



Australian Government
Bureau of Meteorology



**Climate
Systems**

National Environmental Science Program

Developing a methodology for generating future weather files for building energy simulations

David Hoffmann, Surendra Rauniyar, Ramona Dalla Pozza, Dörte Jakob





Developing a methodology for generating future weather files for building energy performance assessment

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Bureau Research Report No. 131

October 2026

This research was conducted as part of the National Environmental Science Program (NESP) Climate Systems Hub project [Building for the Future Project](#)

National Library of Australia Cataloguing-in-Publication entry

Authors: David Hoffmann, Surendra Rauniyar, Ramona Dalla Pozza, Dörte Jakob

Title: Developing a methodology for generating future weather files for building energy performance assessment

ISBN: 978-1-923469-29-7

ISSN: 2206-3366

Series: Bureau Research Report – BRR131



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Executive Summary

Building energy simulation uses specialised hourly meteorological datasets, commonly referred to in the building-energy sector as ‘*weather files*’, to provide the atmospheric conditions required by building simulation software. Within the Australia’s National Housing Energy Rating Scheme (NatHERS), these NatHERS weather files provide variables such as air temperature, atmospheric moisture and pressure, wind and solar radiation to assess the thermal and energy performance of residential buildings. Current NatHERS weather files used for compliance assessment are based on historical meteorological observations and do not account for future climate change or extremes heat events, limiting their effectiveness for resilience planning and climate-adapted design. To address this gap, under the NESP Climate Systems Hub [Building for the future](#) project to support the Department of Climate Change, Energy, the Environment and Water (DCCEEW), we developed an innovative method that integrates regional climate projections from downscaled Coupled Model Intercomparison Project, Phase 6 (CMIP6) climate models with historical observations to construct fit-for-purpose Typical Meteorological Year (TMY) and eXtreme Meteorological Year (XMY) files for 11 representative locations across a range of Australian climate zones, two emissions scenarios (low: SSP1-2.6 and high: SSP3-7.0), and three future periods of 2030s, 2050s and 2070s. Testing confirmed that the generated files are compatible with NatHERS-accredited building simulation software. Within the limitations of the methodology and uncertainties in the underlying climate projections, the files provide a range of representative average and extreme heat conditions for assessing building performance under current and projected future climates, including heatwave conditions.

This report details this methodology, which includes the selection of representative climate model grid cells, derivation of NatHERS-compatible meteorological variables, quality-control procedures, and generation of weather files in the required NatHERS format. Future weather files were produced by bias-adjusting hourly projections from the Bureau of Meteorology’s BARPA-R regional climate model against the existing NatHERS historical weather dataset. The methodology preserves the statistical characteristics of the observed NatHERS climate while incorporating projected changes from climate models using Quantile Delta Change (QDC) bias adjustment. Future TMY weather files were developed to represent typical future climatic conditions, while three complementary XMY weather files were generated to characterise future heatwave events with the greatest intensity, duration and overall severity.

In addition to the weather files, a suite of summary products was developed to support interpretation of the climate projections, including comparative statistics across climate models and metrics describing changes in heating and cooling demand and future heatwave characteristics. The resulting dataset provides a scientifically robust and internally consistent basis for evaluating the resilience of Australian housing under future climates and establishes a transparent, reproducible framework that could be applied to more locations and allow for future updates as new climate projections become available.



1. Introduction

This report documents the methodology developed under the National Environmental Science Program (NESP) Climate Systems Hub *Building for the Future* project to produce weather files representing future climate conditions for the Nationwide House Energy Rating Scheme (NatHERS). The project was undertaken in collaboration with the Department of Climate Change, Energy, the Environment and Water (DCCEEW) to support the development of application-ready weather files for residential building energy assessment. By applying climate change signals from regional climate projections to historical observations, the methodology provides a consistent framework for assessing the energy performance and heat resilience of Australian housing under future climate conditions.

In building energy simulation, the term *weather file* refers to a structural time series of meteorological variables used as external boundary conditions by building thermal performance simulation software. In this research report, the term *NatHERS weather file* is used specifically for datasets formatted for use within the Nationwide House Energy Rating Scheme (NatHERS). The files contain hourly temperature, atmospheric moisture and pressure, wind and solar radiation. NatHERS-accredited software uses these data to simulate building thermal performance, including heating and cooling energy demand, thermal comfort, and overheating risk to ensure compliance of new residential buildings with NatHERS requirements. As Australia's climate continues to warm (Cowan et al. 2014, Trancoso et al. 2020), it is becoming increasingly important that weather files used for building performance assessment adequately represent future climate conditions. Rising average temperatures and more frequent and intense heatwaves are expected to increase cooling demand, reduce occupant thermal comfort, and place greater stress on electricity networks (CSIRO and BoM, 2024; Gergis et al., 2020). Recognising these challenges, several international jurisdictions have begun incorporating future climate considerations into building design and regulatory frameworks (Gaur and Lacasse, 2002; Hinge et al., 2023).

In Australia, compliance assessments for residential buildings under NatHERS currently rely on weather files derived from historical observations for the 1991–2015 period (NIWA, 2017; Ren et al., 2020). These Typical Meteorological Year (TMY) files are constructed by statistically comparing individual months with the long-term distribution of key meteorological variables and selecting the months that are most representative of the historical climate. The selected months are then combined to form a synthetic year, thereby preserving realistic hourly weather sequences and seasonal variability (Marion and Urban, 1995; Wilcox and Marion, 2008). Although well suited for standardised energy performance assessments, TMY files are not intended to represent future climates or the increasing frequency and severity of extreme heat events (Upadhyay et al., 2022; Machard et al., 2024).

Previous Australian studies have developed future weather files using climate change "morphing" techniques, whereby projected monthly mean climate changes are applied to historical weather observations (Lee, 2018; Ren et al., 2021, 2022). While these



approaches capture long-term changes in average climate, they do not fully represent projected changes in day-to-day weather variability or future heatwave characteristics, limiting their suitability for assessing overheating risk and peak cooling demand (Molina et al., 2025).

These limitations have been addressed by developing a new methodology for generating future NatHERS weather files by applying climate change signals derived from high-resolution regional climate model projections to historical NatHERS observations. The methodology produces two complementary types of future weather files. For each future 20-year period, projected climate change signals are first applied to the historical NatHERS observations. Typical Meteorological Year (TMY) files characterise typical climatic conditions using statistically representative months selected from these future-adjusted series. Extreme Meteorological Year (XMY) files are constructed by selecting years containing heatwaves with high intensity, long duration and high severity to support building stress testing. Future climate change signals are derived from the Bureau of Meteorology's BARPA-R regional climate model projections (Su et al., 2022a) and applied to the historical NatHERS weather data using the Quantile Delta Change approach described in Section 4.

This new methodology preserves the projected changes in both average climate and weather variability contained within the regional climate model simulations. Separate XMY weather files are generated to represent different characteristics of future heatwaves, recognising that heatwave intensity, duration and cumulative severity each influence building thermal performance in different ways (Machard et al., 2020; Machard et al., 2024).

This report documents the methodology developed to produce future NatHERS weather files, including the selection of climate projections, bias-adjustment procedures, construction of future TMY and XMY weather files, and the resulting dataset delivered. Stakeholder co-design of the methods and testing of the outputs are described in Dalla Pozza et al. (2026), and Ren et al. (2026).

2. Methodology framework

A four-stage methodology was developed to generate future weather files compatible with the Nationwide House Energy Rating Scheme (NatHERS). The framework applies climate change signals derived from hourly regional climate model projections to the existing NatHERS observational weather data. This produces future-adjusted weather sequences that:

- remain consistent with the structure and variable requirements of the current NatHERS weather files;
- retain the observed hourly, daily and seasonal sequencing of weather conditions;
- incorporate projected changes in average climate and the distribution of weather conditions; and

- provide complementary representations of statistically typical future conditions and selected heatwave conditions for building performance and stress testing.

The methodology framework is shown in Figure 1. The four main stages are:

1. selection and preparation of the historical and future climate datasets, including matching each NatHERS location to a representative regional climate model grid cell;
2. application of Quantile Delta Change method to transfer projected climate changes from BARPA-R onto the historical NatHERS weather sequence;
3. derivation, conversion and formatting of the meteorological variables required by NatHERS; and
4. generation of future Typical Meteorological Year and Extreme Meteorological Year weather files.

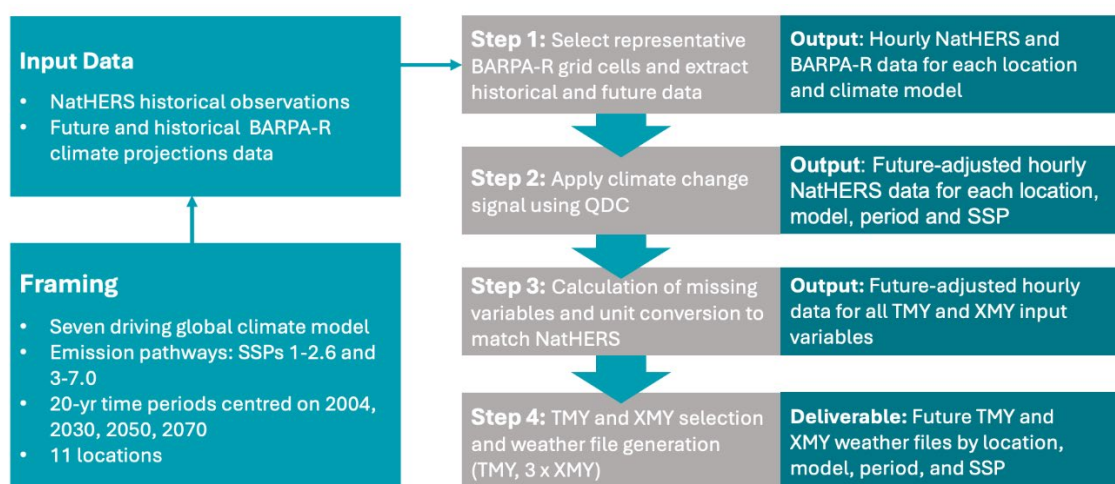


Figure 1: Methodology framework

The methodology was implemented for 11 NatHERS locations requested by the Australian Building Codes Board (ABCB): Darwin, Cairns, Brisbane, Longreach, Mildura, Adelaide, Perth, Sydney, Melbourne, Canberra and Hobart (Table 1). These locations represent a broad range of Australian climatic conditions and associated building energy requirements, including predominantly cooling-dominated, heating-dominated and mixed heating-and-cooling climates.

Table 1: Subset of locations for proposed methodology. These cover a range of NatHERS climate zones and seven of the eight ABCB climate zones for the National Construction Code (NCC).

Location	Latitude	Longitude	Altitude	Climate zone	
	Degrees (°)	Degrees (°)	Metres (m)	NCC	NatHERS
Darwin (CBD), NT	-12.46	130.84	28	1	1
Cairns (CBD), QLD	-16.93	145.75	8	1	32
Brisbane (CBD), QLD	-27.48	153.04	8	2	10
Longreach (CBD), QLD	-23.44	144.25	192	3	3
Mildura (CBD), VIC	-34.21	142.14	53	4	27
Adelaide (CBD), SA	-34.92	138.60	50	5	16
Perth (CBD), WA	-31.95	115.86	20	5	13
Sydney (Mascot), NSW	-33.95	151.17	39	5	56
Melbourne (Tullamarine), VIC	-37.67	144.83	31	6	60
Canberra (CBD), ACT	-35.28	149.13	580	7	24
Hobart (CBD), TAS	-42.88	147.32	54	7	26

Although the current implementation uses NatHERS observations and BARPA-R regional climate projections, the broader framework is designed to be transferable. It could be applied to other observational reference datasets, regional climate model ensembles, geographical locations or building simulation formats, provided that sufficiently complete hourly meteorological data are available. Application to another dataset would require careful assessment of variable definitions, units, calendars, time zones, data quality and the availability of physically comparable variables in the historical and future datasets.



3. Data sources and extraction

3.1. Historical Data

The existing NatHERS historical dataset was adopted as the observational basis for this study because it was developed specifically for use by NatHERS and provides the reference meteorological data used in Australian residential building performance assessments. Using the same historical basis ensures consistency with existing NatHERS applications and means that differences between the historical and future files primarily reflect the imposed climate change signals rather than a change in the underlying observational dataset or its processing.

