRENT AND FUTURE CLIMATES

The detached and high-rise buildings fail to meet higher BASIX standards when modelled using NCC 2022 NatHERS climate file, currently experienced and future climate scenarios. However, the low-rise building satisfies the BASIX caps when modelled using NCC 2022 NatHERS climate file as NSW Government did not increase thermal comfort standard for this building type. It is observed that the buildings that failed to comply with the higher BASIX standards often exceeded the BASIX cooling cap or total cap. None of the buildings exceed the BASIX heating cap.

Figure 13 illustrates the thermal loads obtained from the NatHERS simulation tool for the two detached dwellings and four selected apartments from multi-unit buildings. BASIX caps are superimposed to compare the performance of the dwellings visually. It is noticed that the total load for each building type remained almost similar while they are simulated using different climate files. As the dwellings were modelled using climate files with warmer scenarios, the cooling load increased and the heating load reduced. These dwellings may achieve similar NatHERS star rating which is derived using the total of heating and cooling energy loads. Therefore, overall NatHERS star rating of building may not be the best thermal performance indicator.

Overall climate warming is just one aspect of climate change that dwellings must be designed to withstand. Given projections for more frequent, prolonged and severe heatwaves, it is equally important that dwellings maintain an acceptable indoor temperature during extreme heat or heatwave scenarios to ensure thermal safety. The next section explores thermal performance of the selected dwellings during heatwave.

> Houses and high-rise apartments that pass today's BASIX and NCC standards, fail when modelled using NCC 2022, currently experienced, and future climate files.
>
> The low-rise building did not see equal failure rates because the NSW Government did not increase thermal comfort standards for this building type.

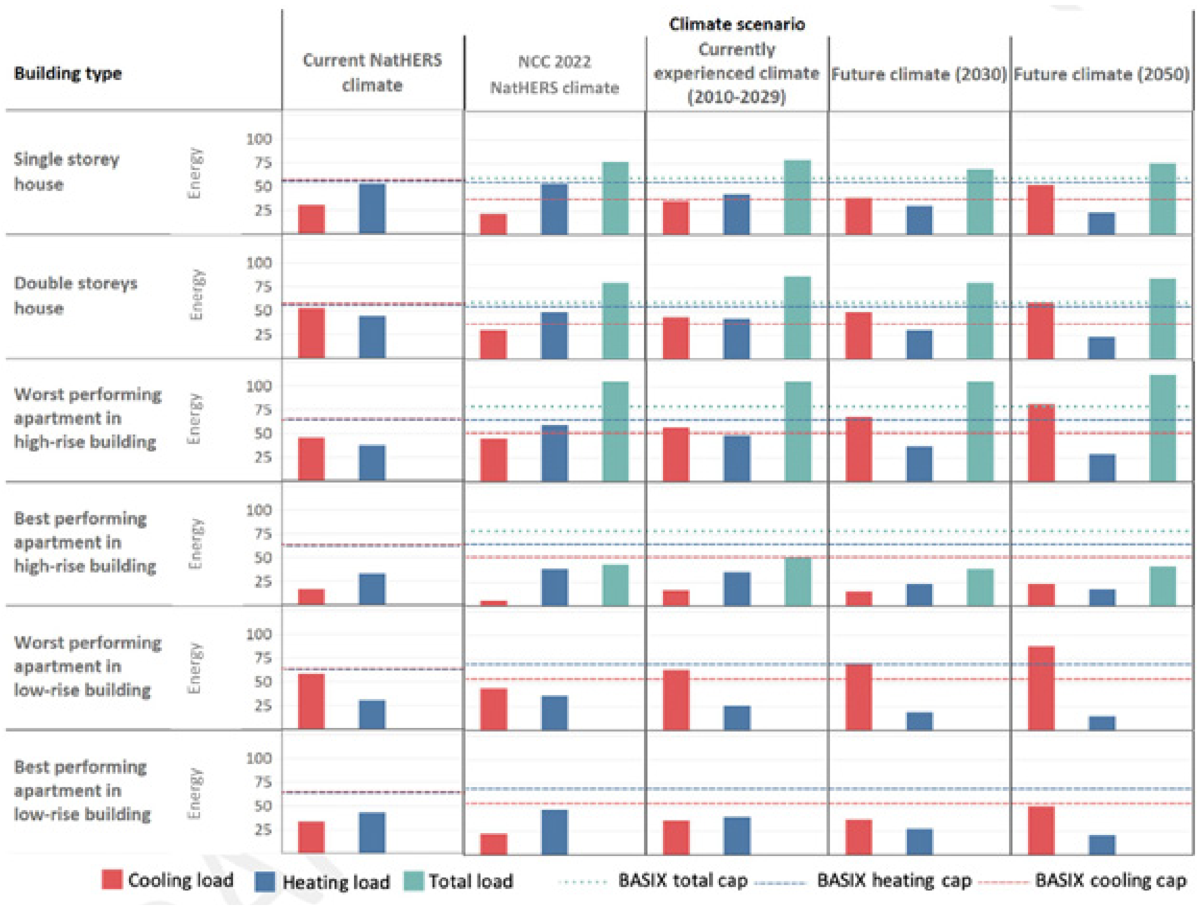

Figure 13: Comparing heating, cooling and total loads and BASIX caps for houses and selected apartments from multi-unit buildings

THERMAL PERFORMANCE OF BUILDINGS DURING HEATWAVE

Often houses are designed for average climatic conditions, and it is expected that the occupants may use heating/cooling systems to maintain thermal comfort when indoor environmental conditions become uncomfortable. In this section, both detached houses and the four apartments from the two multi-unit buildings are further analysed to understand their behaviour during heatwave conditions. A six-day period during January 2017 is selected for this analysis. Day 1 (7th January) and Day 6 (12th January) are relatively milder, but the maximum temperature exceeds 35°C for the remaining four days. On the fifth day (11th January), the temperature reaches 41.4°C and for seven hours remains more than 35°C.

Estimated indoor average temperature and hourly cooling energy demand are used to illustrate the impact of the heatwave in each dwelling. The average temperature of each house or apartment is calculated by averaging all zones (both conditioned and unconditioned zones) temperature for each hour. NatHERS regulates set point temperature in conditioned zones based on assumed occupancy profile, whereas unconditioned zones are unregulated. To calculate cooling energy demand, a typical 2-star air-conditioning system (EER 3.5) is considered.

SINGLE STOREY HOUSE DURING A HEATWAVE

Figure 14 presents outdoor and indoor temperature and estimated hourly cooling energy demand of the single storey house during a heatwave period. It also shows a free running temperature profile if the occupants do not use an air conditioner or there is a blackout.

The single-storey house used 67.7kWh during six days of heatwave and maintained an average indoor temperature (across all rooms) of 25.3°C with standard deviation of 2degreeC. On a few occasions, the temperature crossed 28°C even with the air conditioner running. On the hottest day, peak energy demand surged to 3.8kWh at 5pm.

If the occupant did not use the air conditioner during this heatwave period, the average temperature of the house would rise to 26.2°C with a standard deviation of 2.6degreeC. The indoor temperature reached or exceeded 30°C during the heatwave event. The worst condition would be experienced on 11th January when the indoor temperature crossed 30°C for six hours with a maximum of 32.6°C.

The indoor temperature at night-time and early morning hovered around 24 - 25°C on 4th and 5th days of heatwave and tracked in line with the outdoor temperatures. Although NatHERS assumes these indoor temperatures are within the comfort range, the high minimum outdoor temperature significantly reduces the opportunity of flushing out heat from indoors.

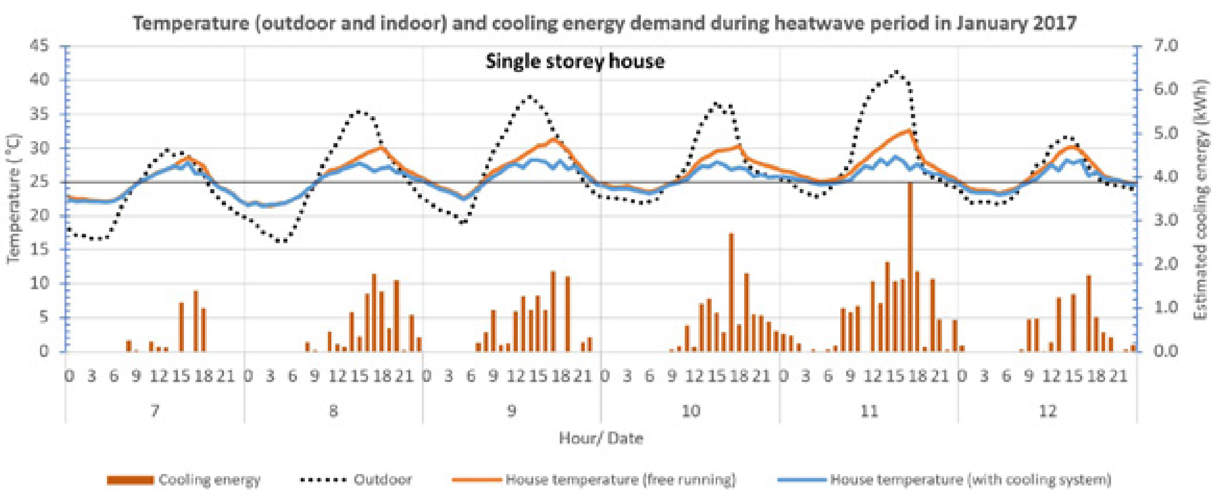

Figure 14: Thermal performance of single storey house during heatwave a period in January 2017

The temperature in different zones within the house varies significantly. As illustrated in Figure 15, the master bedroom attained the highest temperature and bedroom 2 attained the lowest in this house.

A temperature difference of 5degreeC was observed during the hottest day. On average, the master bedroom temperature was 1.3degreeC higher than the temperature of bedroom 2.

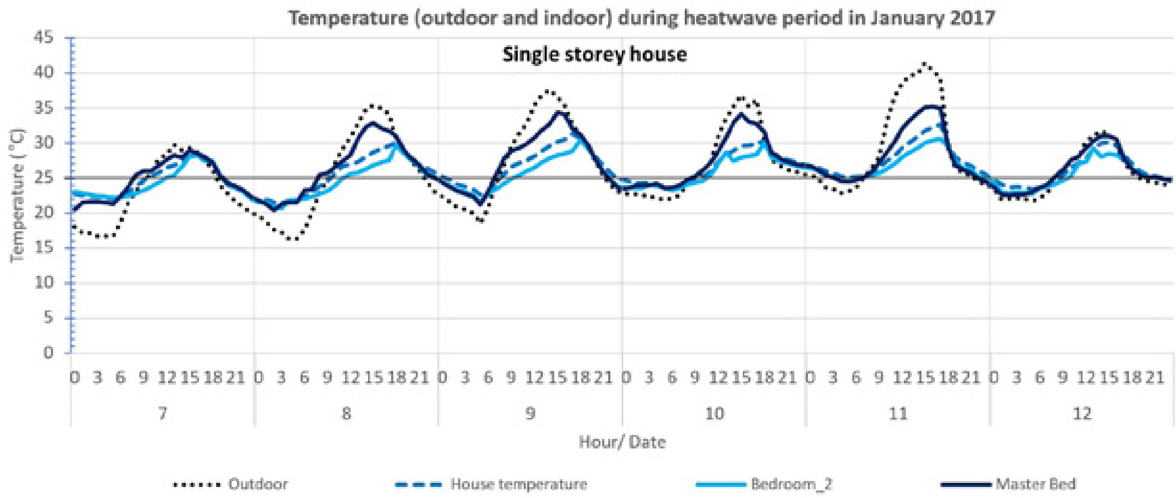

Figure 15: Indoor temperature profile in free running mode in single storey house during a heatwave period in January 2017

DOUBLE STOREY HOUSE DURING A HEATWAVE

The double-storey house used 57.6kWh during six days of heatwave and maintained an average indoor temperature of 25.2°C (across all rooms) with a standard deviation of 2.3degreeC. On a few occasions, the temperature crossed 28.5°C even with the air conditioner running. On the hottest day, peak energy demand surged to 3.7kWh at 5pm (Figure 16).

If the occupant did not use the air conditioner during this heatwave period, the average temperature of the house would rise to 26.2°C with a standard deviation of 3.7degreeC. The indoor temperature reached or exceeded 35°C during the heatwave event. The worst condition would be experienced on 11th January when the indoor temperature crossed 30°C for 7 hours with a maximum of 37.6°C. The double-storey house exhibited slightly lower overnight temperature than single storey house during first two days of heatwave. However, on 4th and 5th days of heatwave, the indoor minimum temperature followed the outdoor minimum temperature.

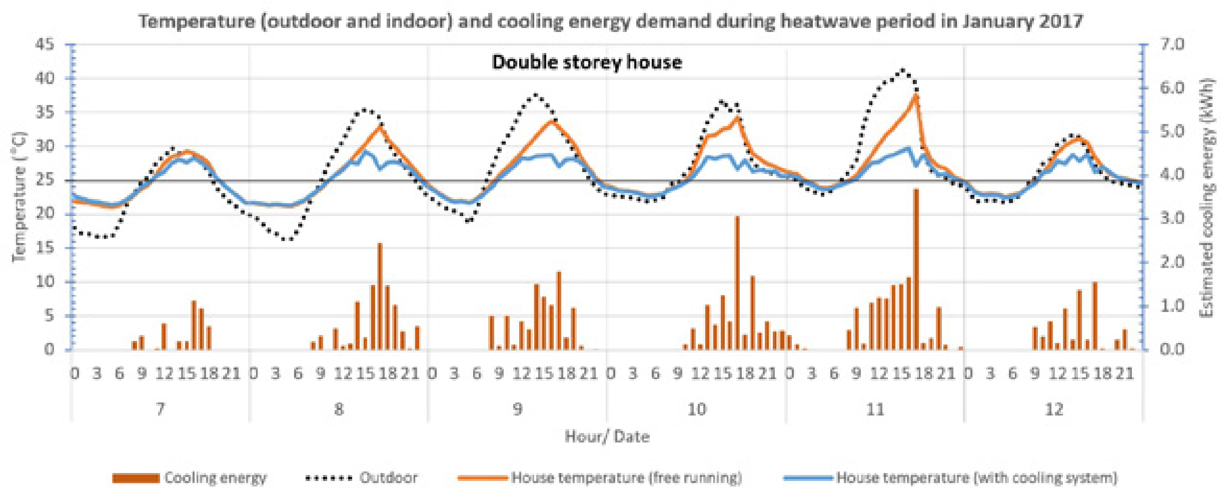

Figure 16: Thermal performance of the double storey house during a heatwave period in January 2017

In the double-storey house, the upper floor temperature was 0.5degreeC higher than the ground floor temperature. As illustrated in Figure 17, bedroom 4 on the first floor attained the highest temperature and the kitchen/living area on the ground floor attained the lowest in this house. On the hottest day, bedroom 4 temperature was 2degreeC higher than the kitchen/living area temperature. Throughout the heatwave period, bedroom 4 closely followed the maximum outdoor ambient temperature profile and stayed well above the minimum outdoor ambient temperature.