NatHERS defines 69 climate zones representing the range of climatic conditions experienced across Australia. In the 2016 dataset, these zones were represented by a larger set of designated reference locations, reflecting that some zones have more than one reference location and that a reference location does not necessarily lie within the boundary of the zone it represents (Liley, 2017). Each climate zone is associated with one or more designated reference locations. The files contain the meteorological variables required for building energy simulation (Delsante, 2005), including:

- dry-bulb air temperature ($^{\circ}\text{C}$);
- moisture content (kg/kg);
- atmospheric pressure (hPa);
- wind speed (m/s);
- wind direction (0-16, 0=calm, 1=NNE, 16=N)
- cloud cover (oktas);
- global horizontal solar irradiance (W/m^2);
- diffuse horizontal solar irradiance (W/m^2); and
- direct normal solar irradiance (W/m^2).

The NatHERS historical climate data were developed primarily from the Bureau of Meteorology station observations at designated reference locations for each climate zone. Temperature, moisture, pressure and wind components were mainly obtained from Automatic Weather Stations, with synoptic or nearby station data and temporal or spatial interpolation used where required to complete the hourly records. Cloud cover was derived from human observations, ceilometers or satellite-based estimates, depending on availability. Solar radiation was obtained from ground-based measurements at a limited number of sites and predominantly from the Bureau satellite-derived irradiance estimates on a 5 km grid. Detailed station sources, substitutions, interpolation and quality-control procedures are documented in Liley (2017, 2020).



The original NatHERS weather files are supplied in local standard time. Before further processing, the files were converted to Coordinated Universal Time and reformatted as NetCDF files. This provided a consistent data structure and time basis for comparison with the BARPA-R simulations and allowed the same hourly bias-adjustment workflow to be used at all locations.

The complete NatHERS observational record covers 1990–2015. However, the Quantile Delta Change calculations used the period 1995–2014 as the historical reference period. This 20-year period corresponds to the common temporal overlap between the NatHERS observations and the available historical BARPA-R simulations. It also provides a consistent baseline duration for comparison with the three 20-year future periods used here.

An alternative approach considered was to use the Bureau of Meteorology Atmospheric high-resolution Regional Reanalysis for Australia, BARRA-R2 (Su et al., 2022a), as the historical reference dataset. Reanalysis products provide spatially complete and physically coherent meteorological fields and offer advantages for generating weather files at arbitrary locations. However, evaluation against the existing NatHERS observational weather files identified systematic differences in several variables such as temperature and wind speed which are relevant to building energy simulation. Using BARRA-R2 as the reference would therefore have introduced an additional source of difference between the current NatHERS files and the future files developed here.

Because a primary objective of this method was to maintain direct comparability with the current NatHERS weather files, the existing NatHERS observational dataset was retained as the historical reference.

The use of reanalysis remains a promising direction for future development. A gridded historical reference dataset could improve spatial consistency, reduce reliance on individual station records that often have incomplete records and support weather-file generation beyond the existing 69 NatHERS stations. Future work should reassess the suitability of reanalysis-based reference data as products and methods improve, including the development of approaches to reconcile systematic differences between reanalysis fields and the observations used by NatHERS.

3.2. Future Climate Data

Future climate information was obtained from the Bureau of Meteorology Atmospheric Regional Projections for Australia regional climate model, BARPA-R (Su et al., 2022n). BARPA-R forms part of the [National Partnership for Climate Projections](#) (NPCP) CMIP6 regional climate modelling suite and contributes to the Coordinated Regional Climate Downscaling Experiment for CMIP6 (Gutowski et al., 2016).

BARPA-R dynamically downscales selected CMIP6 global climate model simulations to an approximately 17 km grid across Australia. The global climate models and model runs used here are listed in Table 1.



Future conditions were represented under two Shared Socioeconomic Pathway emissions scenarios:

- SSP1-2.6, representing a low-emissions future; and
- SSP3-7.0, representing a plausible high-emissions future.

These scenarios were selected to span a plausible lower and upper range of future climate outcomes relevant to adaptation and building performance assessment and are consistent with current Australian climate projection guidance (IPCC, 2021; DCCEEW, 2026, <https://nesp2climate.com.au/resource/understanding-ssps/>). SSP3-7.0 was adopted as the upper scenario rather than SSP5-8.5, which is no longer generally regarded as representative of emissions under current policies (Van Vuuren et al. 2026). Nevertheless, the range of warming projected under SSP3-7.0 includes high-end outcomes relevant to risk and resilience assessment (DCCEEW, 2026).

Weather files were produced from BARPA-R for the following 20-year periods:

- historical reference centred on 2004: 1995–2014;
- 2030 future period: 2021–2040;
- 2050 future period: 2041–2060; and
- 2070 future period: 2061–2080.

The future periods were selected following consultation and user feedback from the wider project group. Twenty-year periods provide sufficient data to characterise climate distributions and sample internal climate variability while remaining relevant to building design, asset planning and adaptation decisions.

Figure 2 places these periods in the broader context of projected atmospheric carbon dioxide concentrations and Australian mean temperature change under SSP1-2.6 and SSP3-7.0. Temperature changes in Figure 2 are calculated relative to 1960–2014 using anomalies derived separately within each climate model, thereby removing differences in model mean-state climate.

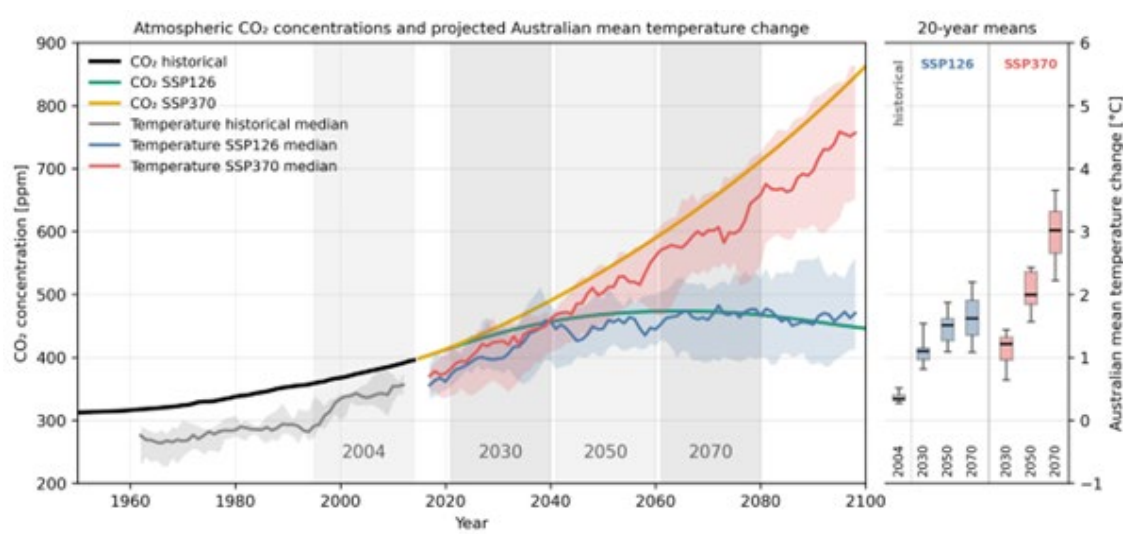


Figure 2: Left: Time series of atmospheric CO₂ concentration in parts per million (ppm) for the Southern Hemisphere for historical (solid black line), SSP1-2.6 (green) and SSP3-7.0 (red) emission pathways (Meinshausen et al. 2020), and BARPA-R mean annual temperature changes over Australia for historical (grey), SSP1-2.6 (blue) and SSP3-7.0 where the solid line shows the multi-model median and the shading around the ensemble spread. Changes are relative to the baseline from 1960-2014 and were derived model-internally to remove each model's mean-state bias. Grey vertical shading displays 20-year periods considered in this study. The box plots on the right show the respective 20-year mean for temperature anomalies, where the thick line represents the median, the upper/lower box ends the 25th/75th percentile and the upper/lower whiskers the coldest/hottest model of the ensemble.

3.2.1. Selection Criteria for Climate Projection Data

The selection of global climate projection data to drive the BARPA-R regional climate model was guided by three main criteria:

- model credibility and fitness for purpose;
- spatial coverage, temporal resolution and variable availability; and
- representation of a range of plausible future climates through a multi-model ensemble.

Model credibility was assessed by Grose et al. (2020), who evaluated the representation of Australian climate and relevant climate processes in CMIP6 models. Drawing from this evaluated suite reduces the risk of relying on models that are unsuitable for the intended application but does not eliminate uncertainty in the resulting projections. In particular, future heatwave duration remains uncertain because it depends on how well models represent the atmospheric persistence and land-surface processes that sustain consecutive hot days (Hirsch et al 2021).

The BARPA-R downscaled regional model provides complete spatial coverage of Australia and hourly climate information at approximately 17 km resolution. Regional climate model output represents coastlines, topography and regional-scale climate processes in greater spatial detail than the driving global climate models. These



characteristics are important for building energy applications, particularly at locations influenced by coastal exposure, elevation or regional circulation patterns.

The available hourly output includes the meteorological fields required to generate NatHERS-compatible weather files, including air temperature, humidity, atmospheric pressure, wind and solar radiation. Hourly data are necessary to represent the diurnal cycle, calculate derived variables and maintain the temporal detail required by NatHERS building simulation software.

The methodology was initially developed using BARPA-R, and BARPA-R was retained throughout this project to maintain a consistent processing workflow. However, the methodology is not inherently restricted to this model output and could be applied to other suitable high-resolution regional climate projections in future work.

Seven BARPA-R simulations, each driven by a different CMIP6 global climate model, were used to represent uncertainty arising from differences in model structure, climate sensitivity and regional climate response (Table 2) (Narsey et al. 2025). The simulations were processed individually rather than being averaged into a single ensemble weather sequence. Future weather files are therefore available separately for each climate model, enabling users to consider the ensemble range, individual projections and selected warmer or more central outcomes rather than relying on a single future climate realisation. This step ensures greater assurance of the files maintaining the modelled relationships between variables that may be lost by averaging across data forced by different global climate models.

Table 2: Global climate models and their runs downscaled by BARPA-R hourly at 17km spatial resolution for SSPs 1-2.6 and 3-7.0 with variables used.

GCM	Run	SSP	Resolution	Variables
ACCESS-ESM1-5	r6i1p1f1	1-2.6, 3-7.0	17km, hourly	• Near-surface Air Temperature [tas] • Near-surface Specific Humidity [huss] • Near-surface Wind Speed [sfcWind] • Eastward Near-Surface Wind [uas] • Northward Near-Surface Wind [vas] • Surface Direct and Diffuse Downwelling Shortwave Radiation [rsdsdir,rsdsdif] • Sea Level Pressure [psl] • Cloud Cover Fraction [clt]
ACCESS-CM2	r4i1p1f1			
CESM2	r11i1p1f1			
CMCC-ESM2	r1i1p1f1			
EC-Earth3	r1i1p1f1			
MPI-ESM1-2-HR	r1i1p1f1			
NorESM2-MM	r1i1p1f1			



3.2.2. Selection of representative BARPA-R grid cells

NatHERS weather files represent specific reference locations, whereas BARPA-R represents atmospheric and land-surface conditions resolved at model grid cell scale. The two are therefore not directly equivalent, and the geographically closest model grid cell does not necessarily provide the most physically representative match. This issue is particularly important near coastlines and complex topography, where local heat advection and overnight temperatures during heatwaves may not be fully resolved. Although the Quantile Delta Change adjustment reduces systematic distributional differences, it cannot correct deficiencies in the physical processes represented by the regional climate model.

An objective grid-cell selection procedure was applied for each of the 11 NatHERS locations. A BARPA-R grid cell was considered suitable when:

1. its model elevation differed from the NatHERS location elevation by no more than ± 150 m; and
2. at least 80% of the grid-cell area was classified as land.

The geographically closest grid cell satisfying both criteria was selected. Figure 3 shows the NatHERS locations, the selected BARPA-R grid cells and cells excluded by the elevation or land-fraction criteria.

The elevation criterion was particularly important for locations near steep terrain. For example, the grid cell geographically closest to the Hobart NatHERS location is strongly influenced by the elevation of kunanyi/Mount Wellington and is not representative of the lower-elevation urban environment. Applying the elevation criterion avoided transferring the climatic characteristics of this elevated grid cell to the Hobart weather file.

The selected grid-cell approach provides a transparent and reproducible method for matching station-based weather files to gridded climate projections. It does not, however, reproduce sub-grid-scale urban or site-specific effects that are not resolved by BARPA-R.

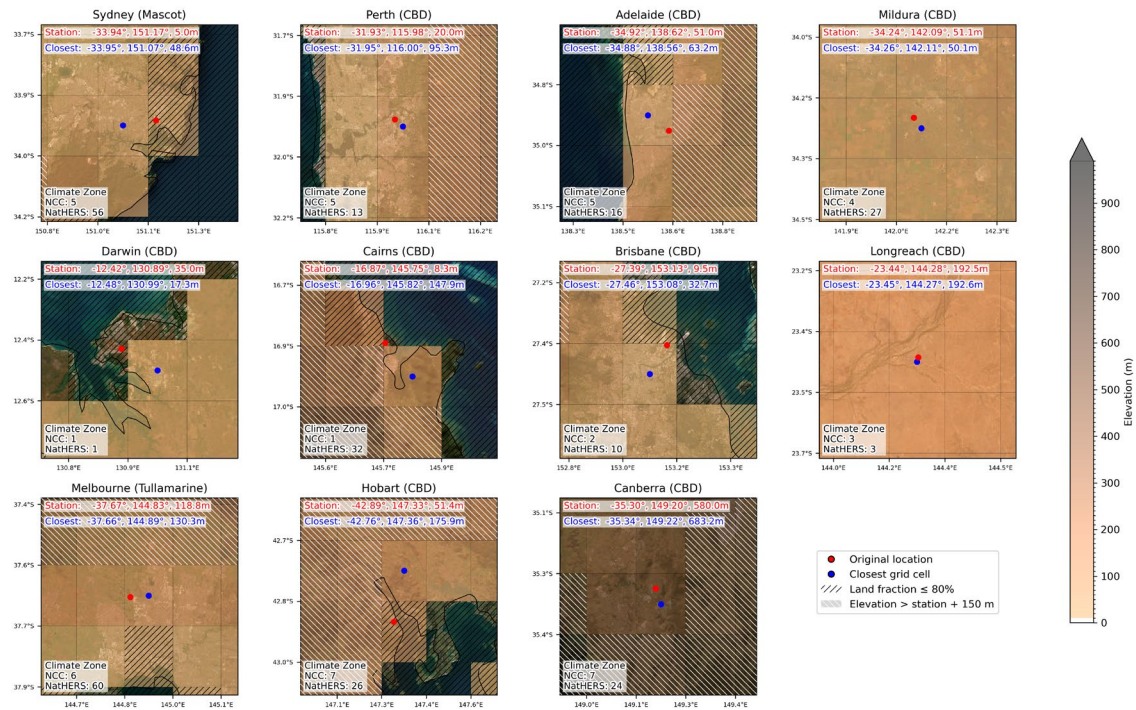


Figure 3: The 11 selected NatHERS station locations (red dot) and corresponding closest appropriate BARPA-R grid cells (cell with centred blue dot). Hatched cells are deemed unsuitable by the elevation and land fraction selection criteria.

3.3. Initial data preparation and variable alignment

Hourly BARPA-R variables were extracted for the selected grid cell at each location. The following variables were used with native model units in brackets (refer to Table 1 for model variable name):

- near-surface air temperature (K);
- near-surface specific humidity (g/kg);
- near-surface wind speed (m/s);
- eastward and northward near-surface wind components (m/s);
- direct and diffuse downwelling shortwave radiation (W/m^2);
- mean sea-level pressure (Pa); and
- total cloud fraction (%).

Applying the bias adjustment between comparable variables is important. Therefore, before bias adjustment, variables were transformed or calculated where necessary to ensure that the BARPA-R and NatHERS datasets represented physically equivalent quantities. Full details and equations are presented in Appendix A.



These included:

- converting temperature and humidity to common units (Eqs. 1+2);
- deriving station pressure from mean sea-level pressure using the elevation of the NatHERS location (Eq. 6);
- deriving wind direction from the eastward and northward wind components (Eqs. 7+8);
- converting total cloud fraction to cloud cover in oktas (Eq. 5); and
- checking the consistency of global, direct and diffuse radiation components; and
- deriving global horizontal irradiance from direct and diffuse horizontal irradiance components (Eq. 3).

3.4. Wind

Wind direction was derived from the eastward and northward BARPA-R wind components during data preparation and checking following Eq (7).

Wind direction in the output files was computed to represent 16 compass sectors (Eq. 8):

- 1 = north;
- 2 = north-northeast;
- continuing clockwise to
- 16 = north-northwest.

A value of zero represented calm conditions when near-surface wind speed was below 0.5 m s^{-1} . However, because wind direction was not bias adjusted, the historical NatHERS wind-direction sequence was retained in the prototype future files.

3.5. Cloud cover

BARPA-R total cloud fraction ranges from zero to one and can be converted to cloud cover in oktas ranging from zero to eight using Eq. 5. However, because cloud cover was not bias adjusted, the historical NatHERS cloud-cover sequence was retained in the prototype files.

Future work should investigate methods for representing changes in cloud cover and wind direction while maintaining compatibility with the discrete NatHERS representation and consistency with the associated solar radiation variables.

All variable transformations and output conventions used for deriving station level pressure, wind direction, and cloud cover calculations are provided in the Appendix in Table 2 and subsequent equations below it.



4. Quantile Delta Change scaling

4.1. Rationale

Regional climate model simulations contain systematic differences from observed climate. These arise from limitations in the driving global climate models, regional model parameterisations, differences between the model resolution and point observations and the representation of local land-surface and atmospheric processes.

Dynamic downscaling improves the representation of regional climatic processes but does not remove all model bias. Biases are particularly important for building energy simulation because heating and cooling demand, thermal comfort and overheating metrics can be sensitive to relatively small differences in temperature, humidity, wind and radiation. Threshold-based metrics may also be strongly influenced by model bias.

A Quantile Delta Change approach was therefore applied following Irving and Macadam (2024). The method estimates projected changes between the historical and future climate model distributions and applies those changes to the observational reference data.

Quantile-based adjustment has previously been applied to high-resolution weather datasets in Australia. Brown et al. (2016), for example, used conventional quantile mapping to adjust temperature, relative humidity and wind speed from a 4 km regional model simulation against station observations. Their adjustment relationships were calculated separately by month and hour of day to account for seasonal and diurnal variations in model bias. The present approach uses a similar quantile-based and temporally conditioned framework but has a different purpose. Rather than mapping historical regional model values directly onto the observed distribution, QDC calculates the change between historical and future BARPA-R quantiles and applies that change to the corresponding quantiles of the historical NatHERS data. The approach is therefore conceptually consistent with Quantile Delta Mapping, which is designed to preserve model-projected changes at individual quantiles when adjusting climate model output against an observational reference dataset (Cannon et al., 2015).

This differs from conventional weather-file morphing approaches, which commonly apply monthly mean climate changes to historical observations (Belcher et al., 2005; Chen et al., 2020). Mean-change approaches can represent shifts in average climate but tend to retain historical variability and may not capture projected changes in the upper and lower parts of a variable's distribution. QDC applies changes separately across the distribution and can therefore incorporate modelled changes in average conditions, variability and distributional tails, including the hot conditions relevant to overheating and heatwave assessment.

Because these projected changes are applied to the historical NatHERS sequence, the method retains the timing and persistence of observed weather events. The resulting future data preserve realistic hourly and day-to-day weather structure while incorporating the distributional changes projected by BARPA-R.



The mathematical formulation of the additive and multiplicative QDC methods is provided in Appendix A 10.2 Eqs. 11-15.

4.2. Historical and future periods

The 1995–2014 historical BARPA-R simulations were used to characterise the models' historical distributions. These were compared with BARPA-R data for each future period:

- 2021–2040;
- 2041–2060; and
- 2061–2080.

Quantile-specific changes between the historical and future model simulations were calculated and applied to the corresponding NatHERS observations for 1995–2014.

A separate future dataset was produced for every combination of:

- location;
- driving global climate model;
- emissions scenario; and
- future period.

4.3. Monthly and hourly implementation

The QDC relationships were calculated separately for each calendar month and hour of day at Coordinated Universal Time (UTC). This allowed projected changes in both the seasonal and diurnal cycles to be represented.

A three-hour sliding window was used when estimating the adjustment relationship for each target hour. For example, the adjustment applied at 12:00 was calculated using model values from 11:00, 12:00 and 13:00.

The ± 1 -hour window increased the number of samples available for estimating the distributions while retaining hour-specific climate change information. It also reduced the likelihood of abrupt differences in the adjustment between adjacent hours.

One hundred quantiles were used to characterise each monthly and hourly distribution.

4.4. Variables included in the bias adjustment

Near-surface air temperature was adjusted using an additive formulation, because projected changes in temperature are appropriately expressed as differences.

The following variables were adjusted multiplicatively:

- specific humidity;
- near-surface wind speed;
- station pressure; and



- global horizontal solar irradiance.

Multiplicative adjustment was used because projected changes in these quantities are more appropriately expressed as proportional changes and because their values are physically constrained, such as radiation cannot have negative values.

4.5. Variables not included in the bias adjustment

Wind direction and cloud cover were not bias adjusted. In the NatHERS file format, these variables are represented as discrete or categorical quantities rather than continuous distributions and are not directly suited to conventional quantile mapping. The historical NatHERS sequences were therefore retained for these variables.

Retaining historical wind direction and cloud cover means that the future weather files do not explicitly include projected changes in their distributions. This is a limitation of the current prototype methodology and should be reconsidered in future development.

4.6. Treatment of solar radiation

Solar radiation required additional processing because multiplicative adjustment can become unstable when historical irradiance is zero or very small. Low solar angles may also produce unrealistic adjusted values and unstable calculations of direct normal irradiance.

Global horizontal irradiance was the only radiation component adjusted directly using QDC. Values below 1 W m^{-2} , generally corresponding to night-time conditions, were left unchanged rather than being subjected to multiplicative scaling.

Adjusted radiation values were subsequently checked against solar geometry and physical limits. At solar altitude angles below 5° , adjusted global irradiance values were replaced with the corresponding historical NatHERS values. This avoided unrealistic scaling around sunrise and sunset. Adjusted values above 1300 W m^{-2} were also considered physically implausible and replaced with the corresponding historical value.

Following adjustment of global horizontal irradiance, direct and diffuse horizontal irradiance were reconstructed using the monthly and hourly direct-radiation fraction calculated from the raw future BARPA-R simulation. This retained the future model's average partitioning between direct and diffuse radiation while ensuring that the two components summed exactly to the adjusted global irradiance.

The equations used to calculate the direct-radiation fraction and reconstruct the radiation components are provided in Appendix A 10.3 Eqs. 16-18.



5. Derivation of NatHERS-compatible variables

Following bias adjustment, the hourly data were converted into the variables, units and categorical classifications required by the NatHERS weather-file format. Table 3 in the Appendix summarises the complete set of transformations.

5.1. Temperature, humidity and pressure

These variables only required unit conversion. Air temperature was converted from Kelvin to degrees Celsius (Eq.1) and specific humidity was converted between kilograms per kilogram and grams per kilogram (Eq. 2). Station pressure was converted from pascals to kilopascals.

5.2. Dew-point temperature and relative humidity

Following bias adjustment, relative humidity and dew-point temperature were derived from the bias-adjusted air temperature, specific humidity and station pressure using the `relative_humidity` and `dewpoint_temperature` functions provided by the Australian Climate Service `atmos` Python package (Warren 2025). Relative humidity was first calculated from station pressure, specific humidity and saturation vapour pressure (Eqs. 9+10), and dew-point temperature was subsequently derived from the calculated relative humidity and air temperature using the thermodynamic relationships implemented within the `atmos` package. The resulting dew-point temperature was converted from Kelvin to degrees Celsius following Eq. (1) for compatibility with the NatHERS weather-file format. Calculating these variables after bias adjustment ensured that they remained physically consistent with the adjusted temperature, humidity and pressure fields.

5.3. Solar radiation

Global horizontal and diffuse horizontal irradiance were retained in W m^{-2} .

NatHERS also requires direct normal irradiance. BARPA-R direct horizontal irradiance was converted to direct normal irradiance using the solar altitude angle. To prevent unrealistically large values when the Sun was close to the horizon, direct normal irradiance was set to zero when the solar altitude angle was below 5° .

The use of the same 5° threshold for radiation adjustment and direct normal irradiance calculation provided a consistent treatment of low-sun conditions.

5.4. Variables retained from the historical NatHERS files

Several fields required by the NatHERS weather-file structure were not modified as part of the climate change adjustment. These were transferred from the historical files, including:

- solar altitude angle;
- solar azimuth angle;



- weather-file quality-control flags;
- wind-direction classifications; and
- cloud-cover classifications.

Retaining these fields maintained compatibility with the current NatHERS file structure and downstream building simulation software.