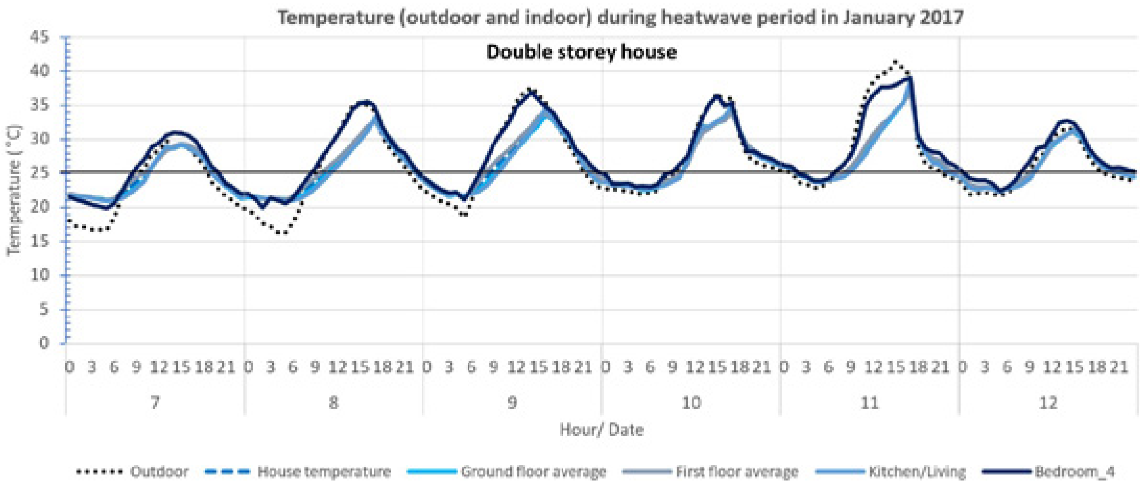

Figure 17: Indoor temperature profile in free running mode in double storey house during a heatwave period in January 2017

WORST PERFORMING APARTMENT IN THE HIGH-RISE BUILDING DURING HEATWAVE

The worst performing apartment in the high-rise building used 51.2kWh during six days of heatwave and maintained an average indoor temperature of 25°C (across all rooms) with a standard deviation of 2.2degreeC. On a few occasions, the temperature exceeded 28.5°C even with air conditioner running. On the hottest day, peak energy demand surged to 2.7kWh at 5pm (Figure 18).

In free running mode (i.e., without air conditioning), the average temperature of the apartment would rise to 26.9°C with a standard deviation of 4.3degreeC. The indoor temperature reached or exceeded 35°C during the heatwave event. The worst condition was experienced on 11th January when the indoor temperature crossed 30°C for 8 hours with a maximum of 40.1°C. Overall, the indoor temperature and outdoor temperature tracked well throughout the day.

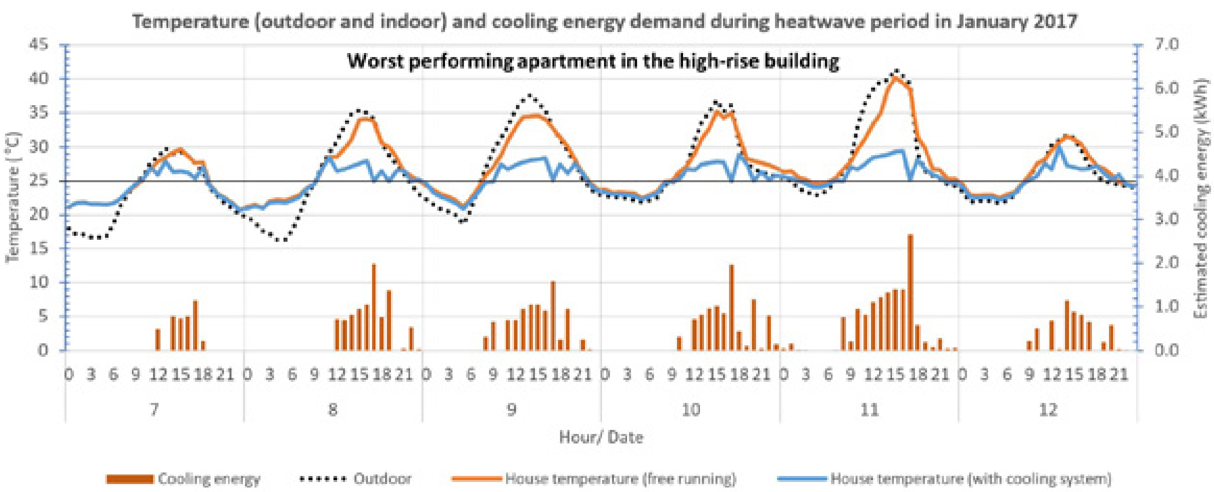

Figure 18: Thermal performance of the worst performing apartment in high-rise building during a heatwave period in January 2017

Night-time temperature in conditioned as well as in free running modes exhibited similar characteristics and aligned with the outdoor minimum temperature. The insignificant temperature difference between indoor and outdoor prevented heat dissipation from building fabric and that would further make the indoor environment more uncomfortable at night.

In this apartment the temperatures across all zones were almost the same and track well with outdoor ambient temperature all along (Figure 19). Overall, the kitchen/living area attains slightly higher minimum temperature than bedroom 2.

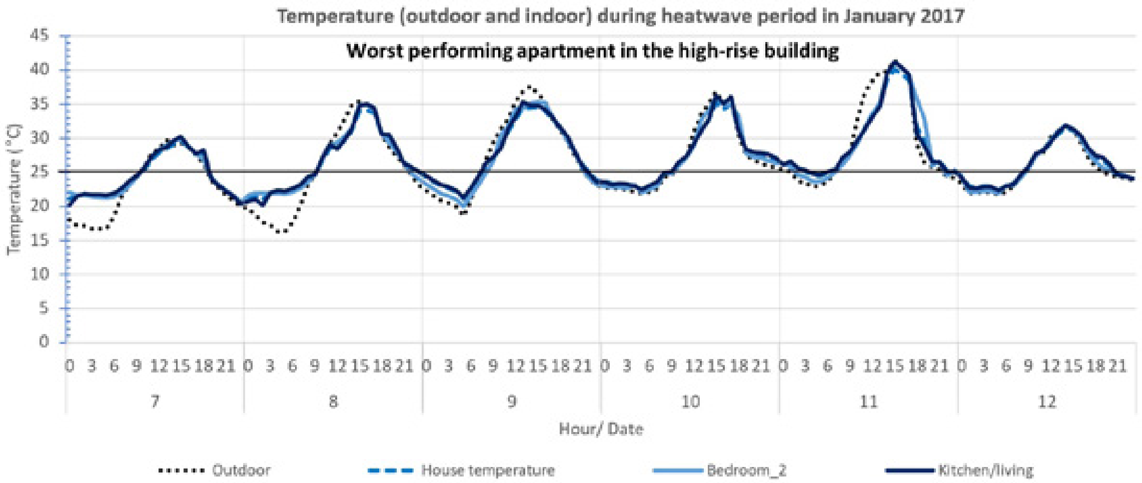

Figure 19: Indoor temperature profile in free running mode in the worst performing apartment in a high-rise building during heatwave period in January 2017

BEST PERFORMING APARTMENT IN THE HIGH-RISE BUILDING DURING HEATWAVE

The best performing apartment in the high-rise building used 11.6kWh during six days of heatwave and maintained an average indoor temperature of 24.5°C (across all rooms) with a standard deviation of 1.4degreeC. In this apartment, temperature stayed within 27°C while the air conditioner was turned on.

On the hottest day, peak energy demand surged to 0.9kWh at 5pm (Figure 20).

In free running mode, the average temperature of the apartment would rise to 24.9°C with a standard deviation of 2.1degreeC. Indoor temperature did not exceed 28°C during the heatwave event. The worst condition was experienced on 11th January when the indoor temperature crosses 27°C for 5 hours with a maximum of 28.2°C.

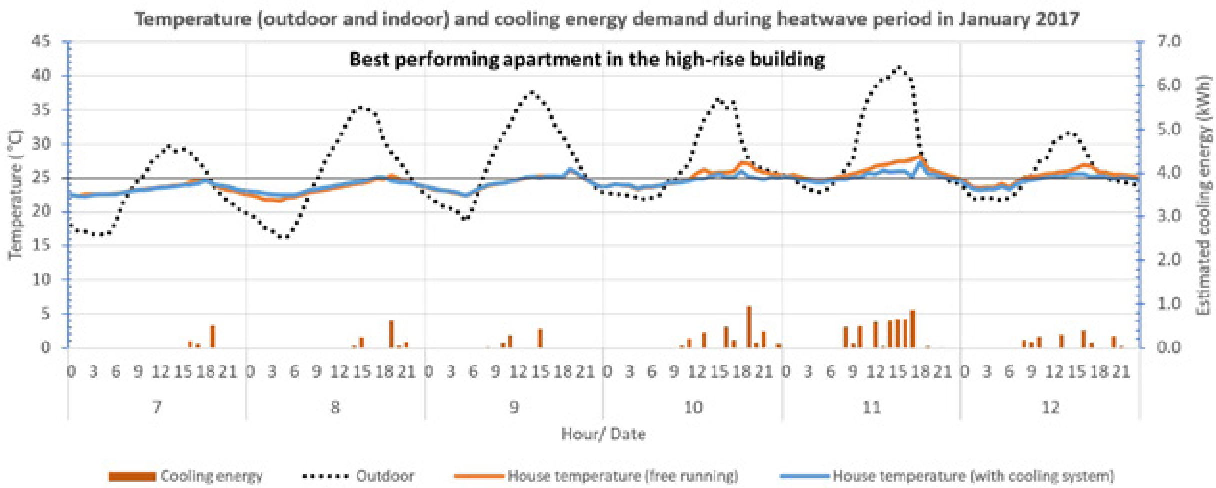

Figure 20: Thermal performance of the best performing apartment in high-rise building during a heatwave period in January 2017

Although this apartment moderated daytime temperature spikes well, night-time temperatures remained relatively higher than outdoor minimum temperatures. This may cause significant discomfort to the occupants at night.

In this apartment, bedroom 1 performs relatively poorly as occasionally temperature reached or exceeded 30°C (Figure 21). The kitchen/ living area is thermally stable and comfortable in this apartment as the temperature rarely exceeded 27°C. Overall, bedroom 1 attains 0.7degreeC higher temperature than the kitchen/living room during this heatwave period.

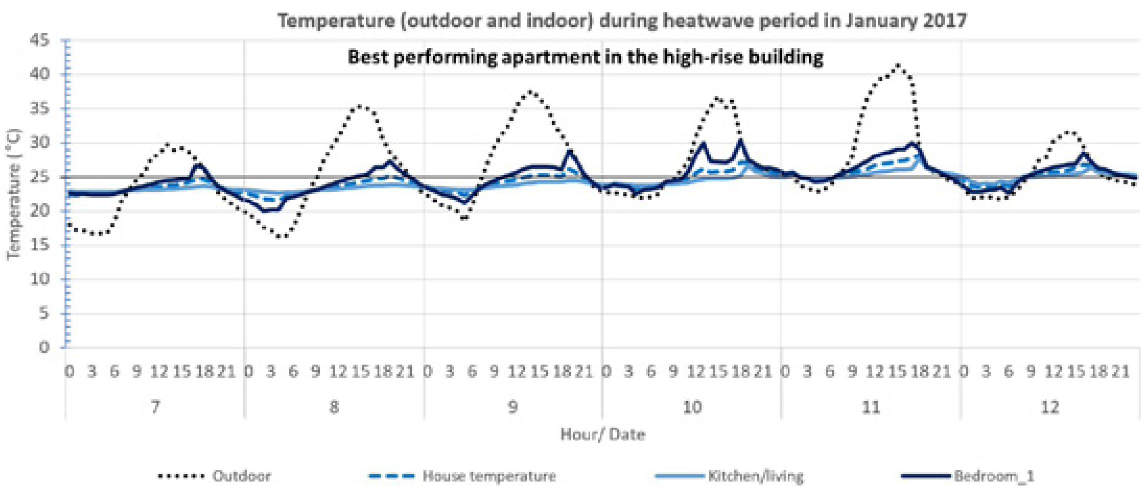

Figure 21: Indoor temperature profile in free running mode in the best performing apartment in high-rise building during a heatwave period in January 2017

WORST PERFORMING APARTMENT IN THE LOW-RISE BUILDING DURING HEATWAVE

The worst performing apartment in the low-rise building used 68.5kWh during six days of heatwave and maintained an average indoor temperature of 25.5°C (across all rooms) with a standard deviation of 1.9degreeC. On few occasions, the temperature crossed 28°C even with the air conditioner running.

On the hottest day, peak energy demand surged to 3.1kWh at 5pm (Figure 22).

In free running mode, the average temperature of the apartment would rise to 27.3°C with a standard deviation of 3.6degreeC. The indoor temperature reached or exceeded 35°C during the heatwave event. The worst condition would be experienced on 11th January when the indoor temperature crossed 30°C for 8 hours with a maximum of 37.6°C.

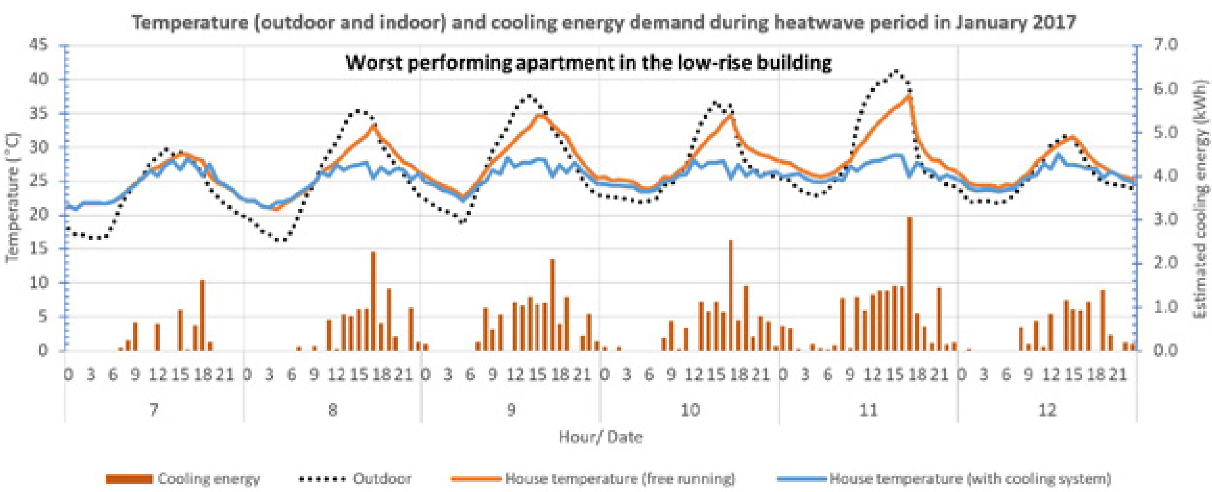

Figure 22: Thermal performance of the worst performing apartment in low-rise building during a heatwave period in January 2017

This apartment maintains high night-time temperature, exceeding 25°C on the early morning of 11th January for both free running and using a cooling system.