5.5. Calendar and time handling

Processing and bias adjustment were undertaken in UTC. The completed data were subsequently returned to the time convention required by the NatHERS weather-file format.

Leap days were removed from all time series. Each completed year therefore contained 8760 hourly records, consistent with the no-leap calendar used for NatHERS weather-file generation.

6. Generation of future weather files

Two types of prototype future weather files were generated:

- Typical Meteorological Year (TMY) files, representing typical conditions within each future period; and
- Extreme Meteorological Year (XMY) files, representing complete years containing significant future heatwaves.

Files were generated separately for each location, global climate model, emissions scenario and future period.

6.1. Typical Meteorological Year files

A Typical Meteorological Year (TMY) is a synthetic year assembled from 12 representative calendar months selected from a multi-year weather record. Each selected month is taken from an actual year, but the 12 months generally originate from different years.

A TMY provides a compact representation of typical climatic conditions while retaining realistic hourly, daily and seasonal weather variability. It is intended for standardised comparison of building energy performance rather than assessment of rare extremes.

The TMY files were generated using the established methods described by Marion and Urban (1995) and Wilcox and Marion (2008), informed by subsequent Australian applications including Ren et al. (2021) and Liley (2024).

For each calendar month, all candidate months from the relevant 20-year period were compared with the climatological distribution for that calendar month across the full 20-year period. The comparison used the Finkelstein–Schäfer statistic, which measures the



average absolute difference between the cumulative distribution of a candidate month and the corresponding long-term distribution (Finkelstein and Schafer, 1971).

The statistic was calculated for 10 indices across four meteorological variables and combined using variable-specific weights (see Table 3). Candidate months with lower weighted scores more closely represented the long-term distribution.

Table 3: Variables and corresponding weights used in the FS-statistics calculation.

Variable Name	Daily statistic	Weight
Dry Bulb Temperature	Max	1
	Min	1
	Mean	2
Dew Point Temperature	Max	1
	Min	1
	Mean	2
Wind Speed	Max	1
	Mean	1
Global Radiation	Mean	5
Direct Radiation	Mean	5
Total weights		20

Candidate months were ranked using the weighted score. The final month selection also considered:

- differences between candidate-month means and long-term monthly means;
- persistence of weather conditions;
- the occurrence of unusually long weather sequences; and
- the suitability of transitions between adjacent selected months.

Two TMY selection approaches were applied independently: the Sandia method (Wilcox and Marion 2008) and the Machard method (Machard et al. 2024). Under the Sandia method, candidate months were further evaluated based on persistence criteria, with preference given to months that avoided unusually long, frequent, or absent warm, cool, and low-radiation periods. Under the Machard method, candidate months were assessed based on wind-speed representativeness, with preference given to the month exhibiting the lowest deviation from the long-term wind-speed statistics.

For each approach, the final month selection also considered agreement between candidate-month means and long-term monthly means, the occurrence of anomalous



weather sequences, and the suitability of transitions between adjacent selected months. The 12 selected months were concatenated to create one synthetic year and discontinuities at the month interfaces were smoothed for 6 hours each side using linear interpolation, representative of the relevant 20-year climate period. As a result, two distinct TMY datasets were generated for each location and climate period: one based on the Sandia method and one based on the Machard method, enabling comparison of the influence of alternative month-selection criteria on the resulting typical year. Historical and future TMYs use the same internally consistent selection procedure, but each TMY represents the typical conditions of its own period. Future candidate months are therefore selected from the future dataset itself, and the contributing years may consequently differ among climate models, scenarios and future periods. Because TMY selection favours representative months, it does not intentionally retain the most extreme heatwaves in the source period. Separate XMY files were therefore produced for stress-testing buildings under future extreme heat.

6.2. Extreme Meteorological Year files

6.2.1. Purpose of the XMY files

Heatwaves can be defined in several ways, depending on their intended application. The Bureau of Meteorology's Excess Heat Factor, for example, uses the three-day mean temperatures and accounts for both exceedance of a location-specific climatological threshold and acclimatisation relative to conditions during the preceding 30 days (Nairn and Fawcett, 2014). Daily mean temperature incorporates both daytime and overnight temperatures and therefore reflects to some extent the limited overnight relief that is particularly important for occupant heat exposure and the capacity of buildings to release accumulated heat. Other definitions apply percentile thresholds to daily minimum, maximum or mean temperature (Perkins and Alexander, 2012).

For building performance assessment, a single heatwave measure may not adequately describe all relevant thermal stresses. Among events satisfying the minimum duration criterion, a heatwave with high peak temperature may produce a high instantaneous cooling load, whereas a long event may prevent a building from cooling overnight and lead to progressive indoor heat accumulation. An event combining persistent and substantially elevated temperatures may place sustained stress on occupants, building systems and electricity supply.

The XMY methodology therefore characterises heatwaves according to three complementary dimensions: intensity, duration and cumulative severity. These metrics distinguish between the maximum temperature reached, the persistence of the event and the accumulated thermal exceedance over its duration.

6.2.2. Heatwave detection

Heatwaves were detected using daily mean temperature calculated from the hourly future-adjusted weather data. Daily mean temperature incorporates both daytime and overnight conditions and was selected because persistent high overnight temperatures



can limit heat release from buildings and contribute to the accumulation of indoor heat over successive days.

The heatwave definition was adapted from the percentile-based framework of Ouzeau et al. (2016). This framework was selected because it identifies discrete events using fixed, location-specific thresholds and characterises them according to peak intensity, duration and cumulative severity. These characteristics are directly relevant to building performance and allow the weather files to be selected for different types of thermal stress testing. This approach was also applied in building resilience studies by Machard et al. (2020, 2024) and recommended for future weather file development by Ren (2025).

The Bureau of Meteorology's Excess Heat Factor was not used here because it was developed primarily for heat-health applications and includes short-term acclimatisation based on the preceding 30 days (Nairn and Fawcett, 2014). For XMY selection, fixed location-specific percentile thresholds were preferred as they allow heatwave intensity, duration and cumulative thermal loading to be compared consistently across climate models, future periods and emissions scenarios. The two approaches are therefore complementary and serve different purposes.

The heatwave thresholds were calculated separately for each NatHERS location from the 1995–2014 historical distribution of daily mean temperature. Three thresholds were used to identify and delimit heatwave events:

- The 99.5th percentile defined the peak threshold that a qualifying event was required to exceed;
- The 97.5th percentile defined the principal event continuation threshold; and
- The 95th percentile defined the interruption threshold used to determine whether a temporary reduction in temperature ended the event.

A potential heatwave was identified when daily mean temperature exceeded the location-specific 99.5th-percentile peak threshold (Spic in Figure 4). The event was delimited using the 97.5th-percentile start and end threshold (Sdeb in Figure 4) and the 95th-percentile interruption threshold (Sint in Figure 4). Following Ouzeau et al. (2016), an event ended when daily mean temperature remained below the 97.5th-percentile threshold for three consecutive days or fell below the 95th-percentile threshold for a single day. This rule allows one or two days between the 95th- and 97.5th-percentile thresholds to occur without dividing a persistent heatwave into separate events.

A minimum duration of three days was applied to all locations to exclude isolated hot days and brief hot spells. To qualify for a heatwave, an event was required to last for at least three consecutive days and contain at least one day above the location-specific 99.5th-percentile threshold.

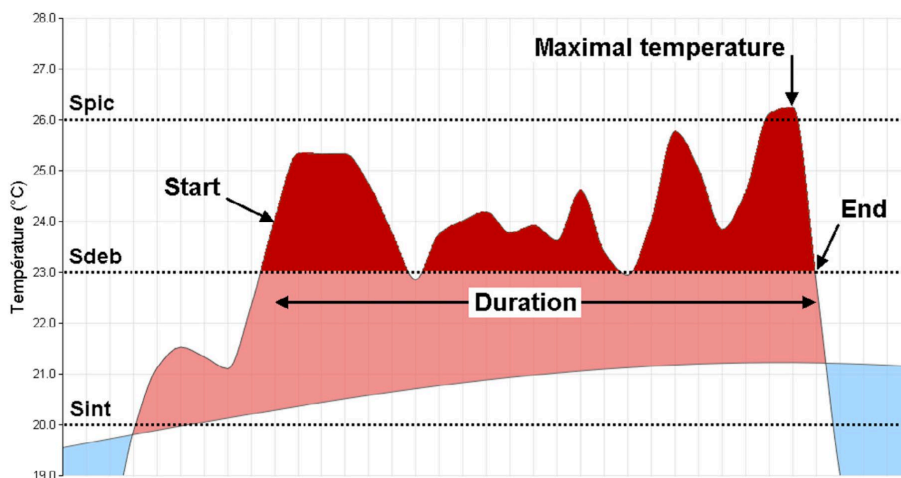


Figure 4: Characterization of a heat wave from a daily mean temperature indicator over France (example of a time series from June 30 to August 5, 1983): Duration (start and end) marked by the 97.5th percentile start and end threshold (Sdeb), maximal temperature that needs to be above the 99.5th percentile (Spic) and global intensity (red area of the plot). Sint denotes the 95th percentile interruption threshold that causes a heatwave to end. Temperatures above (below) climatological line (1981–2010 reference period) are represented by pink (blue) area. From Ouzeau et al. 2016.

6.2.3. XMY selection categories

Three XMY categories were generated for each model, scenario, period and location. Each category selects a weather year containing the event that ranks highest according to one of the three heatwave characteristics described below.

6.2.3.1. Most Intense XMY

The Most Intense XMY was selected from the 12-month period containing the qualifying heatwave with the highest single-day mean temperature. It represents the event with the greatest peak thermal intensity. By definition, each qualifying event must contain at least one day above the location-specific 99.5th percentile of the historical daily mean temperature distribution.

6.2.3.2. Most Severe XMY

The Most Severe XMY was selected from the 12-month period containing the heatwave with the greatest cumulative normalised heat stress.

Severity accounts for both the magnitude and persistence of elevated temperatures. For each event, it was calculated by summing daily mean temperature exceedances above the location-specific 97.5th-percentile threshold and normalising them by the temperature difference between the 99.5th- and 97.5th-percentile temperatures.

6.2.3.3. Longest Duration XMY

The Longest Duration XMY was selected from the 12-month period containing the qualifying heatwave with the greatest duration. Duration was calculated from the number of consecutive days above the 97.5th-percentile threshold, provided that the event



includes at least one day over the 99.5th percentile threshold and satisfied the specified minimum duration requirement of at least three days. A temporary interruption below the 97.5th percentile does not end the event unless daily mean temperature also falls below the 95th-percentile interruption threshold.

6.2.4. Interpretation of the XMY files

Each XMY is a continuous 12-month period selected from the relevant 20-year future period. Unlike a TMY, it is not a synthetic year assembled from months selected from separate years. The 12-month period does not necessarily run from January to December. Where a heatwave crosses the calendar-year boundary, the event is retained as a continuous sequence and the 12-month extraction period spans both years.

This approach retains the natural meteorological sequence before, during and after the selected heatwave, including:

- overnight temperature behaviour;
- humidity, wind and radiation during the event;
- the weather conditions preceding the event; and
- the transition back to less extreme conditions.

Winter months are retained as part of the 12-month sequence but do not influence the selection of the heatwave. The XMY files should therefore be interpreted as a complete weather sequence containing a selected extreme heatwave rather than as years that are consistently hot or representative of cold extremes.

The same heatwave may simultaneously be the most intense, most severe and longest event within a 20-year period. Consequently, two or three XMY categories may occasionally identify the same underlying event and 12-month period. Separate files are nevertheless supplied for each category to provide a consistent set of outputs and a straightforward application workflow for building assessors.

The selected events represent plausible heatwave conditions under the adopted climate-projection and QDC framework, rather than predictions of specific future heatwaves. Confidence is higher in the broad warming signal than in the timing, duration and meteorological evolution of individual events. In particular, QDC retains the historical weather sequence and does not independently represent projected changes in the atmospheric persistence of heatwaves. At the same time, warming can push previously non-heatwave periods above the historical thresholds, creating additional events and different XMY selections.

A minimum duration of three days was used for all locations to target prolonged events for assessing cumulative impacts on building thermal performance and indoor overheating when there are limited opportunities for buildings to cool between successive hot days (Machard et al., 2020, 2024). Consequently, the XMY files are stress-test datasets focused on prolonged heat and do not represent every potentially consequential future heat events.



7. Quality-control and validation checks

Quality control was undertaken throughout the workflow to identify errors introduced by source-data inconsistencies, variable transformations, bias adjustment and weather-file construction.