In this apartment, bedroom 1 attained the highest temperature and bedroom 3 maintained the lowest all along (Figure 23). On the hottest day, the average temperature of bedroom 1 was 1.5degreeC higher than bedroom 3. Bedroom 1 closely followed maximum outdoor ambient temperature profile and stayed well above the minimum outdoor ambient temperature throughout the period.

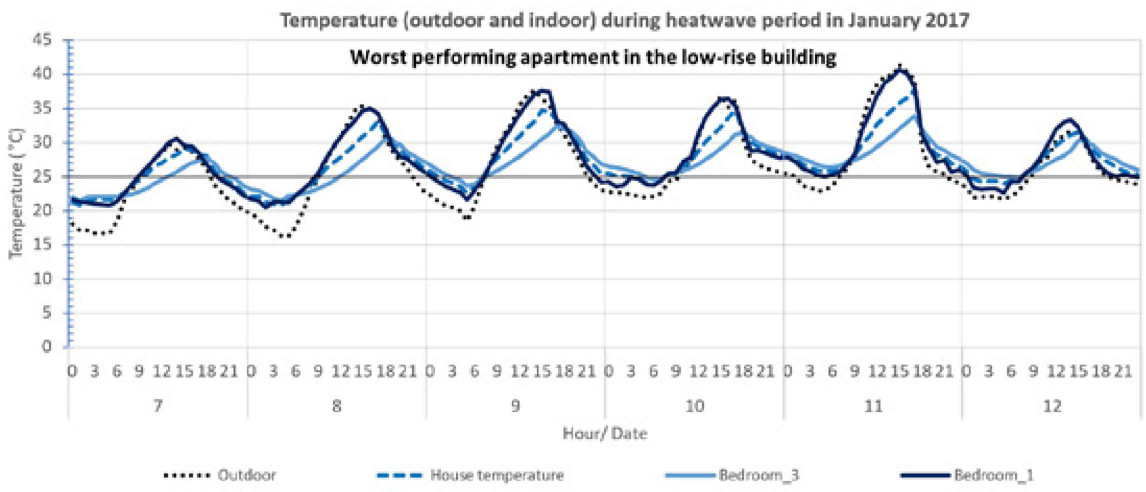

Figure 23: Indoor temperature profile in free running mode in the worst performing apartment in low-rise building during a heatwave period in January 2017

BEST PERFORMING APARTMENT IN THE LOW-RISE BUILDING DURING HEATWAVE

The best performing apartment in the high-rise building used 48.0kWh during six days of heatwave and maintained an average indoor temperature of 25.2°C (across all rooms) with a standard deviation of 1.9degreeC. In this apartment, temperature stayed within 29°C while the air conditioner was running.

On the hottest day, peak energy demand surged to 2.7kWh at 5pm (Figure 24).

In free running mode, average temperature of the house would rise to 26.2°C with a standard deviation of 2.8degreeC. The indoor temperature often reached or exceeded 30°C during the heatwave event. The worst condition was experienced on 11th January when indoor temperature crossed 30°C for 6 hours with a maximum of 33.2°C.

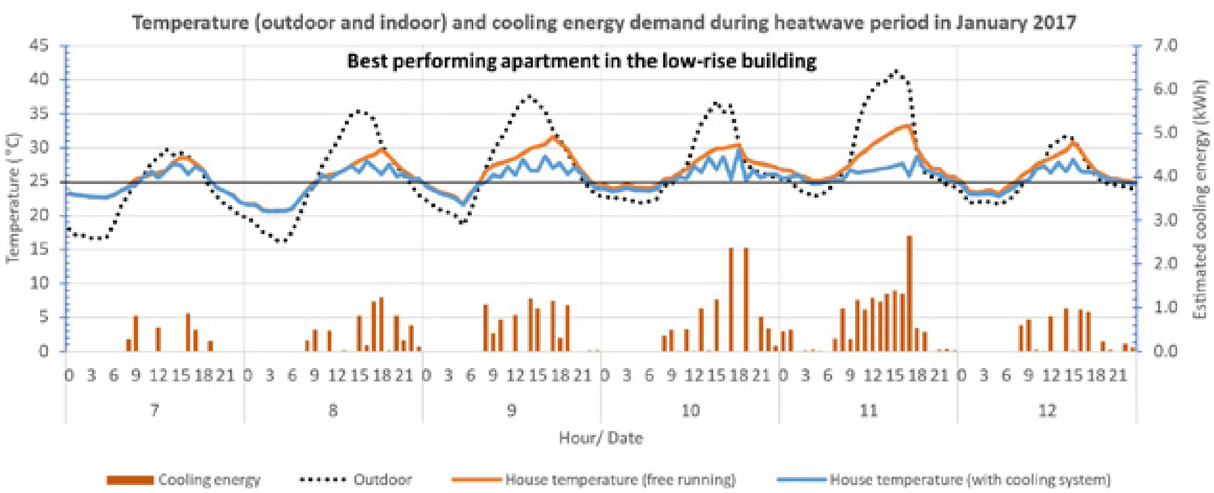

Figure 24: Thermal performance of the best performing apartment in low-rise building during a heatwave period in January 2017

Overall, night-time temperature rises progressed through heatwave conditions. Night-time temperature spiked by 5degreeC (from 20 – 25°C) from Day 2 of heatwave to Day 5.

In this apartment, bedroom 2 performed relatively poorly as occasionally the temperature reached or exceeded 30°C (Figure 25). Bedroom 3 is thermally stable in the apartment as the temperature rarely exceded 30°C. Overall, bedroom 2 attained 1.0degreeC higher temperature than bedroom 3 during this heatwave period.

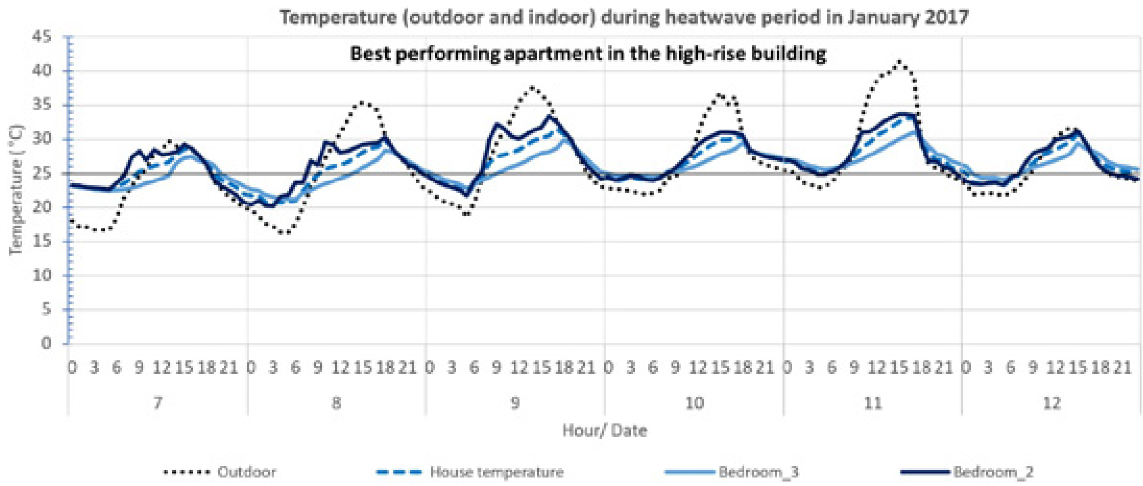

Figure 25: Indoor temperature profile in free running mode in the best performing apartment in low-rise building during a heatwave period in January 2017

DWELLINGS ARE THERMALLY UNSAFE DURING HEATWAVE

The selected dwellings performed poorly during heatwave. Daytime average indoor temperature hovered around 27°C when the air conditioners were operated as per the NatHERS thermostat settings. The higher indoor daytime temperature is expected as NatHERS assumes bedrooms are not occupied during the daytime (i.e., 9am to 4pm), therefore no cooling is applied in bedrooms during these hours. However, in a typical house more than two-thirds of the total floor area is often attributed to bedrooms and without cooling the whole house it is impossible to maintain an acceptable indoor temperature on a hot day.

The energy use for air conditioners increased proportionally with outdoor temperature. The energy spike at 5pm is due to the additional energy demand to maintain set point temperature in bedrooms in the evening. The energy load estimated by NatHERS is not practical as households usually cool the whole house (including bedrooms) during a heatwave and therefore use significantly higher amounts of energy.

> The indoor temperature profile during heatwave suggests dreadful and unsafe indoor environment as indoor temperature hovers around 25°C even at night-time.

In free running mode, daytime average indoor temperature tracked in line with outdoor temperature, often attaining the same indoor average temperature as outdoor. The indoor temperature profile during heatwave suggests dreadful and unsafe indoor environment as temperature hovers around 25°C even at night (Kenny, Flouris et al. 2019). Prolonged exposure to elevated temperatures has been associated with increased risk of death for people with risk factors including: cardiovascular disease, respiratory diseases, kidney disease, diabetes, old and young age, mental illness and substance abuse (Ebi, Capon et al. 2021).

Whilst heatwave performance was poor overall, the significant difference between the best and worst performing apartments demonstrates the impact design can have on thermal performance. The next section explores how dwelling designs could be modified to improve thermal performance under future conditions, reducing both energy use and occupant exposure to heat.

DESIGNING FOR THE FUTURE CLIMATE (2050)

The current NatHERS climate file guides us to design homes for much cooler conditions than experienced today or expected in future, i.e., 2.1degreeC cooler than 2050 scenario. Figures 26 and 27 show average hourly temperature and humidity levels between current NatHERS climate file and 2050 scenarios for warm and cool periods. The dotted lines represent average monthly values. In general, increased temperature profiles in 2050 can be observed with a striking spike (i.e., 3.6degreeC) for the maximum temperature in January. The minimum temperature in January and February 2050 will hover around 20°C. Overall, average hourly temperature difference between current NatHERS climate file and 2050 scenario in warm period is 1.9degreeC. Western Sydney will experience prolonged warm periods with increased temperature and humidity levels; therefore, building design should prioritise heat rejection strategies such as, well shaded windows and well insulated building envelope. The design should maximise heat and moisture dissipation through natural as well as low power mechanical ventilation systems.

The current NatHERS climate file guides us to design homes for much cooler conditions than experienced today or expected in future.

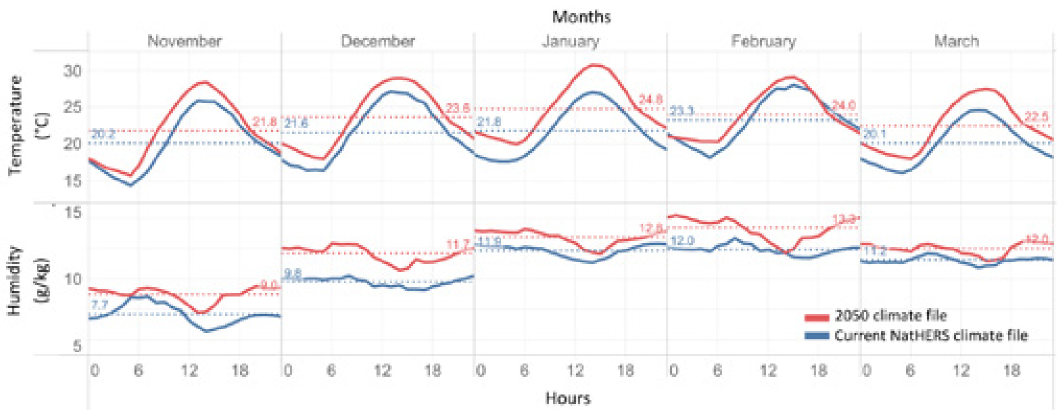

Figure 26: Comparing average hourly temperature and humidity profiles between current NatHERS climate file and 2050 scenario for warm period

The average maximum temperature in the 2050 cool period will increase to 20°C and minimum temperature around 7.5°C. Both maximum and minimum temperatures are on average 2degreeC higher than the current NatHERS climate file (Figure 27). Humidity levels in the cool period remains almost the same in both climate scenarios. Overall, increased temperature and clear sky conditions in the cool period help achieve indoor thermal comfort relatively easily if passive solar heating strategies such as, larger windows on northern façade coupled with internal thermal mass to absorb the solar heat gain, and airtight construction are adopted. Table 7 illustrates broad design strategies for reducing energy demand in improving thermal comfort in Western Sydney's future climate by responding to the local climate.