The checks were organised into four groups: source-data checks, checks following bias adjustment, weather-file integrity checks and checks of the selected TMY and XMY files.

7.1. Source-data and preprocessing checks

Before bias adjustment, the NatHERS and BARPA-R datasets were checked for:

- expected variable names and dimensions;
- complete hourly time series;
- duplicated or missing timestamps;
- consistency of calendar and time-zone conventions;
- correct ordering and interpretation of time coordinates;
- expected source units;
- missing or non-finite values;
- physically plausible variable ranges; and
- consistency between the global, direct and diffuse radiation components.

Grid-cell selections were checked against location coordinates, elevation and land fraction. The selected cells were also inspected spatially, as shown in Figure 3, to identify matches that were technically valid but physically unrepresentative.

7.2. Checks following bias adjustment

Bias-adjusted time series were checked to confirm that:

- temperature changes followed the expected additive behaviour;
- multiplicatively adjusted variables remained non-negative where physically required;
- no invalid values were generated through division by very small historical quantiles;
- the historical hourly sequence and number of records were retained;
- adjusted distributions reflected the projected BARPA-R changes;
- diurnal and seasonal cycles remained physically plausible;
- radiation values remained within the defined physical limits; and
- direct and diffuse horizontal irradiance summed to global horizontal irradiance.



7.3. NatHERS weather-file integrity checks

Before weather files were written, each output was checked for:

- exactly 8760 hourly records;
- absence of 29 February;
- correct chronological ordering;
- correct local-time conversion;
- required NatHERS variables and column order;
- correct units and data types;
- non-negative solar radiation;
- zero or appropriately constrained direct normal irradiance at low solar angles;
- physically plausible temperature, humidity and pressure values; and
- completeness of file-name and metadata fields.

The completed files were run by building simulation practitioners from the NESP Building for the Future project group using NatHERS accredited residential building simulation software (<https://www.nathers.gov.au/accredited-software>) including HERO, FirstRate5, and Accurate in the same way they would typically assess a building design for NatHERS compliance e.g. energy efficiency. Results on future building energy performance from the tests can be found in Dalla Pozza et al. (2026).

7.4. TMY and XMY selection checks

The TMY files were checked to confirm:

- that exactly one month was selected for each calendar month;
- that selected months originated from the correct model, scenario and future period;
- that the Finkelstein–Schäfer rankings were applied correctly;
- that transitions between selected months did not introduce missing or duplicated hours;
- that each completed TMY contained 8760 records; and
- that the resulting annual and monthly statistics were representative of the corresponding 20-year period.

The XMY files were checked to confirm:

- that all identified events met the applicable minimum-duration threshold;
- that intensity, severity and duration metrics were calculated consistently;
- that the selected event was the highest-ranked event for the relevant category;



- that the complete calendar year containing the selected event was extracted;
- that duplicate underlying events across XMY categories were identified; and
- that the selected event dates and metrics were recorded in supporting metadata (see next section).

7.5. Output files, directory structure and supporting metadata

The completed Typical Meteorological Year and Extreme Meteorological Year data were written as NatHERS-compatible text weather files. The future dataset is currently hosted at the National Computational Infrastructure (NCI) and is available and can be used **only for research purposes**.

The files are organised using a consistent directory hierarchy ():

```
{location}/{scenario}/{time_period}/{model}/{weather_file_type}/
```

For example:

```
Adelaide/ssp370/2050/ACCESS-ESM1-5/TMY/
```

The hierarchy separates the files by:

- NatHERS location;
- emissions scenario;
- historical or future period;
- driving global climate model; and
- weather-file type.

The weather-file type directory identifies whether the file is a Typical Meteorological Year or one of the Extreme Meteorological Year categories. This structure allows users to locate all files associated with a particular location and progressively narrow the selection by scenario, future period, model and application.

Historical files do not require an emissions scenario or driving climate model. They are stored within the corresponding historical directory structure using the historical reference period centred on 2004.

File names provide additional information about the location, NatHERS climate zone, source dataset or climate model, scenario, period and weather-file type. Example file names include:

- Adelaide_CZ0514_AD_NatHERS_historical_2004_TMY-machard.txt
- Adelaide_CZ0514_AD_NatHERS_historical_2004_XMY-HWintense.txt
- Adelaide_CZ0514_AD_ACCESS-ESM1-5_ssp370_2050_TMY-machard.txt



Future XMY file names use the relevant XMY category identifier to distinguish files selected for heatwave intensity, severity and duration. The naming convention makes it possible to identify the source and purpose of a file without opening it and provides traceability to the climate model, scenario and processing period from which it was generated.

For each of the 11 locations, seven climate models, two emissions scenarios and three future periods produce 42 future model–scenario–period combinations. For each combination, the delivered dataset contains:

- one future TMY file for each approach (Sandia and Machard);
- one XMY containing the most intense heatwave;
- one XMY containing the most severe heatwave; and
- one XMY containing the longest heatwave.

Historical NatHERS-based TMY and XMY files are also provided as reference files. These allow future files to be compared with weather files derived from the historical climate period using the same selection methodology.

7.5.1. Supporting TMY summary files

A supporting comma-separated value (CSV) file¹ is provided to assist users in comparing future TMY results and selecting an appropriate climate model for a particular assessment. The summaries are derived from the 20-year bias-adjusted climate datasets produced in Methodology Step 3, prior to the generation of the TMY weather files. For each location, scenario, future period and climate model, the files report the annual mean temperature together with the corresponding historical reference value and the projected change relative to the historical climate.

The models are ranked according to their projected annual mean temperature, allowing users to identify:

- a relatively cooler model;
- a model close to the ensemble median; and
- a relatively warmer model.

This ranking provides a practical model-selection framework for building simulations. Rather than requiring users to run all seven future weather files, it allows assessments to be undertaken using a smaller set of models representing a central projection together with the cooler and warmer parts of the ensemble. Because the ranking is based on the full 20-year climate simulations rather than the selected TMY weather files, it provides a more robust representation of each model's projected future climate and is not influenced

¹ The provided file is called: `model_temperature_summary_step3output.csv`.

by the characteristics of a single representative year. The full model-level results remain available where a more comprehensive assessment of projection uncertainty is required.

The summary CSV files also include the values used to derive the rankings, ensuring the selection process is transparent and allowing users to adopt alternative selection criteria if required for specific building applications. The historical reference climate is included to provide the baseline against which future changes are quantified.

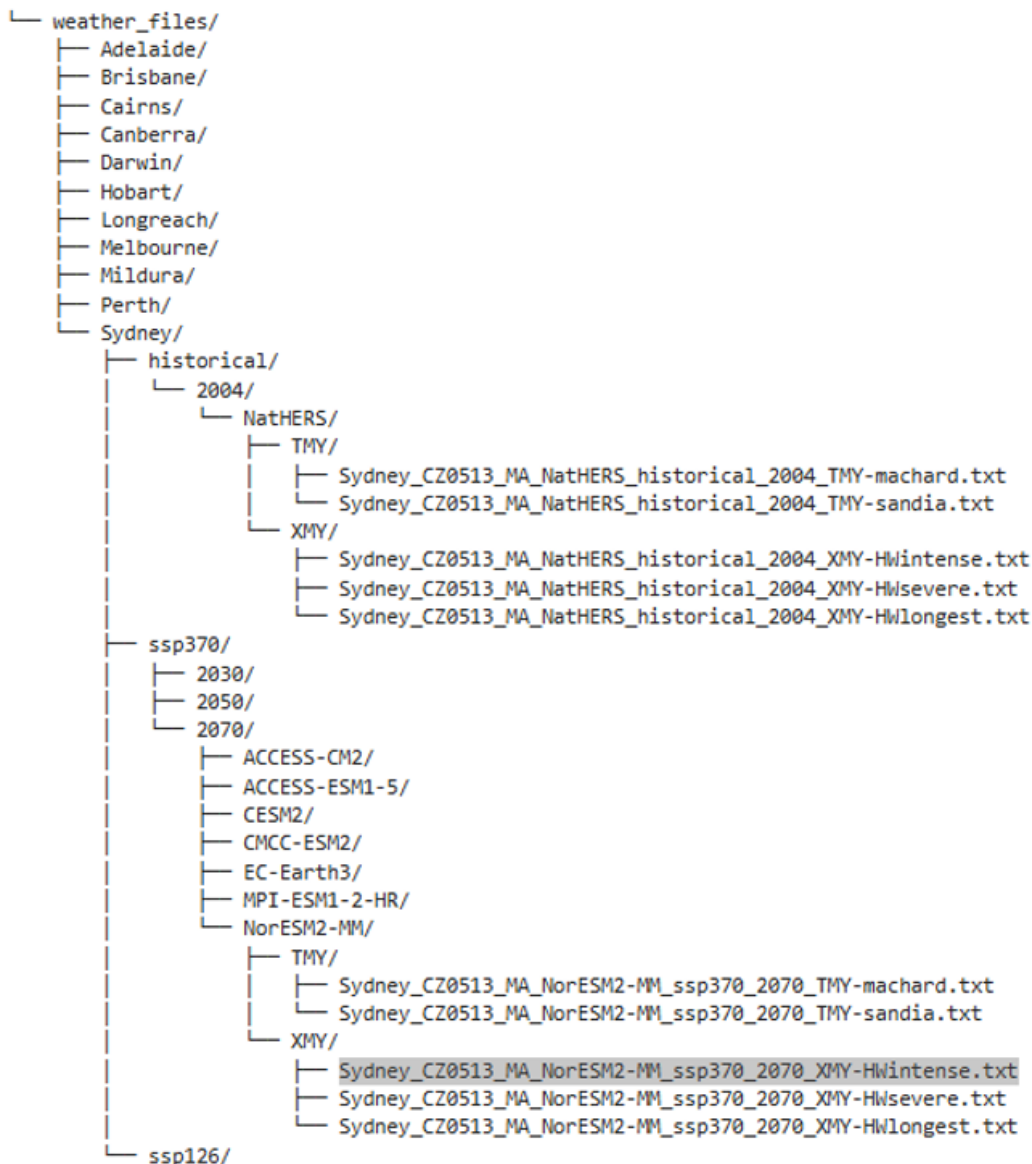


Figure 5: Directory tree structure of weather files on NCI.

7.5.2. Supporting XMY summary files

Separate summary CSV files are provided to support interpretation of the XMY dataset. Six heatwave statistics files are supplied, one for each combination of emissions scenario (SSP1-2.6 and SSP3-7.0) and future time period (2030, 2050 and 2070), e.g.



heatwave_stats_ssp370_2050_all_stations.csv. These files contain all heatwave events identified within the 20-year climate simulations for each location and climate model, including the event start and end dates, duration, maximum temperature, date of peak temperature, cumulative heatwave severity, the calendar year from which the event was selected, and associated metadata describing the location, scenario, time period and source climate model. These summaries were used to derive the heatwave frequency, duration, intensity and severity statistics presented in this report and enable users to undertake additional analyses without processing the hourly weather files.

A second summary file², documents the heatwave event selected for each XMY weather file. In addition to the heatwave characteristics described above, this file identifies the XMY category (most_intense, most_severe and longest) together with the corresponding location, emissions scenario, future time period and source climate model. The summary provides a direct link between each generated XMY weather file and the heatwave event that resulted in its selection, and identifies cases where the same heatwave event is selected for multiple XMY categories.

7.5.3. Traceability and use of the dataset

Together, the directory structure, file-naming convention and supporting CSV files identify the:

- NatHERS location and climate zone;
- historical reference dataset or driving global climate model;
- BARPA-R regional climate projection;
- emissions scenario;
- historical or future period;
- TMY or XMY weather-file type;
- XMY selection category, where applicable; and
- model ranking or heatwave metric used to support file selection.

This information enables each weather file to be traced to its source climate projection and processing pathway and supports comparison among locations, models, scenarios and future periods.

7.5.4. Guidance note

Important: These files are prototype datasets generated for research, testing and feedback purposes only. They should not be used to inform building design, regulatory compliance, policy, NatHERS assessments or operational energy efficiency assessments or to assess current regulations.

² The second summary file is called:

selected_XMY_file_details_for_all_stations_scenarios_time-periods.csv.



The future weather files were produced as part of the Building for the Future research project under the National Environmental Science Program Climate Systems Hub.

The objective of the prototype dataset is to explore the use of regional climate model projections to generate future climate weather files compatible with the NatHERS simulation framework.

The prototype files support testing of workflows for generating NatHERS-compatible weather files from climate model simulations, bias-correction approaches suitable for building simulation variables, and potential future climate datasets for building performance modelling.