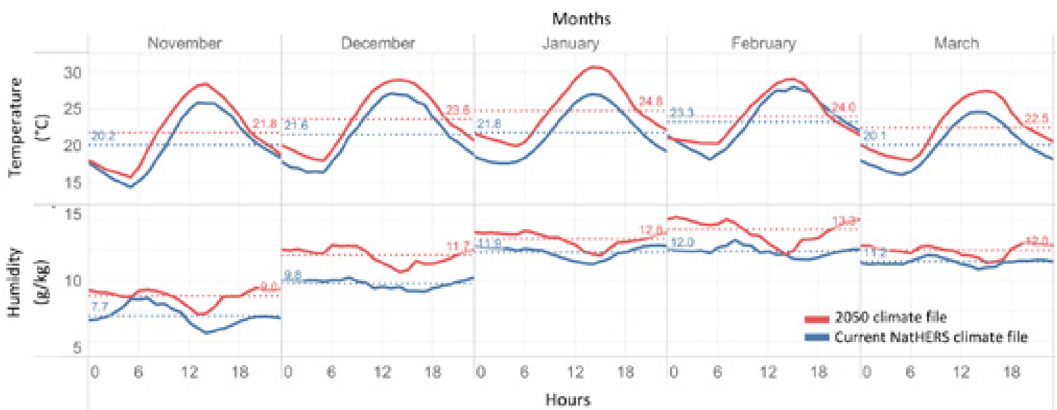

Figure 27: Comparing average hourly temperature and humidity profile between current NatHERS climate file and 2050 scenario for cool period

DESIGN STRATEGIES

Table 7: A summary of design strategies considering future climate for Western Sydney (Adapted from Upadhyay, Munsami et al. 2019)

CLIMATIC VARIABLES	LAYOUT (Orientation, topography)	SPATIAL CONFIGURATION (Room positioning, alfresco, pergolas, verandas, patios, courtyards, terraces and balconies)
Temperature and humidity Moderate to high level discomfort due to temperature and relatively high humidity in the warm period. Moderate to high level discomfort due to low temperature in cool period.	• Building layout should avoid heat gain in the warm period and allow solar penetration in the living areas in the cool period.	• Temperature controlling measures can be undertaken using room positioning, design variations and outdoor shading elements; • Daytime living spaces should be oriented towards the north and other non-daytime use spaces can be allocated to the east and the west; • Services can be located to the south; however, if living spaces need to be located there, design may utilise clerestory windows to the north and skylights can be incorporated to allow solar penetration in the cool period; • Moisture control is required in living areas. Kitchens, bathrooms and laundries need to be segregated from the living areas to avoid moisture flow to the living areas when necessary.
Solar radiation and glare Warm period is often cloudy and therefore glary. Cool period is mostly sunny and pleasant.	• Building layout should maximise north facing walls for solar heat gain and roof for photovoltaic panels/solar hot water system installations.	• Outdoor covered areas can be arranged in such a way that the northern exposure of rooms can still be maintained for solar heat gain; • Based on site opportunities and constraints, an outdoor semi-covered area to the eastern/ western sides of the building can help to control low angle sun penetrating into the living areas while also creating outdoor living spaces.
Wind speed and direction Mostly light wind (<5m/s) with scattered wind directions.	• Due to low wind speed and variable wind directions, direct ventilation may not be as eff However, casement windows would be better than the top/bottom hung windows for c	

	FABRIC/ENVELOPE (Wall wrap, wall systems, ventilation, roof design and insulation, sun shading for windows and western façades)	FORM, STRUCTURE, & MATERIALS (Volume, height, roof, walls and floor)
	• Wall wrap is a key to avoid infiltration/exfiltration, particularly in the air-conditioned spaces; • Based on outdoor environmental conditions, specific details need to be developed for walls orientated differently to avoid heat gain/loss and moisture and water penetration; • Due to high humidity in the warm period, direct ventilation may not be suitable. In addition, Richmond only experiences a low wind speed (<5m/s); therefore, a dedicated low energy mechanical ventilation system may be required; • Metal/Tile roof with roof insulation (sarking) can help to achieve air-tight attic space as well as it creates a thermal barrier. Further, ceiling insulation can help to thermally isolate living and attic spaces.	• A double storey house is preferred as it has almost half the roof area and receive half the amount of solar radiation from the roof compared with a single storey house of the same floor area; • A balance between the north facing window area and the amount of thermal mass in internal walls can contribute towards building energy efficiency in Western Sydney; • A strategically placed internal thermal mass, i.e. thermal mass exposed to the sun for space heating and thermal mass protected from sunlight for space cooling, are effective in maintaining indoor thermal comfort in both cool and warm periods; • Similar to the roof, an air-tight floor is expected for thermal efficiency of a building. A solid floor (e.g. concrete or tile) is preferable to a timber subfloor; • Building height should be at least 2700 mm to accommodate ceiling fans to achieve thermal comfort in warm (humid) period.
	• Western walls should be shaded appropriately to avoid unnecessary heat gain in the warm periods; • Western walls should have higher R-value than the northern walls to withstand high heat gain if it is unshaded; • All windows should be appropriately shaded to avoid heat gain in the warm period; however, arrangements should be made to allow sun penetration in the cool period.	• The solar load on each façade should be carefully considered as well as the window types (frames, glazing and opening arrangement); • The western façade will benefit from using reflective glass, whereas double glazing will be appropriate for southern windows; • Thermally broken window frames are beneficial for managing thermal bridging in both the warm and the cool periods.

ective and therefore its influence in design decision is insignificant.
atching breezes when available.

MODIFICATION STRATEGIES FOR SELECTED DWELLINGS TO ACHIEVE BASIX COMPLIANCE USING FUTURE (2050) CLIMATE SCENARIO

The design strategies outlined in Table 7 are more relevant at early design stage as designers have freedom and flexibility in design decisions, materials selection and educating clients to achieve the best outcome for the specific project. In this study, the selected dwellings are modified without making any changes in the layout of dwellings and broadly adopting the following treatment strategies feasible for each dwelling:

1. **Increase air movement**
   a. Choose windows with higher operability to allow rapid airflow when outdoor thermal environmental conditions are favourable.
   b. Install ceiling fans in living areas and bedrooms.
2. **Avoid unnecessary solar heat gain**
   a. Change roof colour to 'light'.
   b. Shade north facing window using longer eaves (750 mm) or dedicated shading device of 600 mm projecting from lintel level.
   c. Use vertical adjustable shading device on east and west windows.
   d. Increase reflective insulation (added R value) for western walls.
   e. Use cavity brick wall on western façade.
3. **Glazing area optimisation**
   a. Maximise windows on north-east, north and north-west (windows to harness sun and solar heating).
   b. Minimise windows on south-east, south, south-west and west (windows for daylighting and ventilation).
   c. Ensure external shading is installed to avoid excessive heat gain and glare from western windows.
   d. Consider using clerestory windows on western façade to minimise glare effect.
4. **Glazing and frame choice**
   a. Use composite frame or thermally broken aluminium frame to minimise thermal bridging impact.
   b. Use low-e glass on windows facing to the west.
   c. Use double glazing in large windows on south-east, south, south-west and west to prevent heat loss as these façades do not receive solar heat gain in winter. If windows are arranged sensibly (greater proportion of windows on northern façade and lowest on the southern façade) and within 25% of floor area, often single glazing (high solar gain low-e) windows in composite frame deliver similar outcome as of double-glazed clear window in aluminium thermally broken frame.
5. **Improve building fabric**
   a. Wall wraps should be used to minimise moisture movement across wall section and prevent air leakage through walls.
   b. Use reverse brick veneer (or introduce internal thermal mass) to balance indoor temperature
   c. Increase overall insulation R value of western façade to dampen heat flow through western façade.
   d. Use hard floors and thermal mass indoors to prevent indoor temperature rise instantaneously.
   e. Increase building height and introduce vents (controlled) with 300 mm from ceiling to escape hot air and maintain indoor air quality.

THERMAL PERFORMANCE OF THE MODIFIED HOUSES TO SUIT FUTURE CLIMATE SCENARIO

The current BASIX complied single-storey house performed poorly (Heating: 23.1 MJ/m2, Cooling: 51.9 MJ/m2) and exceeded the BASIX cooling cap when modelled using future climate (2050) file (Refer Table 4). Incorporating modifications such as, increasing air movement, installing external shading devices, and changing walls and roof colour to 'light', allowed the single storey house to meet the higher BASIX standards for thermal comfort (Table 8).

The double-storey house also exceeded the BASIX 2022 cooling and total caps (Heating: 24.2 MJ/m2, Cooling: 60.1 MJ/m2) when modelled using future climate (2050) file (Refer Table 4). Along with modifications adopted for single storey house, additional treatment options were required for the double storey house to further reduce cooling load and meet the BASIX requirements (Table 8). In the first treatment, additional thermal mass was introduced by substituting the timber first floor slab with a concrete slab. The second treatment used a slightly better performing glazing system and reduced glazing to floor area ratio from 33% to 30%.

Table 8: Various modifications on houses are performed to suit the future climate

TREATMENTS APPLIED	SINGLE STOREY HOUSE	DOUBLE STOREY HOUSE (TREATMENT-1)	DOUBLE STOREY HOUSE (TREATMENT-2)
Increase air movement	Added ceiling fans to all living/bedroom zones		
Avoid unnecessary solar heat gain	External shading devices were introduced to all windows to avoid heat gain in warm period		
Glazing area optimisation			Glazing to floor area ratio reduced to 30%
Glazing and frame choice		Used single glazing in aluminium frame (U-value 6.6/SHGC 0.49)	Used single glazing in composite frame (U-value 4.6/SHGC 0.36)
Improve building fabric		Introduced concrete suspended slab between floors	
	Changed external walls and roof colour to 'light'		

Aerial image of a new housing estate under construction.

The modified houses meet the BASIX total energy caps for 2030 and 2050 future climate scenarios but exceed the heating cap when simulated using both current and 2022 NatHERS climate files (Table 9).

However, the modified houses show a significant reduction in cooling energy demand with NatHERS climate files compared with future climate scenarios.

Table 9: Thermal performance outcomes of modified single free-standing dwellings for various climate scenarios

CLIMATE SCENARIO	BASIX CAPS (MJ/m²)			SIMULATION RESULTS – LOADS (MJ/m²)			BASIX status
	Heating	Cooling	Total	Heating	Cooling	Total	
Single storey house							
Future climate (2050)	56	37.5	60	26.5	32.0	58.5	Pass
Future climate (2030)	56	37.5	60	34.7	22.2	56.9	Pass
NCC 2022 NatHERS climate	56	37.5	60	**60.6**	11.0	**71.6**	**Fail**
Current NatHERS climate	55.8	56.2	–	**61.0**	18.0	–	**Fail**
Double storeys house *(Treatment-1)*							
Future climate (2050)	56	37.5	60	31.0	28.2	59.2	Pass
Future climate (2030)	56	37.5	60	39.3	20.2	59.5	Pass
NCC 2022 NatHERS climate	56	37.5	60	**63.2**	11.0	**74.2**	**Fail**
Current NatHERS climate	55.8	56.2	–	**62.2**	17.4	–	**Fail**
Double storeys house *(Treatment-2)*							
Future climate (2050)	56	37.5	60	31.3	27.9	59.2	Pass
Future climate (2030)	56	37.5	60	38.9	20.6	59.5	Pass
NCC 2022 NatHERS climate	56	37.5	60	**59.8**	11.8	**71.6**	**Fail**
Current NatHERS climate	55.8	56.2	–	**60.1**	16.5	–	**Fail**

THERMAL PERFORMANCE OF THE MODIFIED APARTMENTS TO SUIT FUTURE CLIMATE SCENARIO

The current BASIX complied apartment in the high-rise building exceeds the BASIX cooling and total caps (Heating load: 29.7 MJ/m2, Cooling load: 82.0 MJ/m2) when modelled using future climate (2050) file (Refer Table 5). This apartment was modified to improve cooling load by increasing air movement, installing external shading devices, and changing walls and roof colour to 'light'. These modifications were not sufficient to bring down cooling load; therefore, further additional modifications including glazing area reduction and glazing system performance were applied (Table 10).

The apartment in the low-rise building also exceeds the BASIX cooling cap (Heating load: 15.3 MJ/m2, Cooling load: 88.5 MJ/m2) when modelled using future climate (2050) file (Refer Table 6). Simple modifications such as, increasing air movement, installing external shading devices, and changing walls and roof colour to 'light' were enough to bring down cooling load to meet the BASIX cap (Table 10).

Homes and apartments modified to perform well in 2030 and 2050, could not be built today despite providing energy savings on cooling.

Table 10: Various modifications on apartments in multi-unit buildings are performed to suit the future climate

TREATMENTS APPLIED	AN APARTMENT IN HIGH-RISE BUILDING (TREATMENT -1)	AN APARTMENT IN HIGH-RISE BUILDING (TREATMENT -2)	AN APARTMENT IN LOW-RISE BUILDING
Increase air movement	Added ceiling fans to all living/bedroom zones		
Avoid unnecessary solar heat gain	External shading devices were introduced to all windows to avoid heat gain in warm period		
Glazing area optimisation	Reduced glazing area to 30%		
Glazing and frame choice	Used single glazing in composite frame (U-value 4.6/SHGC 0.36)	Used double glazing in aluminium frame (U-value 3.1/SHGC 0.27)	
Improve building fabric	Changed external walls and roof colour to 'light'		

The modified apartment (Treatment-1) in the high-rise building meets the BASIX caps for future climate scenario but exceeds the total cap when simulated using NCC 2022 NatHERS climate files (Table 11). The second modification (Treatment-2) demonstrates a significant improvement in thermal performance of this apartment and satisfies BASIX caps associated with their respective NatHERS climate files. The modified apartment in the low-rise building also satisfies BASIX heating and cooling caps associated with NatHERS climate files.

These modified apartments also show a significant reduction in cooling energy demand with NatHERS climate files compared with future climate scenarios.

Table 11: Thermal performance outcomes of modified apartments in multi-unit buildings for various climate scenarios

CLIMATE SCENARIO	BASIX CAPS (MJ/m^2)			SIMULATION RESULTS – LOADS (MJ/m^2)			BASIX status
	Heating	Cooling	Total	Heating	Cooling	Total	
An apartment in high-rise building (12.10) *(Treatment-1)*							
Future climate (2050)	65.1	50.6	79	28.5	50.4	78.9	Pass
Future climate (2030)	65.1	50.6	79	36.3	40.5	76.8	Pass
NCC 2022 NatHERS climate	65.1	50.6	79	59.1	24.9	**84.0**	**Fail**
Current NatHERS climate	63.3	63.7	–	52.9	30.4	–	Pass
An apartment in high-rise building (12.10) *(Treatment-2)*							
Future climate (2050)	65.1	50.6	79	24.0	39.3	63.3	Pass
Future climate (2030)	65.1	50.6	79	30.8	30.4	61.2	Pass
NCC 2022 NatHERS climate	65.1	50.6	79	50.7	18.4	69.1	Pass
Current NatHERS climate	63.3	63.7	–	44.8	23.4	–	Pass
An apartment in low-rise building (1.09)							
Future climate (2050)	69.7	54.2	–	20.1	53.4	–	Pass
Future climate (2030)	69.7	54.2	–	26.0	40.1	–	Pass
NCC 2022 NatHERS climate	69.7	54.2	–	45.8	24.7	–	Pass
Current NatHERS climate	63.3	63.7	–	41.6	32.9	–	Pass

OVERALL THERMAL PERFORMANCE OF SELECTED MODIFIED DWELLINGS TO SUIT FUTURE CLIMATE

The dwellings designed for the future climate demonstrate better thermal performance (i.e., significant reduction in cooling load and overall reduction in total load) when compared with the results obtained from the NCC 2022 NatHERS climate. Importantly, buildings designed for the future climate can significantly reduce cooling energy demand today as outlined in Figure 28. The average cooling energy demand of these selected dwellings would be around 35% of the total load in currently experienced climate (2020) which will increase up to 60% in 2050.