These files are not approved NatHERS weather files and are not suitable for operational or regulatory use. A more comprehensive process would be required before they could be considered for inclusion in any Australian Government policy or regulatory application.

The prototype files will be accessible for research purposes on the National Computational Infrastructure Data Catalogue until March 2031.

Access is open and free. There are no restrictions or controls on who can download the files.

Without future funding, there will be no resources from the NESP Climate Systems Hub project team, including Bureau of Meteorology staff, to support use of the files or further develop them.

In using the files, researchers acknowledge that projected building performance can vary significantly depending on the climate model and emissions pathway selected. The choice matters.

More testing and ongoing collaboration are needed to develop guidance on how this additional climate information should be used in practice and which aspects are most useful for informing design responses.

The code for producing the data is currently here: https://github.com/dahoal2/nesp_bff.



8. Characteristics of the generated weather files

This section summarises the climate characteristics of the generated Typical Meteorological Year (TMY) and eXtreme Meteorological Year (XMY) weather files. The figures provide an overview of how the future weather files differ from the historical NatHERS reference files across the ensemble of climate models, emissions scenarios and future time periods. Locations are grouped into cooling-dominant, balanced, and heating-dominant climates to facilitate comparison between regions with similar climatic characteristic.

8.1. Typical Meteorological Year (TMY) weather files

Figures 5-7 summarise the characteristics of the future TMY weather files using four metrics representative of the thermal conditions relevant to residential building performance. Cooling degree days (CDD24) quantify the cumulative exceedance of a daily mean outdoor temperature above a base temperature of 24°C and provide an indication of cooling demand, while heating degree days (HDD18) quantify the cumulative deficit below a base temperature of 18°C and represent heating demand. Warm-season (October–March) specific humidity characterises atmospheric moisture content during the cooling season, and warm-season daytime solar radiation represents the average incoming solar radiation during daylight hours (solar radiation >10 W m⁻²). Together, these metrics provide a concise summary of the temperature, humidity and solar conditions represented by the generated TMY weather files.

Across all climate zones, the generated TMY weather files show a consistent shift towards warmer climatic conditions relative to the historical NatHERS weather files. Cooling degree days increase progressively with future time period, while heating degree days decrease, reflecting reduced heating requirements and increased cooling demand. These changes are evident under both emissions scenarios but become increasingly pronounced towards the end of the century, particularly under SSP3-7.0.

Warm-season specific humidity also increases across most locations, particularly in tropical and subtropical climates where baseline humidity is already high. In contrast, projected changes in daytime solar radiation are comparatively small and show greater variability between climate models than systematic long-term trends. Consequently, projected changes in building thermal performance are expected to be driven primarily by increases in temperature and humidity rather than changes in incoming solar radiation.

The ensemble spread shown in the figures illustrates the uncertainty associated with individual climate models. While model differences generally increase with future time horizon, particularly for cooling degree days and humidity, the direction of projected change is highly consistent across the ensemble. Similarly, differences between the SSP1-2.6 and SSP3-7.0 scenarios are relatively small in the 2030s but become increasingly apparent by the 2050s and 2070s as greenhouse gas concentrations diverge.

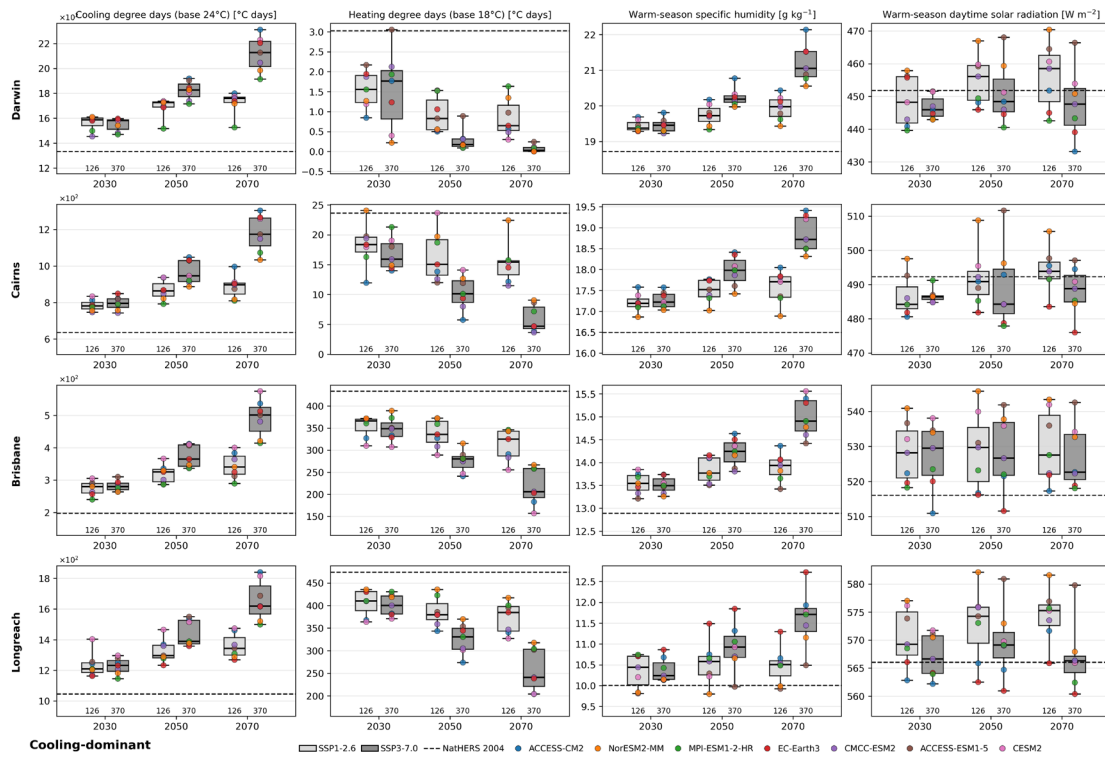


Figure 6: Climate characteristics of TMY files for cooling-dominant locations. From left to right: Cooling degree days with a comfort level of 24°C, heating degree days with a comfort level of 18°C, warm-season (October to March) specific humidity and warm-season daytime solar radiation (when solar radiation exceeds 10W/m-2). Boxplots are paired for SSP1-2.6 and SSP3-7.0 for each future time period, with the thick black line representing the multi-model median, upper/lower box edges are the 25th/75th percentile ensemble range and whiskers show the hottest/coolest, most/least humid, and most/least sunny climate model. The horizontal dashed line represents conditions from NatHERS TMY files.

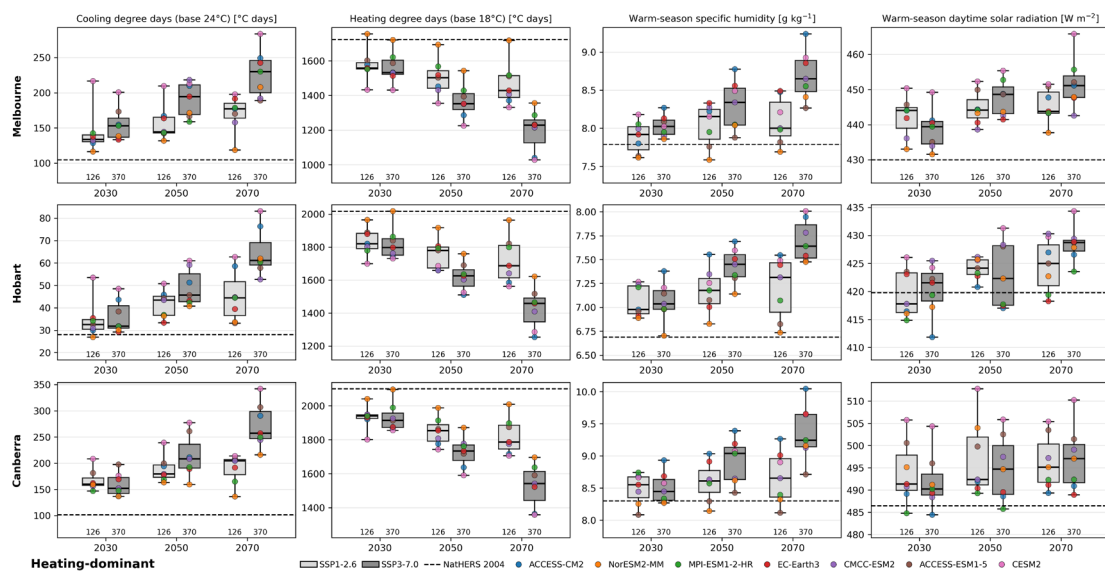


Figure 7: Same as Figure 6 but for heating-dominant locations.

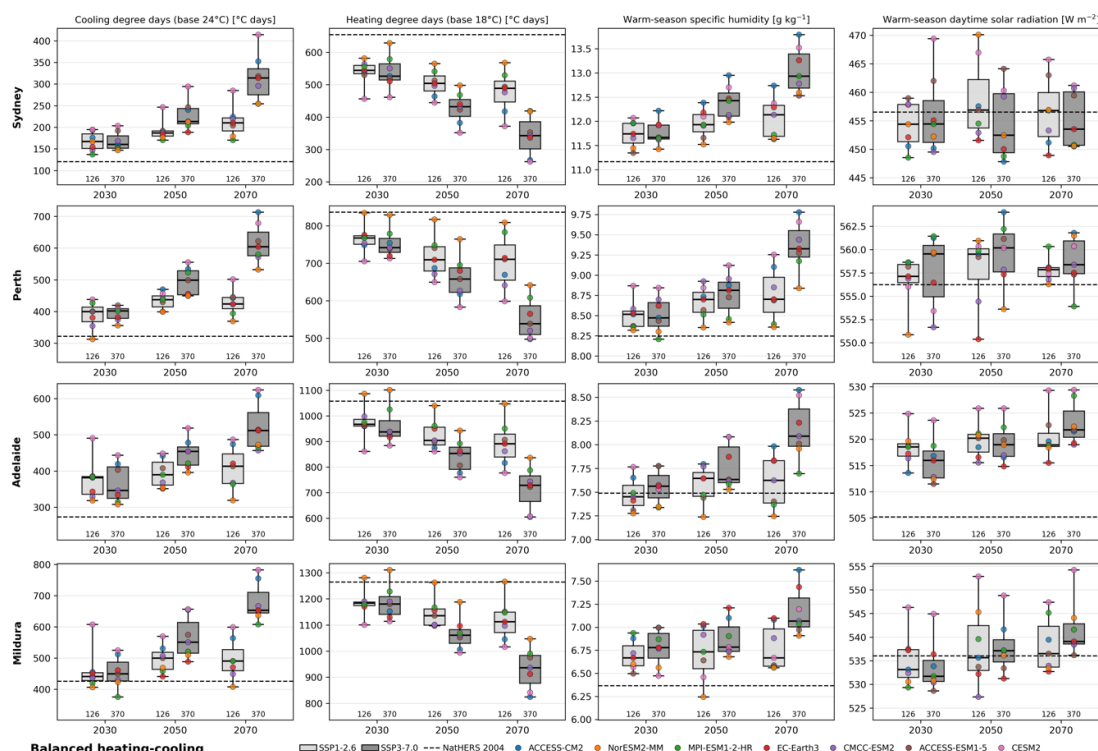


Figure 8: Same as Figure 6 but for balanced heating and cooling dominant locations.

8.2. eXtreme Meteorological Year (XMY) weather files

The XMY weather files are selected to represent three different aspects of extreme heat: the longest, most intense and most severe heatwave occurring within each 20-year climate simulation. In addition to these selection metrics, heatwave frequency was calculated across the complete 20-year simulation to provide an indication of how often heatwave events occur under future climate conditions. Unlike the other three metrics presented in Figures 8-10, heatwave frequency is therefore a characteristic of the underlying future climate rather than of an individual XMY weather file.

Relative to the historical NatHERS XMY weather files, all future XMY files exhibit increased heatwave activity, although the magnitude of change varies between locations, emissions scenarios and future time periods. The most pronounced and consistent increases occur in heatwave frequency and maximum heatwave severity, while changes in peak intensity are comparatively modest. The results should be interpreted in the context of uncertainty in the regional climate projections, particularly in the representation of the atmospheric and land-surface processes controlling the development, persistence and termination of individual heatwaves.