If designers would like to improve the thermal performance of buildings (i.e., aiming to achieve higher NatHERS rating) in a 2050 scenario, they should attempt to reduce cooling demand as in future, the share of cooling will be higher than heating. On the other hand, if a designer attempts to achieve higher star rating using NCC 2022 NatHERS climate file, the obvious strategy would be to reduce heating load as it is significantly high compared with cooling (Figure 28). However, design which prioritises reduction of heating load would have perverse outcomes for the long-term thermal performance of the building over its lifecycle. It is important to understand that as the climate is getting warmer year after year, long term strategies are necessary to develop a heat resilient building for the future.

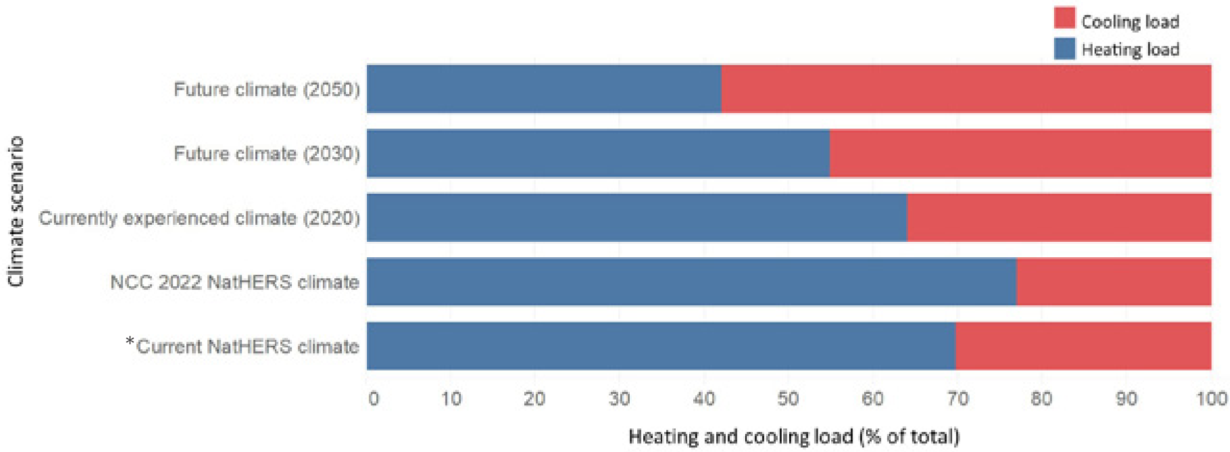

Figure 28: Share of heating and cooling loads of selected dwellings (modified to suit future climate) in different climate scenarios.

Higher cooling load is associated with lower cooling thermostat setting in the current NatHERS accredited tools which is 24.5°C. It is increased to 25°C in the beta version of NatHERS tool which is used for NCC 2022 NatHERS climate file, currently experienced and future climates.

If a designer attempts to achieve higher star rating using NCC 2022 NatHERS climate file, the obvious strategy would be to reduce heating load. However, this would have perverse outcomes for the long-term thermal performance of the building over its lifecycle.

Waterside apartment buildings in Western Sydney.

SUMMARY OF THE FINDINGS

NATHERS CLIMATE FILES DO NOT REPRESENT THE CURRENTLY EXPERIENCED CLIMATE

The current NatHERS climate file for Western Sydney represents pre-1980 climate scenario which portrays a cooling dominated climate. However, Australia has been experiencing much warmer conditions since 2010 and Western Sydney follows the same trend (Commonwealth of Australia 2022). The average temperature of the last 22 years (2000-2021) is 18°C as shown in Figure 29; whereas yearly average temperature of the current NatHERS climate file is 17.4°C.

The recently released NCC 2022 NatHERS climate file for Western Sydney is prepared using weather files from 1990 to 2015 with a yearly average temperature of 17.9°C. This update is better than the current NatHERS climate file but fails to capture the warmer scenario experienced in the last decade. As outlined in Figure 29, Western Sydney experienced warmest years on the record from 2016 to 2019 with average yearly temperature exceeding 18.5°C. The analysis presented in this study highlights that the NatHERS climate files are outdated and do not represent current climate experienced in Western Sydney.

THE LATEST SUSTAINABLE BUILDING POLICY (NCC 2022) IS OUTDATED

The Australian Government adopted residential building energy efficiency in the National Construction Code (NCC) in 2002. Building designers need to demonstrate the minimum thermal performance of houses through Deemed-to-satisfy (DTS) provisions or using Nationwide House Energy Rating Scheme (NatHERS) accredited software packages. The current NCC 2019 requires houses or multi-unit buildings to achieve a minimum of NatHERS 6-stars.

In August 2022, Commonwealth, State and Territory building ministers endorsed to increase minimum thermal performance of residential dwellings to NatHERS 7-stars through NCC 2022 which will be fully effective from 1st October 2023. It is a significant step to ensure houses will be more resilient and require less energy for space heating and cooling. However, this good intention is overshadowed by the outdated climate files used in NatHERS tools which represent pre-2010 climate scenario for Western Sydney. In the last decade (2011 to 2020), Australia experienced a significant increase in temperature (Commonwealth of Australia 2022) together with gradual increase in the frequency of heatwaves (Trancoso, Syktus et al. 2020).

Figure 29: Yearly mean temperature for Western Sydney is ranked for the last 50 years (1972 – 2021) and results are displayed since 2000. Later part of 2010s (2016 to 2019) were the warmest years on the record with yearly mean temperature exceeding 18.5°C.

If the houses that are designed and built in 2023 cannot withstand the current climate, it is futile to expect these houses will save energy, as well as offer heat resilience to the occupants during blackouts and heatwave conditions as demonstrated through this study. Most importantly, houses designed to achieve a higher NatHERS star rating based on outdated climate files will be more vulnerable to heat as they are specifically designed to perform well in much cooler climate.

If NatHERS continue using outdated climate files, homes will continue to be designed for a historical, irrelevant climate. As a result, homes of the future will require significant amounts of energy for cooling. If we do not update regulations, Australian dwellings will neither be energy efficient nor heat resilient. The Government needs to ensure NatHERS climate files represent a realistic climatic context that reflects current as well as future climate scenarios predicted by the latest climate models.

CURRENT BASIX-COMPLIANT DWELLINGS MAY CONSUME MORE THAN DOUBLE ENERGY FOR COOLING IN FUTURE

The average heating and cooling loads of current BASIX compliant dwellings are almost equal as shown in Figure 30. The same dwellings when simulated using beta version of NatHERS tool, which uses the NCC 2022 NatHERS climate file, demonstrate increased heating load, i.e., almost two-thirds of the total energy is used for heating and just one third for cooling. This result is counter intuitive as one expects that the cooling load should increase if the climate file had higher average temperature. The main reason for the decreased cooling load is associated with the decision to increase the cooling thermostat temperature (the temperature at which it is assumed occupants will turn on cooling) from 24.5°C to 25°C in the beta version of NatHERS tool.

The demand for cooling energy will continue to increase in future as the climate warms. It is expected that dwellings which satisfy the current BASIX standards will require more than double the amount of cooling energy in future (2050) compared to the energy estimated using the NCC 2022 NatHERS climate file.

> If we do not update regulations, Australian dwellings will neither be energy efficient nor heat resilient.

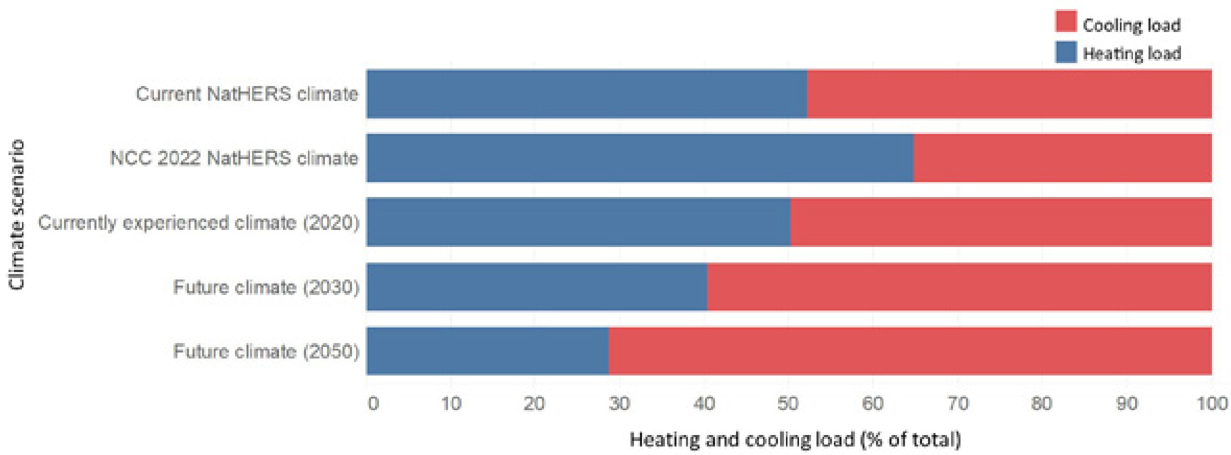

Figure 30: Share of heating and cooling loads of current BASIX affected dwellings in different climate scenarios.

CURRENT BASIX AFFECTED DWELLINGS ARE THERMALLY UNSAFE DURING EXTREME WEATHER

The average hourly temperature profile of the selected BASIX affected dwellings (i.e., single-storey and double-storey houses, and the best and worst performing apartments from high-rise and low-rise buildings) during heatwave is presented in Figure 31. These dwellings maintain average maximum indoor temperature below 28°C with a cooling system on thermostat setting, and schedule set by the NatHERS tool.

These houses are thermally unsafe if not equipped with air conditioners, or if the air conditioners were not turned on during the heatwave period. Indoor temperatures in the afternoon would exceed 28°C regularly for more than six hours each day. The average minimum indoor temperature would hover between 23°C to 25°C from Day 3 to Day 6 of the heatwave either with the air conditioner running or without. The night-time indoor minimum temperature would exceed 23°C which can be uncomfortable whilst sleeping. Most importantly, indoor temperature tracked closely with outdoor temperature, therefore the heat accumulated indoors could not be purged effectively at night.

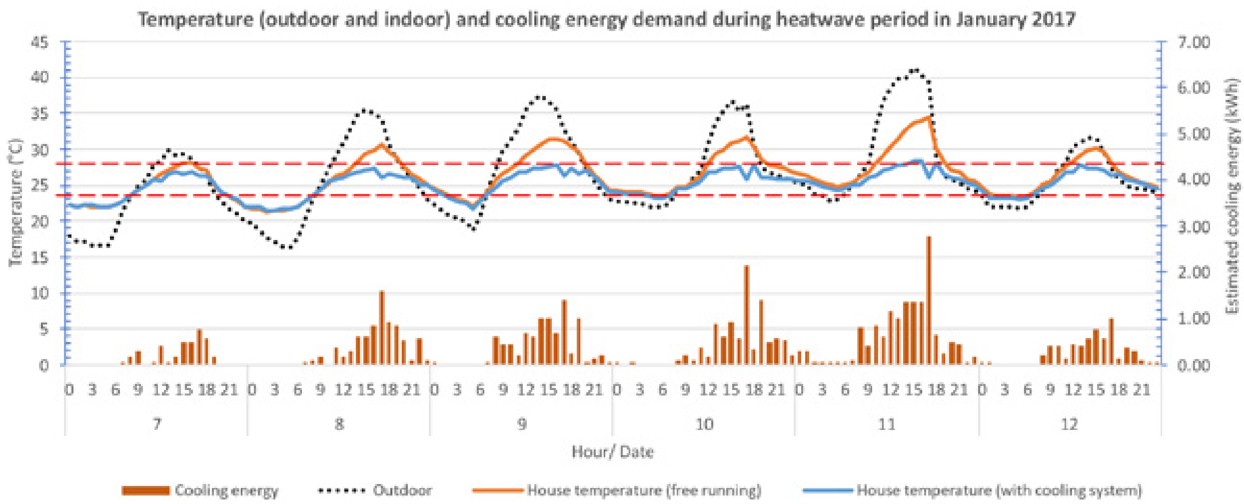

Figure 31: Average indoor temperature of selected dwellings during a heatwave period in January 2017

The upper dotted line at 28°C is considered as upper limit for thermal comfort. The lower dotted line at 23.5°C represents average night-time (9pm – 6am) house temperature during heatwave

BUILDING DESIGNERS NEED TO UNDERSTAND THE FUTURE LOCAL CLIMATE AND DEVELOP DESIGN STRATEGIES TO SUIT

This study analysed various climate files and highlighted the changing climate in Western Sydney. In recent years, Western Sydney has experienced longer warm periods with more frequent heatwaves and relatively short cool periods compared with the climate outlook used in the current NatHERS software. In 2050, Western Sydney will experience a warm period for about 20 weeks (from mid-November until early April) and cool period for 22 weeks (from early May to September).

From 1st October 2023, in achieving minimum NatHERS 7-star, houses will still be designed for much cooler climate than experienced today because NCC 2022 portrays Western Sydney as a heating dominated climate with relatively shorter, 16 weeks of warm period (from mid-November to early March) and much longer 26 weeks of cool period (from early April to September). If building designers blindly chase for higher NatHERS stars, they will fine-tune buildings to perform well in the cool period and these buildings will struggle to cope in extended warm periods with frequent heatwaves; a norm in Western Sydney over the last decade.

This study presents and tests broad design strategies to assist building designers and builders to design homes to suit future climate conditions. The modelling outlined in this report shows that a future-resilient design should address increasingly warm environmental conditions, as well as a cool period experienced for few months. Buildings in NatHERS climate zone 28 should focus on well shaded and insulated buildings to avoid any heat gain in the warm period but should harness solar exposure to warm up the indoors during the cool period. This study has presented a range of design recommendations for appropriate building layout, spatial configuration, building fabric and envelope, and materials to suit the warmer future climate of Western Sydney.

Man using air-conditioner controls to cool his home.

HOUSES DESIGNED FOR THE FUTURE CLIMATE FAIL TO MEET THE BASIX THERMAL COMFORT REQUIREMENTS (CURRENT AND HIGHER BASIX STANDARDS)

The study modified sample houses (i.e., single and double storey) to meet the higher BASIX standards under future climate conditions of 2050 (Figure 32). With these modifications, the homes used approximately equal amounts of heating and cooling under the 2050 climate scenario. In the 2030 scenario the share of energy use shifted to around two thirds for heating and one third for cooling. When simulated using the NCC 2022 NatHERS climate file cooling load dropped to 16% and heating load jumped to 84% of the total load.

As outlined in this report, the NCC 2022 NatHERS climate for Western Sydney exhibits a cooler climate outlook, and therefore forces houses to be designed primarily to address heating demand. The new dwellings which satisfy the higher BASIX standards will require at least 50% more cooling energy than estimated by NatHERS in the currently experienced climate of 2020, and more than double the cooling energy in the 2050 climate scenario.

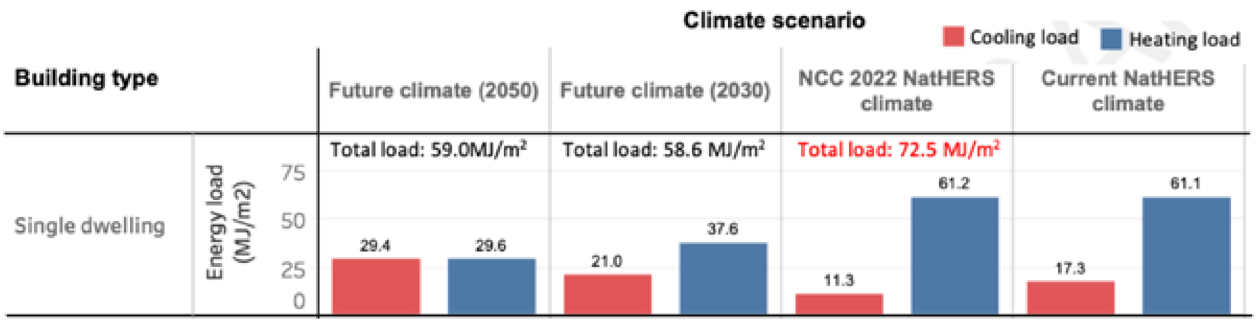

Figure 32: Comparing average heating, cooling loads of modified houses for the future climate (2050) with future (2030) and NatHERS climate files.

APARTMENTS DESIGNED FOR THE FUTURE CLIMATE MEET THE BASIX THERMAL COMFORT REQUIREMENTS (CURRENT AND HIGHER BASIX STANDARDS)

The apartments in the multi-unit buildings modified to suit the future warming climate of 2050 satisfy the current as well as the higher BASIX standards (Figure 33). In high-rise buildings, cooling and heating energy demand flip when the same dwelling is simulated using the 2050 versus current NatHERS climate file. The cooling load will be reduced to less than half with NCC 2022 NatHERS climate file with respect to 2050 climate scenario.

Across all the dwellings used in this study, energy demand for cooling is highest in the apartment in a low-rise building. This is due to the lower thermal comfort requirements set by the BASIX for multi-unit buildings up to five storeys. Similar to other dwellings, this modified apartment also exhibits the same trend of cooling energy reduction to less than half with NCC 2022 NatHERS climate file when compared with 2050 climate scenario (Figure 33).

BASIX caps for multi-unit buildings are less stringent than houses and it is possible for developers to design multi-unit buildings to respond to the future warming climate while satisfying the current regulations. This may be possible as individual apartments (in 6-storey and higher multi-unit building) are only required to meet NatHERS 6-star (as opposed to NatHERS 7-star for houses) which allows flexibility in responding to heating and cooling requirements. As the NatHERS stars increase, homes must show they can use less energy. The higher NatHERS stars can only be achieved by optimising designs for the dominating climate portrayed by the climate file. Therefore, the dwellings with the higher NatHERS star-rating using cooling dominated climate of 2050 will struggle to meet the BASIX heating cap when simulated in the heating dominated climate portrayed by the NCC 2022 NatHERS climate file for Western Sydney.

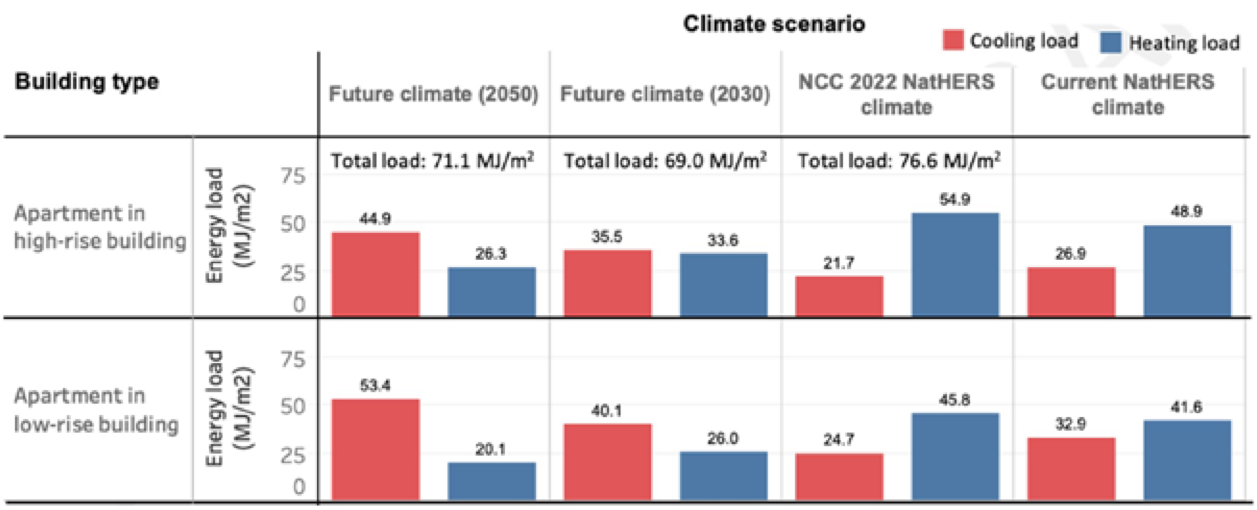

Figure 33: Comparing average heating, cooling loads of modified apartments in multi-unit buildings for the future climate (2050) with future (2030) and NatHERS climate files.

RECOMMENDATIONS

GOVERNMENT POLICIES SHOULD ACKNOWLEDGE THE CHANGING CLIMATE

The recent update of the NatHERS climate file through NCC 2022 fails to acknowledge the climate change in Australia over the last decade despite extensive research showing the impact of climate change (CSIRO 2022, Commonwealth of Australia 2018, Foo 2020, Australian Academy of Science 2021, Commonwealth of Australia 2022, NSW Government 2022). In 2015, CSIRO and the Australian Bureau of Meteorology (BoM) released the latest set of national climate projections for Australia (CSIRO 2022). More recently, CSIRO (2022) released future climate files compatible with NatHERS software packages. Future updates of the building energy efficiency regulations should use more representative future climate files to ensure minimum energy consumption and better heat resilience for the future warmer climate.

ENSURE NATHERS TOOLS USE FUTURE CLIMATE FILES TO DEMONSTRATE BUILDING ENERGY EFFICIENCY OVER ITS LIKELY LIFECYCLE

This study highlighted the consequences of using outdated climate files in a building design. Buildings in Western Sydney which satisfy the current BASIX standards for thermal comfort will use more than double the amount of energy for cooling in future climate scenarios. Occupants will suffer from heat stress if the houses are without air conditioners, if they cannot turn them on because of concern for costs, or experience power outage during a heatwave event. Buildings that are optimised for much cooler conditions will require excessive energy in extreme heat scenarios putting more stress on the electricity grid (AEMO 2021). This issue can be managed if buildings are designed for the future climate, i.e., 20-30 years ahead of the design date. Designing for the future climate will not only help future proofing buildings until the next renovation in 20 – 30 years, but also reduces pressure on the electricity network, allowing network providers additional time to meet the additional energy demand for cooling.

ENSURE BUILDINGS ARE THERMALLY SAFE DURING EXTREME WEATHER EVENTS

The simulation results demonstrated that the selected BASIX-compliant dwellings would experience extreme heat stress during heatwave events. The average indoor temperature of selected dwellings exceeded 30°C regularly for a few hours each day when outdoor temperature surpassed 35°C. BASIX uses heating and cooling caps to regulate thermal performance of dwellings without any reference to buildings' thermal performance in extreme heat or cold events.

Thermal safety is yet to be considered in Australian buildings (Hatvani-Kovacs, Belusko M. et al. 2016). Thermal safety is important metric to assess resilience of buildings in extreme events (specifically heatwaves in Western Sydney) without air conditioning; modelling a scenario during blackout or a situation when occupants cannot afford to use air conditioning. Future updates of building energy efficiency should address thermal safety requirements to ensure at least a part of a house or apartment maintains a comfortable indoor environment during extreme weather events without relying on mechanical heating and cooling systems.

GOVERNMENT REGULATIONS SHOULD ENCOURAGE BUILDINGS TO BE DESIGNED FOR THE FUTURE CLIMATE

The current and the higher BASIX standards do not allow houses to be designed for the future warmer climate. It means that new houses in Western Sydney are forced to be designed for the historical climate of pre-1980 until October 2023 and pre-2010 climate from October 2023. It is a pity that Western Sydney houses continue to be designed primarily to address significant heating demand whilst the future climate is going to be significantly warmer and would require significant cooling. NatHERS and BASIX should further investigate this issue and promote buildings designed for future warmer climate to save energy consumption and improve heat resilience.

Apartments in multi-unit buildings can be voluntarily designed to meet the BASIX standards using future climate (2050) scenario which will also satisfy both current and the higher BASIX standards. It means that the less stringent BASIX caps for multi-unit buildings allow such buildings to be designed for the future warmer climate if a designer chooses to do so. This demonstrates that achieving higher NatHERS stars using an historical climate file forces designers to optimise the design for historical climate which is counterproductive in future climate scenario.

The 2022 BASIX review did not increase thermal comfort stringency for multi-unit buildings up to five storeys, therefore, the apartment in a low-rise building had the highest cooling energy load compared with other dwellings. The NSW Government should review the thermal comfort targets for low-rise multi-unit buildings and ensure they offer same level of thermal comfort as in houses and apartments in high-rise buildings. Otherwise, occupants of apartments in low-rise multi-unit buildings will need to deal with significant heat stress as well as energy shock due to poor thermal performance of their apartments.

This demonstrates that buildings designed for 2050, also offer significant energy savings for space cooling in today's conditions. Similarly, the dwellings consume around a third less cooling energy in the currently experienced climate than in 2050. This demonstrates that buildings designed for the future climate, also offer significant energy saving potential for space cooling in today's conditions. Therefore, the Government should encourage homeowners, building designers and builders to consider using future climate data to future proof buildings. The Government may need to encourage homeowners/builders by providing incentives and formally recognising best practice.

NATHERS COOLING THERMOSTAT SETTINGS AND DWELLING OCCUPANCY PROFILES SHOULD BE INFORMED BY EMPIRICAL DATA

NatHERS cooling thermostat settings for each climate zone are derived using the adaptive thermal comfort model (Chen 2016). This model assumes occupants will adapt to a higher temperature in warmer climates, and therefore operate their air conditioner at a higher temperature as the local climate gets warmer. The cooling thermostat setting for NCC 2022 NatHERS climate file for Western Sydney is 25°C. This is 0.5degreeC higher than the thermostat setting used in the current NatHERS climate file. However, NatHERS Whole-of-Home (WoH) cooling thermostat setting for Western Sydney is 24°C (Commonwealth of Australia 2019). The cooling energy demand calculated by using the NatHERS WoH method will be significantly higher than it is obtained from NatHERS tool using NCC 2022 NatHERS climate file. The use of two sets of cooling thermostat settings for the same climate zone is confusing. It raises questions about the methodology of determining the cooling thermostat setting in NatHERS tools. NatHERS should investigate the validity of current thermostat settings by monitoring houses to check if the neutral temperature derived using adaptive thermal comfort method is still valid in residential settings where penetration of air-conditioners has increased significantly in recent years (Nicholls L, Strengers Y et al. 2021). It would be unusual to find a new dwelling in Western Sydney without an air-conditioner.

In addition to thermostat settings, the NatHERS occupancy profile does not mimic a real-life household setting. NatHERS space occupancy assumes that living spaces are occupied from 7am to midnight and bedrooms are occupied from 4pm to 9am. Outside the assumed occupancy period, NatHERS tool does not kick in heating/ cooling systems. Therefore, the bedroom temperature can exceed 30°C in between 9am to 4pm during heatwave. This occupancy profile is considered to be unrealistic for several reasons:

- If a whole house is not cooled from early morning on a hot day, it is almost impossible to maintain thermal comfort throughout the day due to excessive heat trapped inside the house – therefore room occupancy may not correlate with cooling use.
- Following the COVID-19 pandemic a large proportion of the Australian workforce is now working from home (Commonwealth of Australia 2022) during some part of the week. As such there is a high chance at least one family member is working from a bedroom between 9am and 4pm.
- New houses in Australia, and particularly in Western Sydney, often have ducted air conditioning systems which are often turned on to cool the whole house on a hot day rather than a single zone (i.e., living space) as assumed by the NatHERS tool. This is one of the reasons a large energy performance gap is observed in NatHERS rated houses in Greater Sydney (Ding, Upadhyay et al. 2019).

NatHERS should further investigate the assumed occupancy profile and user behaviour associated with operation of air conditioners. This should be informed by monitored empirical data.

GLOSSARY

BASIX	The Building Sustainability Index (BASIX) is an online tool used to regulate thermal comfort, greenhouse gas emissions and water usage of new residential dwellings at design stage in New South Wales. BASIX also applies to all home alterations and additions in NSW that are valued at $50K and over. BASIX is legislated via the BASIX SEPP (State Environmental Planning Policy) and enabled under the EP&A Regulation 2000. From October 2023, BASIX will be part of the new State Environmental Planning Policy (Sustainable Buildings) 2022. BASIX offers multiple options for demonstrating thermal comfort compliance: a Do-It-Yourself (DIY) method, complying with NatHERS pathways (most commonly used), or *Passive House* standards. The NatHERS pathway for thermal comfort compliance requires buildings to meet BASIX heating and cooling caps (including total caps from October 2023). The BASIX tool also assesses water and energy efficiency measures and requires a minimum demand reduction compared to benchmark residential consumption rates.
DCP	Development Control Plan. A council-level document that provides detailed planning and design guidelines to help council staff, developers and community members meet requirements set out in a Local Environment Plan when undertaking new development.
FR5	Common abbreviation for the NatHERS-approved FirstRate5 modelling software.
LEP	Local Environmental Plan. A legal document that guides land use and development within a particular local government area. LEPs are developed by local planning authorities (often councils) and approved by the NSW Government. The law outlining the process for making a LEP is the Environmental Planning and Assessment Act 1979 (the EP&A Act).
NatHERS	Nationwide House Energy Rating Scheme (NatHERS) is a federal scheme that provides energy ratings for new residential dwellings to satisfy National Construction Code (NCC) energy efficiency requirements. The NatHERS scheme regulates climate files, modelling software, and establishes modelling rules to determine heating and cooling loads for a given location, associated with maintaining acceptable indoor thermal comfort. The NatHERS pathway is the most common method for demonstrating the thermal comfort requirements of new dwellings in Australia, including NSW.
NCC	National Construction Code is a performance-based code that sets the minimum requirements for new buildings in relation structure, fire safety, access and egress, accessibility, health and amenity, and sustainability.
SEPP	State Environmental Planning Policy. These legislated policies are environmental planning instruments that deal with matters of state or regional environmental planning significance. SEPPs are developed and enacted by the NSW Government, and supersede council planning policies such as LEPs and DCPs.