Changes in the longest heatwave duration are more variable between locations. This behaviour reflects the Quantile Delta Change methodology, which preserves the temporal sequencing of the historical observations while modifying their statistical distributions. As a result, future climates generally contain more frequent and more



severe heatwaves, whereas changes in the duration of individual events depend more strongly on the sequencing and persistence characteristics of the historical climate record at each location. The method does not independently simulate projected changes in heatwave sequencing or atmospheric persistence. Consequently, changes in heatwave duration should be interpreted with greater caution than the broad warming signal or changes in heatwave frequency and severity.

As for the TMY weather files, uncertainty increases with future time horizon and is larger for extreme-event metrics than for mean climate characteristics. Agreement amongst most simulations on increases in heatwave occurrence and severity relative to the historical reference provides confidence in the overall direction of change, but not in the precise timing duration or magnitude of individual future events. The XMY weather files should therefore be interpreted as plausible stress-test weather sequences conditional on the selected climate models, emissions scenarios and QDC methodology, rather than predictions of specific future heatwaves. Differences between the two emissions scenarios become increasingly evident towards the end of the century, with SSP3-7.0 consistently producing more frequent, longer and more severe heatwaves than SSP1-2.6, however, for heating-dominant (Figure 10) and balanced locations (Figure 11) changes in duration are less consistent.

The three XMY weather files represent different aspects of future extreme heat and are selected independently according to the longest, most intense and most severe heatwave events. Consequently, the selected weather files for these categories may originate from the same or different climate models depending on which model best represents each characteristic for a given location, scenario and future time period.

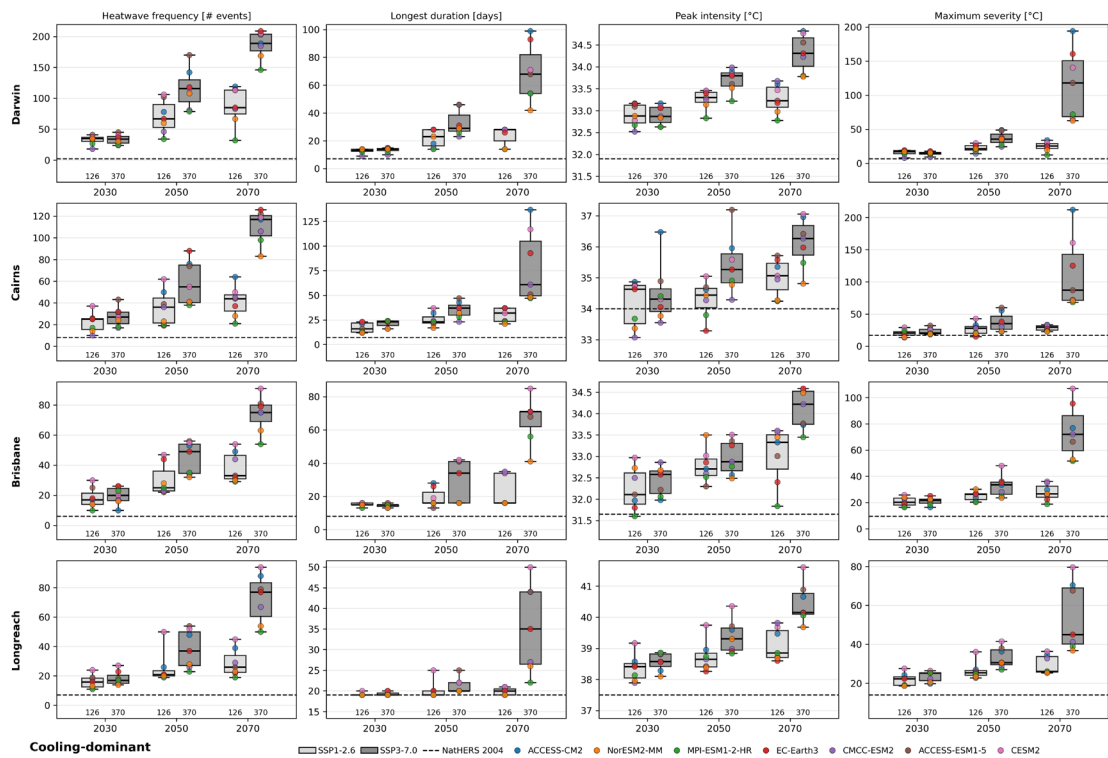


Figure 9: Climate characteristics of XMY files for cooling-dominant locations. From left to right: heatwave frequency in number of events, longest duration in days, peak intensity in °C and heatwave severity in °C. Boxplots are paired for SSP126 and SSP370 for each future time period, with the thick black line representing the multi-model median, upper/lower box edges are the 25th/75th percentile ensemble range and whiskers show the hottest/coolest, climate model. The horizontal dashed line represents conditions from NatHERS (historical) XMY files.

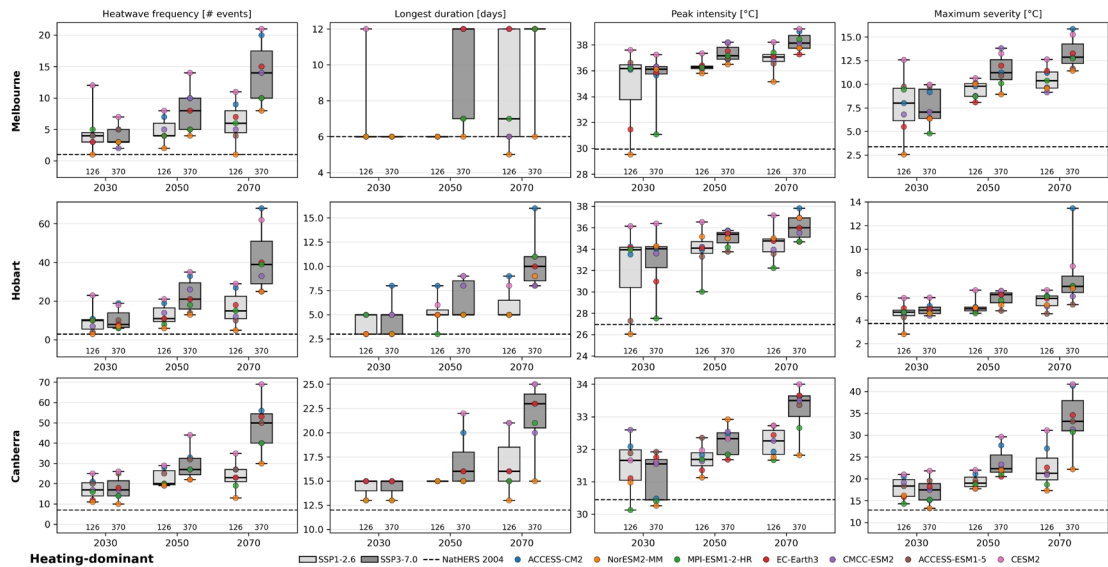


Figure 10: As Figure 9 but for heating-dominant climate.

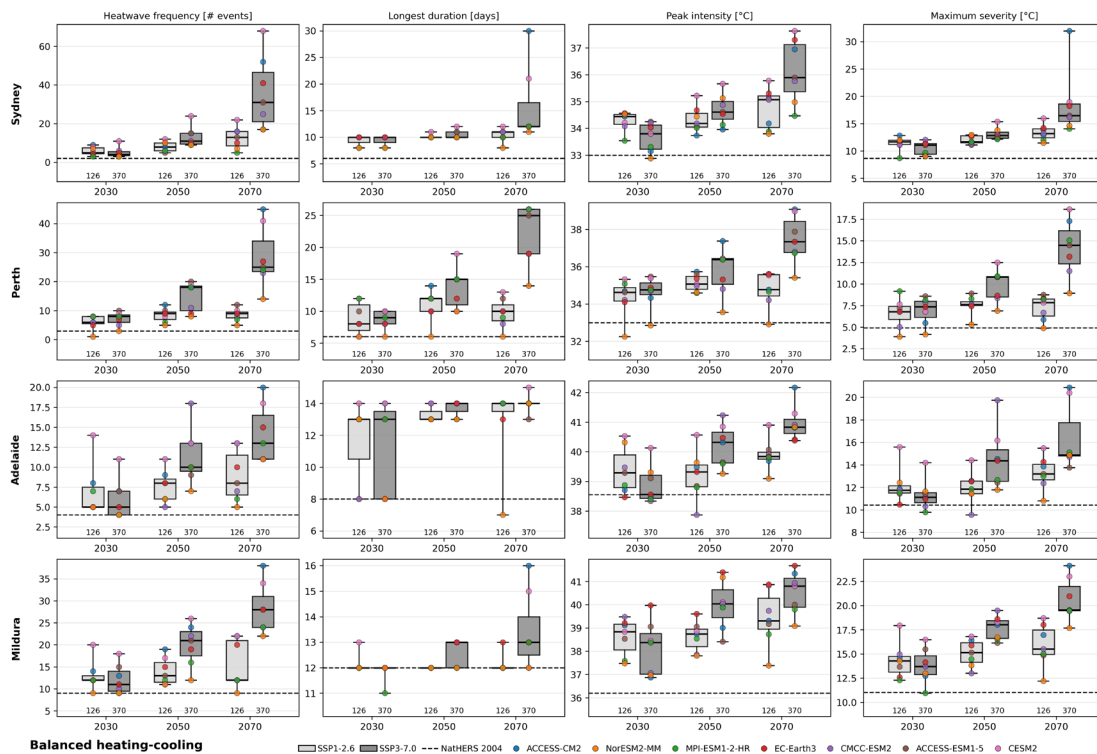


Figure 11: As Figure 9 but for balanced heating-cooling climate.

9. Conclusions, Limitations, Opportunities and Future Development

The methodology developed in this study provides a strong foundation for future weather-file generation and serves as a template for a transferable framework that could be extended to additional locations, alternative observational datasets, different regional climate model ensembles, and other building simulation formats.

Dalla Pozza et al. (2026) describes the stakeholder engagement that supported the development of these methods and the extensive testing that was undertaken by building design experts. Testers confirmed that the weather files were compatible with their software and produced building performance results consistent with the projected climate changes represented in the files. They also noted the need for clearer guidance on interpreting the different XMY weather files, particularly when multiple files were derived from the same heatwave event. Further validation and testing across a wider range of building types, climate zones, and simulation software would strengthen confidence in the methodology and support future operational adoption. Commercial buildings are another area into which similar methodology could be extended. This should include more extensive evaluation of the bias-adjusted datasets relative to both observations and raw climate-model output.



The generated weather files should be interpreted in the context of uncertainties in the historical reference data (Liley 2017, 2020), regional climate projections (Su et al. 2022a) and statistical-adjustment methodology (Irving and Macadam, 2024). Although the selected climate models were evaluated for their representation of Australian climate, model performance varies by location, variable, season and physical process (Grose et al. 2023). The use of an evaluated model ensemble reduces the risk of relying on models with known substantial deficiencies, but does not eliminate uncertainty in projected climate change, particularly for extreme events (Hirsch et al. 2021). Confidence is generally greater in the broad warming signal than in the timing, duration and detailed meteorological evolution of individual future heatwaves.

An additional uncertainty arises from the comparison of point-based NatHERS data with conditions resolved at the BARPA-R grid scale. This mismatch is particularly relevant near coastlines and in areas of complex topography, where local elevation, land-sea contrasts, coastal circulations and the advection of hot continental air may not be fully represented at the model resolution. Overnight minimum temperatures during heatwaves may also be affected by local processes that are not adequately resolved as well as the urban heat island effect, particularly important for large cities like Melbourne, Sydney and Brisbane. QDC reduces systematic differences between modelled and observed distributions, but cannot correct physical processes that are absent or inadequately represented in the regional climate simulations at ~17km spatial resolution.

The QDC method applies projected distributional changes to the historical NatHERS time series while retaining its temporal sequencing. This provides hourly and day-to-day weather sequences based on the historical record, but does not independently simulate projected changes in the timing, sequencing or atmospheric persistence of future weather events. Projected warming may intensify heatwaves already present in the historical sequence and cause previously non-heatwave periods to exceed the historical thresholds. However, changes in heatwave duration remain constrained by the persistence characteristics of the historical sequence and should be interpreted with particular caution. The XMY files are therefore best regarded as plausible stress-test weather sequences conditional on the selected climate models, emissions scenarios and QDC methodology, rather than predictions of specific future heatwaves.

Meteorological variables were adjusted individually, and the method does not explicitly preserve all multivariate physical relationships among temperature, moisture, pressure, wind and solar radiation. Although the use of a common historical sequence retains some observed temporal coherence, separate quantile adjustments may modify relationships among variables, particularly in the distributional tails. Quantile changes at the most extreme percentiles are also estimated from comparatively small samples and are therefore subject to greater sampling uncertainty than changes near the centre of the distribution.