Thermal Comfort	A measure of the internal thermal conditions of a building that does not impose thermal stress on most occupants. Thermal comfort takes into consideration air temperature, radiant temperature from surrounding surfaces, humidity and air speed. NatHERS thermal comfort assessment determines the heating and cooling loads of a dwelling and compares to benchmark thresholds for each NatHERS climate zone considered to result in acceptable energy demands to meet thermal comfort. Buildings with effective passive design features will require less energy for heating/cooling to achieve thermal comfort than buildings that do not consider passive design elements.
Thermal Performance	An indicator of the thermal efficiency of a building envelope. A poor thermally performing house means the house gets hot and cold too easily in summer and winter respectively.
Current NatHERS climate *(currently being used, until October 2023)*	In the context of this report, current NatHERS climate references climate files used in NatHERS software tools as approved for regulatory use in 2022. The current NatHERS climate file for a specific NatHERS climate zone is developed by using weather data from the period 1967 to 2004.
NCC 2022 climate *(will become mandatory from October 2023)*	In the context of this report, NCC 2020 NatHERS climate references climate files used in NatHERS software tools as approved for regulatory use from October 2023 to demonstrate building energy efficiency as per the NCC (including BASIX). The NCC 2020 NatHERS climate file for a specific NatHERS climate zone is developed by using weather data from 1990 to 2015.
Current experienced climate	A climate file developed to represent the climate scenario of 2020. The currently experienced climate file used in this report is derived by using measured temperature data from 1970 to 2021. The mean maximum and minimum temperatures for 2020 (representing 2010- 2029 period) are estimated by using fitting trend lines for each month. The climate file representing 2020 was compiled by selecting relevant monthly weather data from the weather data bank as informed by the projected mean maximum and minimum temperatures. This climate file for NatHERS climate zone 28 is prepared by Dr. Anir Upadhyay, UNSW.
Future climate of 2030	This climate file is prepared by the CSIRO. This study uses RCP8.5 (high emissions) scenario.
Future climate of 2050	This climate file is prepared by the CSIRO. This study uses RCP8.5 (high emissions) scenario.
Heatwave scenario	In the context of this report, a heatwave experienced in Richmond from 7 to 12 January 2017 was considered. The weather file for 2017 was prepared by Exemplary Energy.
NatHERS Whole of Home	Through NCC 2022 (effective from October 2023), NatHERS tools will rate energy performance for the whole home including the major appliances, solar panels and batteries, in addition to the star rating for the building shell.
RCP	Representative Concentration Pathway. A greenhouse gas concentration trajectory adopted by the Intergovernmental Panel on Climate Change. The pathways describe different possible climate futures depending on the volume of greenhouse gases predicted. RCP8.5 is considered the worst case scenario, but is the pathway greenhouse gas concentrations are currently tracking along.
Set point temperature	The temperature at which NatHERS modelling software assumes a building occupant would turn on their heating or cooling systems.
Adaptive thermal comfort method	The Adaptive Thermal Comfort is a metric that relates indoor design temperatures to outdoor temperatures. It is based on the understanding that occupants can adapt to, or even prefer a wider range of conditions.

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APPENDIX

NatHERS SIMULATION RESULTS

The following tables present the individual dwelling results for heating and cooling loads in each sample building modelled.

Green values represent loads within the relevant BASIX caps.
Red values are for loads that exceed the BASIX caps and would presently be deemed non-compliant for BASIX.

House (single-storey)

CLIMATE SCENARIOS															
CURRENT NatHERS CLIMATE FILE				NCC 2022 NatHERS CLIMATE FILE						FUTURE (2030) CLIMATE FILE			FUTURE (2050) CLIMATE FILE		
BASIX targets		Results		BASIX targets			Results			Results			Results		
Heating (MJ/m^2)	Cooling (MJ/m^2)	Heating (MJ/m^2)	Cooling (MJ/m^2)	Heating (MJ/m^2)	Cooling (MJ/m^2)	Total Max (MJ/m^2)	Heating (MJ/m^2)	Cooling (MJ/m^2)	Total (MJ/m^2)	Heating (MJ/m^2)	Cooling (MJ/m^2)	Total (MJ/m^2)	Heating (MJ/m^2)	Cooling (MJ/m^2)	Total (MJ/m^2)
55.7	56.2	52.3	30.6	56	37.5	60	53.4	22.2	75.6	30.4	38.3	68.7	23.1	51.9	75

House (double-storey)

CLIMATE SCENARIOS															
CURRENT NatHERS CLIMATE FILE				NCC 2022 NatHERS CLIMATE FILE						FUTURE (2030) CLIMATE FILE			FUTURE (2050) CLIMATE FILE		
BASIX targets		Results		BASIX targets			Results			Results			Results		
Heating (MJ/m^2)	Cooling (MJ/m^2)	Heating (MJ/m^2)	Cooling (MJ/m^2)	Heating (MJ/m^2)	Cooling (MJ/m^2)	Total Max (MJ/m^2)	Heating (MJ/m^2)	Cooling (MJ/m^2)	Total (MJ/m^2)	Heating (MJ/m^2)	Cooling (MJ/m^2)	Total (MJ/m^2)	Heating (MJ/m^2)	Cooling (MJ/m^2)	Total (MJ/m^2)
55.7	56.2	43.9	52.2	56	37.5	60	49.6	31.1	80.7	30.6	47.9	78.5	24.2	60.1	84.3

Low-rise Multi-unit Building (9 apartments)

UNIT	CLIMATE SCENARIOS											
	CURRENT NatHERS CLIMATE FILE				NCC 2022 NatHERS CLIMATE FILE				FUTURE (2030) CLIMATE FILE		FUTURE (2050) CLIMATE FILE	
	BASIX caps		Results		BASIX caps		Results		Results		Results	
	Heating (MJ/m^2)	Cooling (MJ/m^2)	Heating (MJ/m^2)	Cooling (MJ/m^2)	Heating (MJ/m^2)	Cooling (MJ/m^2)	Heating (MJ/m^2)	Cooling (MJ/m^2)	Heating (MJ/m^2)	Cooling (MJ/m^2)	Heating (MJ/m^2)	Cooling (MJ/m^2)
1	63.2	63.7	61.7	40.8	69.7	54.2	58.9	24.9	34.7	42.9	26.5	56.3
2			59.8	35.8			59.9	23.9	34.2	45.3	25.8	63.2
3			25.8	51.4			30.2	35.3	13.9	57.9	9.6	77.2
4			42.4	33.0			46.6	22	27.2	36.8	20.6	51.1
5			42.5	36.5			48.7	23.9	27.4	43.2	20.4	60.4
6			18.4	45.4			22.2	33.3	9.9	55.4	7.1	73.6
7			52.6	47.1			57.4	37.3	35	56.8	27.8	71.7
8			58.3	51.4			61.5	40.6	36.2	62.3	27.8	80
9			31.1	58.4			35.6	44.4	19.9	70.4	15.3	88.5

High-rise Multi-unit Building (117 apartments)

UNIT	CLIMATE SCENARIOS														
	CURRENT NatHERS CLIMATE FILE				NCC 2022 NatHERS CLIMATE FILE						FUTURE (2030) CLIMATE FILE			FUTURE (2050) CLIMATE FILE		
	BASIX caps		Results		BASIX caps			Results			Results			Results		
	Heating (MJ/m^2)	Cooling (MJ/m^2)	Heating (MJ/m^2)	Cooling (MJ/m^2)	Heating (MJ/m^2)	Cooling (MJ/m^2)	Total (MJ/m^2)	Heating (MJ/m^2)	Cooling (MJ/m^2)	Total (MJ/m^2)	Heating (MJ/m^2)	Cooling (MJ/m^2)	Total (MJ/m^2)	Heating (MJ/m^2)	Cooling (MJ/m^2)	Total (MJ/m^2)
1.01			7.9	37.3				9.1	25.0	34.1	27.6	16.9	44.5	27.6	16.9	44.5
1.02			11.7	26.2				14.1	15.9	30.0	10.5	35.8	46.3	6.8	49.2	56.0
1.03			10.7	24.4				13.1	14.7	27.8	16.4	28.0	44.4	11.8	39.5	51.3
1.04			53.3	47.3				57.6	37.1	94.7	35.4	47.5	82.9	27.9	61.0	88.9
1.05			32.8	37.7				35.0	31.2	66.2	32.6	45.0	77.6	25.9	59.3	85.2
1.06			33.0	25.6				34.9	18.2	53.1	25.1	32.4	57.5	19.3	44.2	63.5
1.07	63.2	63.7	19.4	28.9	65.1	50.6	79.0	20.4	22.3	42.7	15.7	44.3	60.0	11.4	59.6	71.0
1.08			13.7	41.2				32.3	8.5	40.8	30.2	28.2	58.4	23.7	41.5	65.2
1.09			32.0	40.8				33.9	32.5	66.4	21.3	51.8	73.1	16.1	64.5	80.6
1.1			26.6	60.7				30.3	49.9	80.2	13.5	69.9	83.4	9.5	87.4	96.9
1.11			8.6	28.3				9.7	16.5	26.2	4.5	28.1	32.6	2.9	40	42.9
1.12			8.2	29.0				10.5	18.5	26.2	3.3	37.0	40.3	1.9	51.9	53.8
1.13			14.9	25.9				18.0	15.9	33.9	10.6	32.8	43.4	7.0	47.9	54.9

UNIT	CLIMATE SCENARIOS														
	CURRENT NatHERS CLIMATE FILE				NCC 2022 NatHERS CLIMATE FILE						FUTURE (2030) CLIMATE FILE			FUTURE (2050) CLIMATE FILE		
	BASIX caps		Results		BASIX caps			Results			Results			Results		
	Heating (MJ/m²)	Cooling (MJ/m²)	Heating (MJ/m²)	Cooling (MJ/m²)	Heating (MJ/m²)	Cooling (MJ/m²)	Total (MJ/m²)	Heating (MJ/m²)	Cooling (MJ/m²)	Total (MJ/m²)	Heating (MJ/m²)	Cooling (MJ/m²)	Total (MJ/m²)	Heating (MJ/m²)	Cooling (MJ/m²)	Total (MJ/m²)
3.01			8.9	36.1				10.8	23.4	34.2	3.8	39.4	43.2	2.5	54.9	57.4
3.02			12.8	25.4				16.0	14.9	30.9	5.8	28.9	34.7	3.3	42.8	46.1
3.03			11.8	23.8				14.8	14.5	29.3	5.1	27.8	32.9	2.8	41.5	44.3
3.04			38.2	59.3				44.8	45.5	90.3	24.8	69.5	94.3	18.2	85.5	103.7
3.05			34.5	36.9				37.5	29.9	67.4	21.8	49.6	71.4	16.6	64.3	80.9
3.06			34.8	24.7				37.6	16.0	53.6	20.9	28.9	49.8	15.6	39.9	55.5
3.07	63.2	63.7	21.1	27.7	65.1	50.6	79.0	22.8	21.4	44.2	10.4	38.4	48.8	7.1	50.5	57.6
3.08			32.9	16.0				34.3	8.0	42.3	19.5	18.1	37.6	14.7	29.0	43.7
3.09			34.3	38.4				37.3	29.5	66.8	20.3	50.4	70.7	15.1	64.7	79.8
3.1			23.2	23.9				33.5	46.7	80.2	17.3	69.1	86.4	12.4	87.2	99.6
3.11			9.5	27.2				11.6	16.0	27.6	4.1	30.8	34.9	2.6	42.5	45.1
3.12			9.5	27.9				12.7	17.0	29.7	3.3	32.0	35.3	1.6	45.6	47.2
3.13			16.4	25.0				20.4	15.2	35.6	7.9	29.3	37.2	4.7	43.0	47.7

UNIT	CLIMATE SCENARIOS															
	CURRENT NatHERS CLIMATE FILE				NCC 2022 NatHERS CLIMATE FILE						FUTURE (2030) CLIMATE FILE			FUTURE (2050) CLIMATE FILE		
	BASIX caps		Results		BASIX caps			Results			Results			Results		
	Heating (MJ/m²)	Cooling (MJ/m²)	Heating (MJ/m²)	Cooling (MJ/m²)	Heating (MJ/m²)	Cooling (MJ/m²)	Total (MJ/m²)	Heating (MJ/m²)	Cooling (MJ/m²)	Total (MJ/m²)	Heating (MJ/m²)	Cooling (MJ/m²)	Total (MJ/m²)	Heating (MJ/m²)	Cooling (MJ/m²)	Total (MJ/m²)
4.01			8.9	36.1				13.7	20.1	33.8	4.4	33.6	38.0	2.8	46.6	49.4
4.02			12.8	25.4				19.1	13.0	32.1	7.5	26.4	33.9	4.6	38.5	43.1
4.03			11.8	23.8				17.7	12.7	30.4	6.7	25.6	32.3	4.0	37.5	41.5
4.04			38.9	21.5				50.1	38.6	88.7	28.4	59.3	87.7	21.2	73.6	94.8
4.05			34.5	36.9				41.1	25.0	66.1	24.3	43.2	67.5	18.6	56.7	75.3
4.06			34.8	24.7				41.8	13.5	55.3	24.1	24.3	48.4	18.2	31.9	50.1
4.07	63.2	63.7	21.1	27.7	65.1	50.6	79.0	26.8	18.6	45.4	12.9	32.6	45.5	9.0	45.5	54.5
4.08			32.9	16.0				37.8	5.8	43.6	22.1	16.3	38.4	16.8	24.2	41.0
4.09			34.3	38.4				42.0	23.8	65.8	23.7	39.5	63.2	17.8	52.3	70.1
4.1			28.5	19.2				39.2	42.9	82.1	21.5	61.8	83.3	15.8	77.9	93.7
4.11			9.5	27.2				14.9	14.7	29.6	5.6	27.5	33.1	3.4	38.9	42.3
4.12			9.5	27.9				16.2	14.3	30.5	5.1	28	33.1	2.7	39.2	41.9
4.13			16.4	25.0				24.0	14.3	38.3	10.2	27.8	38.0	6.5	39.5	46.0