The analysis also highlights several areas for further improvement of the method, such as a more in-depth assessment of observed wind and solar data to create a high-quality dataset to benchmark against. Here, projected changes in wind direction and cloud cover were retained from the historical NatHERS files in the current implementation because



of their discrete representation, as well as limited observational datasets for comparison. Consequently, the generated files do not represent possible future changes in wind direction or cloud cover. Wind speed is adjusted independently of wind direction, which may also modify their historical relationship.

The representation of wind during heatwaves is subject to further uncertainty. Strong daytime boundary-layer mixing may cause surface conditions to be influenced by winds at higher atmospheric levels, while local terrain, coastal circulations, urban form and surface roughness may not be fully resolved at the BARPA-R grid scale. Because the final weather files retain historical NatHERS wind direction, they do not capture potential changes in heatwave-related circulation or future wind-direction distributions.

Further work could investigate the potential of benefits and limitations of using high-resolution reanalysis products, such as BARRA-R2 or the even higher resolution (4km) convection permitting version BARRA-C2, as a historical reference dataset. A gridded reference dataset could reduce dependence on individual station records, improve spatial consistency, and support the generation of weather files for locations beyond the existing NatHERS climate zones. However, reanalysis products also contain model-dependent biases and would require careful evaluation against observations before replacing the established NatHERS historical dataset. The implications of changing the historical references should also be assessed, as differences between existing and future files could otherwise reflect both climate change and a change in the underlying reference dataset.

Additional research could expand the treatment of extreme events beyond heatwaves to include other climate hazards relevant to building performance and resilience, such as cold extremes, compound heat–humidity events, bushfire-weather conditions, severe wind, extreme rainfall and large hail. There was particular stakeholder interest in extreme rainfall.

Finally, the workflow could be progressively operationalised as a national capability through automation, governance arrangements, routine updates with new climate projections, and enhanced user-support products, including model-selection guidance and climate-risk summary metrics for practitioners.

Collectively, these developments would improve the realism, coverage, usability, and scientific defensibility of future weather files, supporting their transition from a research capability to an operational climate service for the Australian built environment. The present dataset provides an important basis for climate-informed building assessment, but its outputs should be used as an ensemble of plausible future conditions rather than as deterministic predictions of future weather or individual extreme events.



Acknowledgements

This research has been undertaken with support of the Australian government's National Environmental Science Program and Australian Climate Service.

The hub would like to acknowledge the contributions of the broader project team outside the hub Zhengen Ren and Anthony Wright from CSIRO Energy; Anir Upadhyay from the University of New South Wales; Dörte Jakob from the Bureau of Meteorology, Erica Kenna, from Australian Building Codes Board and Daniel Daly, William Tolis, Tim Le Mesurier and Hannah Bubb from the Australian Department Climate Change Energy, the Environment and Water. As well as thanks to the Project Advisory Group members Shane Keating from Housing Industry Australia, Graham Macdonald from WA Department of Housing & Works, Stanford Harrison from the Australian Department Climate Change Energy, the Environment and Water, Anna Schlunke from NSW Department of Planning, Housing and Infrastructure, Ryan Flack from National Australian Built Environment Rating Scheme (NABERS), Jocelyn Dela-Cruz from the NSW Department of Climate Change, Energy, the Environment and Water, Peter Rooks from QLD Department of State Development, Infrastructure, Local Government and Planning, Stuart Fawcett VIC Department of Energy, Environment and Climate Action, Simon Koger from Engineers Australia, and Ruth Robjohns (Nordstrom) from the Australian Institute of Architects.

This project would not have been possible without the generous contributions of the volunteer testers: Chris Lockhart-Smith from Ecodweller, Gerald Turnbull, Govind Maksay and Ian McNicol from Sustainability Victoria, Nazanin Bahadorian from Bera, Warren Li from LCI, Ming Lui from CSIRO Energy, Stephen Greenwood and Shane Keating from Housing Industry Australia, and Steve Watson, Research Education Design Sustainability Consultants.

We would also like to acknowledge and thank Chun-Hsu Su and Christian Stassen from the Bureau of Meteorology for their expertise and reprocessing BARRA and BARPA data.

The datasets used in this research were created with the assistance of resources from the National Computational Infrastructure (NCI Australia).

We thank Mika Peace, Pandora Hope and Danielle Udy from the Bureau of Meteorology for their helpful feedback and reviews of this report.



Glossary

Abbreviation/ Term	Definition
ABCB	Australian Building Codes Board
ACDB	Australian Climate Database
ACS	Australian Climate Service
BARPA-R	Bureau of Meteorology Atmospheric Regional Projections for Australia – Regional
BARRA-R2	Bureau of Meteorology Atmospheric Regional Reanalysis for Australia – Regional
CDD	Cooling Degree Days
CMIP6	Coupled Model Intercomparison Project Phase 6
DCCEEW	Department of Climate Change, Energy, the Environment and Water
GCM	Global Climate Model
HDD	Heating Degree Days
NatHERS	Nationwide House Energy Rating Scheme
NESP	National Environmental Science Program
NetCDF	Network Common Data Form
NCC	National Construction Code
NCI	National Computational Infrastructure
NPCP	National Partnership for Climate Projections
QDC	Quantile Delta Change
SSP	Shared Socioeconomic Pathway
TMY	Typical Meteorological Year
Weather file	A structured time series of meteorological variables used as external boundary conditions in building-performance and energy simulation. In this report, "NatHERS weather file" refers specifically to a weather file formatted for use by NatHERS-accredited building simulation software.
XMY	Extreme Meteorological Year



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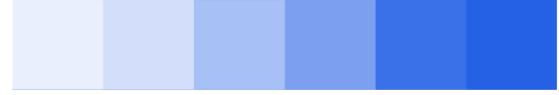
Appendix

A. Mathematical formulation

A.1. Variable transformations

Table 4: NatHERS and BARPA-R variables (with CMIP variable names in []) and units with conversions where applicable. Refer to Equation references where space in the table was too limited to display formula.

NatHERS		BARPA-R		Conversion/Formula
Variables	Unit	Variables	Units	
Dry bulb temperature	°C	Surface air temperature [tas]	K	$T(^{\circ}C) = T(K) - 273.15$ (1)
Absolute moisture content	g/kg	Near-Surface Specific Humidity [huss]	kg/kg	$q(g\ kg^{-1}) = q(kg\ kg^{-1}) * 1000$ (2)
Station level pressure	kPa	Sea Level Pressure [psl]	Pa	Eq. (6)
Wind speed	m/s	Near-Surface Wind Speed [sfcWind]	m/s	retained
Wind direction	0-16, 0=calm, 1=NNE, 16=N	Northward and Eastward Near-Surface Winds [vas, uas]	m/s	Eqs. (7) + (8)
Global solar irradiance	W/m ²	Surface Diffuse and Direct Downwelling Shortwave Radiation [rsdsdif, rsdsdir]	W/m ²	$GHI = rsds_{dir} + rsds_{dif}$ (3)
Direct solar irradiance	W/m ²	Surface Direct Downwelling Shortwave Radiation [rsdsdir]	W/m ²	$DNI = \frac{rsds_{dir}}{\sin(\alpha)}$ (4)
Diffuse solar irradiance	W/m ²	Surface Diffuse Downwelling Short wave Radiation [rsdsdif]	W/m ²	retained
Total cloud cover	Oktas (0-8)	Cloud fraction [clt]	% (0-100)	$N_{okta} = round(8 \frac{c}{100})$ (5) clipped to 0–8
Solar altitude	° (0-90)			Taken from NatHERS
Solar azimuth	° (0-360)			Taken from NatHERS



The simplified hypsometric equation to derive station pressure P_{stn} in kPa from sea level pressure P_{msl} in Pa is

$$P_{stn} (kPa) = \frac{P_{msl}(Pa)}{1000} * \left(\frac{288 - 0.0065h}{288} \right)^{5.2561} \quad (6)$$

Where h is station elevation (in metres) taken from Table 1.

Wind speed and meteorological wind-from direction were calculated from the eastward and northward wind components using `xclim` which follows:

$$\theta = \left[270^\circ - \frac{180^\circ}{\pi} \text{atan2}(v, u) \right] \text{mod } 360^\circ \quad (7)$$

Continuous wind direction was subsequently discretised into 16 compass sectors D_{16} , with a code of zero assigned to calm conditions.

$$D_{16} = \left[\left[\frac{\theta - 11.25^\circ}{22.5^\circ} \right] \text{mod } 16 \right] + 1 \quad (8)$$

Relative humidity as an input for the dew point temperature formulation from the `ACS_atmos` Python package is calculated from:

$$e = \frac{pg}{\epsilon(1 - q) + q} \quad (9)$$

$$RH = \frac{e}{e_s(T)} \quad (10)$$

where p is station pressure, q is specific humidity, e is vapour pressure, $e_s(T)$ is the saturation vapour pressure at air temperature T , and $\epsilon = R_d/R_v$, the ratio of the gas constants for dry air and water vapour. For further details see <https://github.com/AusClimateService/atmos> and Warren (2025).

A.2. Quantile Delta Change (QDC) scaling

Projected climate changes were transferred from the BARPA-R simulations to the historical NatHERS observations using the Quantile Delta Change (QDC) method following Irving and Macadam (2024).



The method estimates climate change separately for each calendar month and hour of the day. Let $F_{H,m,h}$ denote the cumulative distribution function (CDF) of the historical BARPA-R simulation, and $F_{F,m,h}$ the CDF of the future BARPA-R simulation for month m and hour h .

For an observed NatHERS value x_{obs} , the corresponding quantile in the historical model distribution is

$$p = F_{H,m,h}(x_{obs}) \quad (11)$$

A.2.1. Additive variables

For variables whose projected change is represented additively (air temperature), the climate change signal is

$$\Delta_{m,h}(p) = F_{F,m,h}^{-1}(p) - F_{H,m,h}^{-1}(p) \quad (12)$$

The future-adjusted value is then

$$x^* = x_{obs} + \Delta_{m,h}(p) \quad (13)$$

A.2.2. Multiplicative variables

For variables represented multiplicatively (specific humidity, wind speed, station pressure and global horizontal irradiance), the climate change factor is

$$R_{m,h}(p) = \frac{F_{F,m,h}^{-1}(p)}{F_{H,m,h}^{-1}(p)} \quad (14)$$

and the adjusted value becomes

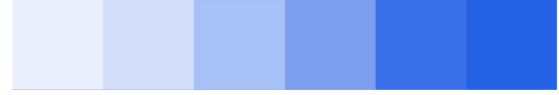
$$x^* = x_{obs} \times R_{m,h}(p) \quad (15)$$

where

- p is the quantile corresponding to the observed value;
- x_{obs} is the historical NatHERS observation; and
- x^* is the future bias-adjusted value.

The QDC procedure was implemented independently for each calendar month and hour of day. To improve the robustness of the estimated distributions, a sliding three-hour window (target hour ± 1 hour) was used when fitting the quantiles. For example, the adjustment applied at 12:00 was estimated using BARPA-R data from 11:00–13:00.

One hundred quantiles were used to characterise each monthly distribution.



Air temperature was adjusted additively, while specific humidity, station pressure, wind speed and global horizontal irradiance were adjusted multiplicatively. Wind direction and cloud cover were not bias adjusted because they are represented as categorical variables within the NatHERS weather-file format. The historical NatHERS sequences were therefore retained.

A.3. Solar radiation treatment

Global horizontal irradiance was the only radiation variable adjusted directly using QDC.

To avoid numerical instability associated with multiplicative scaling:

- values below 1 W m^{-2} were retained unchanged;
- values corresponding to solar altitude angles below 10° were replaced with the raw future BARPA-R values; and
- adjusted values exceeding 1300 W m^{-2} were also replaced with the corresponding BARPA-R values.

Following adjustment, direct and diffuse radiation were reconstructed using the monthly-hourly climatological direct-radiation fraction.

The direct-radiation fraction is

$$f_{dir}(m, h) = \frac{\overline{RSDS_{dir}(m, h)}}{\overline{RSDS(m, h)}} \quad (16)$$

where the overbar denotes the monthly-hourly climatological mean.

The reconstructed direct component is

$$RSDS_{dir}^* = RSDS^* \times f_{dir} \quad (17)$$

and the diffuse component is

$$RSDS_{diff}^* = RSDS^* - RSDS_{dir}^* \quad (18)$$

This approach preserves the projected partitioning between direct and diffuse radiation while ensuring that the two components sum exactly to the adjusted global irradiance.