UNIT	CLIMATE SCENARIOS															
	CURRENT NatHERS CLIMATE FILE				NCC 2022 NatHERS CLIMATE FILE						FUTURE (2030) CLIMATE FILE			FUTURE (2050) CLIMATE FILE		
	BASIX caps		Results		BASIX caps			Results			Results			Results		
	Heating (MJ/m^2)	Cooling (MJ/m^2)	Heating (MJ/m^2)	Cooling (MJ/m^2)	Heating (MJ/m^2)	Cooling (MJ/m^2)	Total (MJ/m^2)	Heating (MJ/m^2)	Cooling (MJ/m^2)	Total (MJ/m^2)	Heating (MJ/m^2)	Cooling (MJ/m^2)	Total (MJ/m^2)	Heating (MJ/m^2)	Cooling (MJ/m^2)	Total (MJ/m^2)
5.01			**8.9**	**36.1**				**14.3**	**20.0**	**34.3**	**3.8**	**38.9**	**42.7**	**2.6**	**54.3**	**56.9**
5.02			**12.8**	**25.4**				**19.6**	**13.1**	**32.7**	**7.8**	**25.8**	**33.6**	**4.8**	**38.3**	**43.1**
5.03			**11.8**	**23.8**				**18.2**	**12.5**	**30.7**	**6.7**	**25.6**	**32.3**	**4.0**	**37.5**	**41.5**
5.04			**39.7**	**21.4**				**50.9**	**38.2**	**89.1**	**29**	**58.8**	**87.8**	**21.7**	**72.1**	**93.8**
5.05			**34.5**	**36.9**				**41.8**	**24.9**	**66.7**	**24.9**	**42.2**	**67.1**	**19.1**	**55.9**	**75.0**
5.06			**34.8**	**24.7**				**42.5**	**13.7**	**56.2**	**24.6**	**24.6**	**49.2**	**18.6**	**31.9**	**50.5**
5.07	**63.2**	**63.7**	**21.1**	**27.7**	**65.1**	**50.6**	**79.0**	**27.4**	**18.6**	**46.0**	**13.3**	**31.9**	**45.2**	**9.3**	**44.7**	**54.0**
5.08			**32.9**	**16.0**				**38.4**	**5.6**	**44.0**	**22.5**	**15.9**	**38.4**	**17.2**	**24.2**	**41.4**
5.09			**34.3**	**38.4**				**42.8**	**21.9**	**64.7**	**25.1**	**37.5**	**62.6**	**19.0**	**48.9**	**67.9**
5.1			**29.5**	**19.1**				**40.1**	**42.2**	**82.3**	**22.2**	**61.4**	**83.6**	**16.3**	**76.5**	**92.8**
5.11			**9.5**	**27.2**				**15.5**	**14.6**	**30.1**	**6.0**	**27.1**	**33.1**	**3.6**	**38.6**	**42.2**
5.12			**9.5**	**27.9**				**16.9**	**14.3**	**31.2**	**5.4**	**27.9**	**33.3**	**2.9**	**38.7**	**41.6**
5.13			**16.4**	**25.0**				**24.6**	**14.3**	**38.9**	**10.6**	**27.6**	**38.2**	**6.8**	**39.2**	**46.0**

UNIT	CLIMATE SCENARIOS															
	CURRENT NatHERS CLIMATE FILE				NCC 2022 NatHERS CLIMATE FILE						FUTURE (2030) CLIMATE FILE			FUTURE (2050) CLIMATE FILE		
	BASIX caps		Results		BASIX caps			Results			Results			Results		
	Heating (MJ/m²)	Cooling (MJ/m²)	Heating (MJ/m²)	Cooling (MJ/m²)	Heating (MJ/m²)	Cooling (MJ/m²)	Total (MJ/m²)	Heating (MJ/m²)	Cooling (MJ/m²)	Total (MJ/m²)	Heating (MJ/m²)	Cooling (MJ/m²)	Total (MJ/m²)	Heating (MJ/m²)	Cooling (MJ/m²)	Total (MJ/m²)
6.01			8.9	36.1				14.7	19.9	34.6	4.7	34.1	38.8	3.1	47.0	50.1
6.02			12.8	25.4				20.0	13.0	33.0	8.0	25.7	33.7	4.9	38.3	43.2
6.03			11.8	23.8				18.5	12.4	30.9	7.2	24.8	32	4.3	37.3	41.6
6.04			40.3	21.1				51.6	38.0	89.6	29.4	58.4	87.8	22.1	71.4	93.5
6.05			34.5	36.9				42.1	25.1	67.2	25.1	41.8	66.9	19.2	55.6	74.8
6.06			34.8	24.7				43.1	13.6	56.7	25.1	41.8	66.9	18.9	31.5	50.4
6.07	63.2	63.7	21.1	27.7	65.1	50.6	79.0	27.9	18.7	46.6	13.6	32.0	45.6	9.6	44.8	54.4
6.08			32.9	16.0				38.9	5.3	44.2	22.9	16.0	38.9	17.4	24.2	41.6
6.09			34.3	38.4				43.3	22.2	65.5	24.6	38.4	63.0	18.6	50.6	69.2
6.1			30.0	19.1				40.7	42.3	83.0	22.7	61.2	83.9	16.7	76.4	93.1
6.11			9.5	27.2				15.9	14.6	30.5	6.0	27.1	33.1	3.6	38.6	42.2
6.12			9.5	27.9				17.4	14.3	31.7	5.7	25.9	31.6	3.1	38.7	41.8
6.13			16.4	25.0				25.1	14.4	39.5	10.9	27.1	38.0	7.0	39.2	46.2

UNIT	CLIMATE SCENARIOS														
	CURRENT NatHERS CLIMATE FILE				NCC 2022 NatHERS CLIMATE FILE						FUTURE (2030) CLIMATE FILE			FUTURE (2050) CLIMATE FILE		
	BASIX caps		Results		BASIX caps			Results			Results			Results		
	Heating (MJ/m^2)	Cooling (MJ/m^2)	Heating (MJ/m^2)	Cooling (MJ/m^2)	Heating (MJ/m^2)	Cooling (MJ/m^2)	Total (MJ/m^2)	Heating (MJ/m^2)	Cooling (MJ/m^2)	Total (MJ/m^2)	Heating (MJ/m^2)	Cooling (MJ/m^2)	Total (MJ/m^2)	Heating (MJ/m^2)	Cooling (MJ/m^2)	Total (MJ/m^2)
7.01			8.9	36.1				14.9	19.8	34.7	4.8	34.4	39.2	3.3	46.4	49.7
7.02			12.8	25.4				20.4	12.8	33.2	8.2	25.2	33.4	5.1	38.0	43.1
7.03			11.8	23.8				18.9	12.2	31.1	7.5	24.9	32.4	4.5	37.1	41.6
7.04			40.9	20.8				52.2	37.8	90.0	29.8	57.7	87.5	22.4	70.6	93.0
7.05			34.5	36.9				42.8	24.7	67.5	25.5	41.1	66.6	19.6	55.0	74.6
7.06			34.8	24.7				43.6	13.5	57.1	25.4	24.2	49.6	19.2	31.6	50.8
7.07	63.2	63.7	21.1	27.7	65.1	50.6	79.0	28.4	18.5	46.9	13.8	32.0	45.8	9.8	44.2	54.0
7.08			32.9	16.0				39.3	5.2	44.5	23.2	15.8	39.0	17.7	23.3	41.0
7.09			34.3	38.4				43.9	21.3	65.2	25.1	37.5	62.6	19	48.9	67.9
7.1			30.7	18.4				41.3	41.6	82.9	23.2	60.9	84.1	17.2	75.2	92.4
7.11			9.5	27.2				16.4	14.6	31.0	6.5	27.2	33.7	3.8	38.3	42.1
7.12			9.5	27.9				17.9	14.2	32.1	6.0	27.3	33.3	3.2	38.4	41.6
7.13			16.4	25.0				25.5	14.1	39.6	11.2	27.3	38.5	7.2	39.3	46.5

UNIT	CLIMATE SCENARIOS															
	CURRENT NatHERS CLIMATE FILE				NCC 2022 NatHERS CLIMATE FILE						FUTURE (2030) CLIMATE FILE			FUTURE (2050) CLIMATE FILE		
	BASIX caps		Results		BASIX caps			Results			Results			Results		
	Heating (MJ/m²)	Cooling (MJ/m²)	Heating (MJ/m²)	Cooling (MJ/m²)	Heating (MJ/m²)	Cooling (MJ/m²)	Total (MJ/m²)	Heating (MJ/m²)	Cooling (MJ/m²)	Total (MJ/m²)	Heating (MJ/m²)	Cooling (MJ/m²)	Total (MJ/m²)	Heating (MJ/m²)	Cooling (MJ/m²)	Total (MJ/m²)
10.01			11.6	31.4				15.9	20.0	35.9	5.4	33.6	39.0	3.5	46.9	50.4
10.02			15.9	22.5				21.2	12.4	33.6	8.8	24.8	33.6	5.5	36.7	42.2
10.03			15.6	19.6				19.8	12.0	31.8	7.9	24.7	32.6	4.8	36.9	41.7
10.04			46.4	47.4				53.7	36.1	89.8	30.8	56.8	87.6	23.3	69.4	92.7
10.05			40.6	29.1				43.6	23.7	67.3	26.1	39.7	65.8	20.1	54.2	74.3
10.06			40.0	21.3				44.8	13.1	57.9	26.3	24.6	50.9	20.0	31.7	51.7
10.07	63.2	63.7	25.2	25.9	65.1	50.6	79.0	29.5	17.4	46.9	14.6	31.4	46.0	10.4	43.8	54.2
10.08			37.4	14.4				40.3	5.9	46.2	24.0	16.4	40.4	18.4	24.2	42.6
10.09			38.9	31.2				44.2	21.5	65.7	25.4	36.7	62.1	19.2	48.0	67.2
10.1			35.3	48.7				43.0	40.8	83.8	24.5	60.9	85.4	18.2	73.7	91.9
10.11			12.3	24.5				17.0	14.3	31.3	6.4	26.6	33.0	4.0	37.9	41.9
10.12			13.2	24.9				19.1	14.1	33.2	6.5	26.0	32.5	3.8	36.1	39.9
10.13			20.6	22.9				26.6	13.8	40.4	12.0	27.2	39.2	7.8	39.1	46.9

UNIT	CLIMATE SCENARIOS															
	CURRENT NatHERS CLIMATE FILE				NCC 2022 NatHERS CLIMATE FILE						FUTURE (2030) CLIMATE FILE			FUTURE (2050) CLIMATE FILE		
	BASIX caps		Results		BASIX caps			Results			Results			Results		
	Heating (MJ/m²)	Cooling (MJ/m²)	Heating (MJ/m²)	Cooling (MJ/m²)	Heating (MJ/m²)	Cooling (MJ/m²)	Total (MJ/m²)	Heating (MJ/m²)	Cooling (MJ/m²)	Total (MJ/m²)	Heating (MJ/m²)	Cooling (MJ/m²)	Total (MJ/m²)	Heating (MJ/m²)	Cooling (MJ/m²)	Total (MJ/m²)
11.01			11.6	31.4				17.6	19.7	37.3	6.4	34.1	40.5	3.7	45.2	48.9
11.02			15.9	22.5				22.9	11.8	34.7	10.0	23.4	33.4	6.3	35.9	42.2
11.03			15.6	19.6				21.4	10.8	32.2	8.9	23.9	32.8	5.6	35.0	40.6
11.04			46.4	47.4				61.5	32.8	94.3	36.9	49.7	86.6	28.4	63	91.4
11.05			40.6	29.1				45.9	21.1	67.0	27.7	36.6	64.3	21.4	50.4	71.8
11.06			40.0	21.3				47.2	13.0	60.2	28	23.1	51.1	21.9	51.5	73.4
11.07	63.2	63.7	25.2	25.9	65.1	50.6	79.0	31.7	15.8	47.5	16.2	30.6	46.8	11.5	42.3	53.8
11.08			37.4	14.4				42.3	5.3	47.6	25.4	14.9	40.3	19.6	22.4	42.0
11.09			38.9	31.2				46.8	19.2	66.0	27.2	34.3	61.5	20.8	45.2	66.0
11.1			35.3	48.7				46.0	38.6	84.6	26.7	58.6	85.3	20.3	44.2	64.5
11.11			12.3	24.5				19.1	14.1	33.2	7.6	26.6	34.2	4.7	36.0	40.7
11.12			13.2	24.9				21.0	12.7	33.7	7.8	24.9	32.7	4.5	34.9	39.4
11.13			20.6	22.9				28.7	13.7	42.4	13.4	26.6	40.0	8.8	37.4	46.2

UNIT	CLIMATE SCENARIOS															
	CURRENT NatHERS CLIMATE FILE				NCC 2022 NatHERS CLIMATE FILE						FUTURE (2030) CLIMATE FILE			FUTURE (2050) CLIMATE FILE		
	BASIX caps		Results		BASIX caps			Results			Results			Results		
	Heating (MJ/m²)	Cooling (MJ/m²)	Heating (MJ/m²)	Cooling (MJ/m²)	Heating (MJ/m²)	Cooling (MJ/m²)	Total (MJ/m²)	Heating (MJ/m²)	Cooling (MJ/m²)	Total (MJ/m²)	Heating (MJ/m²)	Cooling (MJ/m²)	Total (MJ/m²)	Heating (MJ/m²)	Cooling (MJ/m²)	Total (MJ/m²)
12.01			12.7	30.3				27.2	28.1	55.3	14.1	43.6	57.7	10.1	55.0	65.1
12.02			17.1	21.3				32.4	20.7	53.1	17.5	34.9	52.4	12.7	46.3	59.0
12.03			15.8	19.4				30.7	20.9	51.6	16.1	36.0	52.1	11.5	46.4	57.9
12.04			46.4	47.4				64.9	40.4	105.3	40.3	57.8	98.1	31.9	69.6	101.5
12.05			40.6	29.1				54.7	31.9	86.6	34.9	48.9	83.8	27.9	61.4	89.3
12.06			41.8	20.7				56.9	18.7	75.6	35.7	31.6	67.3	28.4	41.3	69.7
12.07	**63.2**	**63.7**	26.8	24.2	**65.1**	**50.6**	**79.0**	42.0	26.9	68.9	24.5	43.1	67.6	18.9	55.1	74.0
12.08			39.0	12.9				51.3	9.6	60.9	32.4	19.1	51.5	26.0	29.1	55.1
12.09			40.9	29.1				57.2	29.8	87.0	36.0	45.7	81.7	28.6	56.9	85.5
12.1			37.7	45.2				58.9	46.2	105.1	37.3	67.2	104.5	29.7	82	111.7
12.11			13.9	23.6				31.3	21.1	52.4	17.3	35.1	52.4	12.7	45.7	58.4
12.12			14.6	22.8				29.4	21.7	51.1	14.4	34.6	49.0	10.0	44.6	54.6
12.13			22.0	21.8				37.8	21.0	58.8	20.7	35.2	55.9	15.1	48.2	63.3

The Western Sydney Regional Organisation of Councils' (WSROC) mission is to build collaboration between local governments across Greater Western Sydney, promoting Western Sydney, its people and places, through advocacy, business improvement, strategic leadership, research and partnerships. WSROC has facilitated the development of this strategy.

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