Disaggregation of Precipitation Data Applicable for Climate-aware Planning in Built Environments

Australasian Building Simulation 2022 Conference
Brisbane, July 20-21

Presenter: Trevor Lee
Executive Director, Exemplary Energy
www.exemplary.com.au

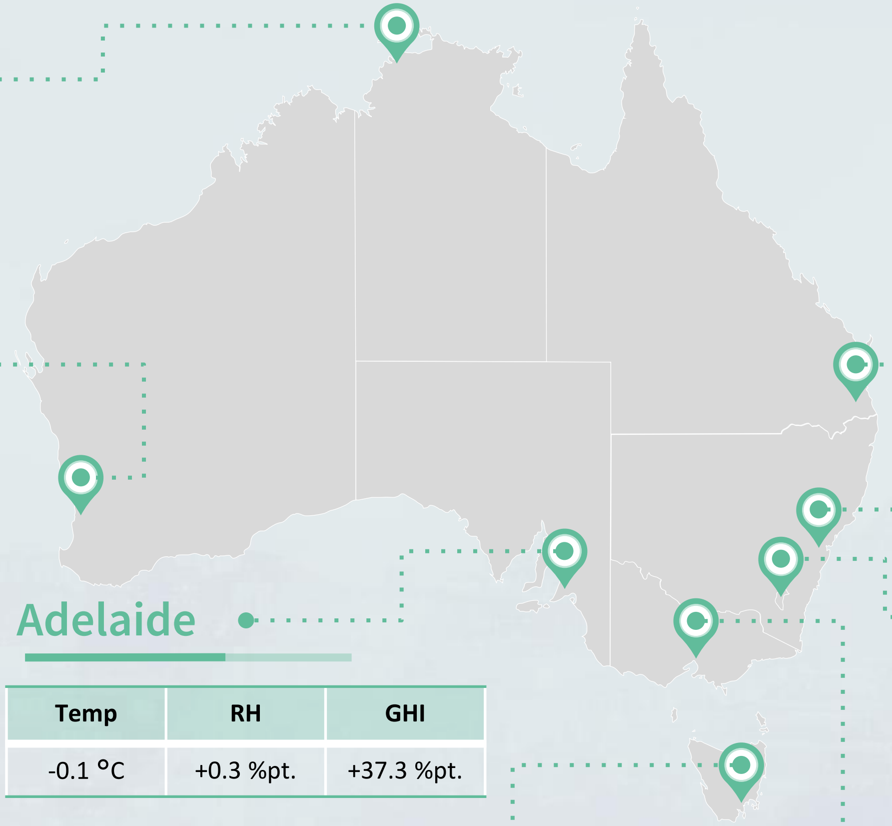
Authors: David Ferrari, Masoume Mahmoodi, Chithral Kodagoda, Nihal Abdul Hameed, Trevor Lee, Graham Anderson

Context of weather and climate data services

exemplary ENERGY

- Exemplary Weather and Energy (EWE) Index published monthly – all 8 capital cities.
- Real Time Meteorological Years (RTYs) generated monthly for sale to simulators seeking calibrated results for existing buildings and systems – all 8 capital cities.
- Full 32-year weather records for ~250 Australian locations including all 80 NatHERS climate zones adhering to time stamp conventions (1990 to 2021 inclusive).
- Reference Meteorological Years (RMYs) derived from those 32-year records based on 3 alternative weightings for solar irradiation in the Cumulative Difference Function (CFD) and including precipitation data.
- Ersatz Future Meteorological Years (EFMYs) for 2030 and 2050 scenarios.
- Extreme Meteorological Years (XMYs) for flat plate solar PV, water penetration and condensation (WPC) and building services (HVAC).
- www.exemplary.com.au blog https://exemplaryenergy.wordpress.com

Weather Index – May Monthly Means



Darwin

Temp	RH	GHI
N.A.	N.A.	N.A.

Perth

Temp	RH	GHI
+0.3 °C	+0.2 %pt.	+9.1 %pt.

Adelaide

Temp	RH	GHI
-0.1 °C	+0.3 %pt.	+37.3 %pt.

Hobart

Temp	RH	GHI
-0.3 °C	+8.3 %pt.	-6.2 %pt.

Brisbane

Temp	RH	GHI
+0.6 °C	+9 %pt.	-47.5 %pt.

Sydney

Temp	RH	GHI
+0.6 °C	+6.6 %pt.	-12.8 %pt.

Canberra

Temp	RH	GHI
+0.1 °C	+7.6 %pt.	-18.8 %pt.

Melbourne

Temp	RH	GHI
-0.6 °C	+5 %pt.	-13.5 %pt.

The need for Precipitation Data

- Several applications in the design and simulation of built environments require input of historical weather data. The accuracy of these models increase proportionally with the resolution of the input weather data.
- Currently, for many sites in Australia the available data of precipitation is either low temporal resolution (e.g. daily) or barely long enough to produce reliable climatically indicative results.
- In this project we developed two algorithms to provide estimates of the half-hourly historical precipitation data in Australian locations, based on daily precipitation measurements for aggregating to hourly data.

The need for Precipitation Data: National Construction Code (NCC)

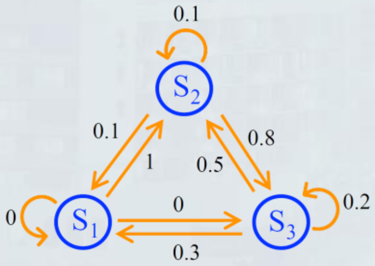
- A recent amendment introduced in 2019 details new provisions in the NCC that aims to minimize moisture impacts on building physics such as water ingress, condensation and mould formation, etc.
- Verification by simulation is permitted using accredited software such as WUFI®
- Climate files fitted to that purpose are required for reliable results
- Currently, no precipitation data of recent Australian origin is available in recognized formats.

The need for Precipitation Data: half-hourly data

- Hourly data is needed for simulation software but the two formats have different time stamp conventions requiring half-hourly data to fulfil both.
- The Australian Climate Data Bank (ACDB) format:
  - Devised by the BoM and CSIRO in 1980s (now little used outside NatHERS);
  - Solar irradiation data convention of the <u>hour centred on</u> the time stamp;
  - No explicit cells for precipitation values, but spare cells at the end of each hour row;
  - Agreed with CSIRO to use those spare cells with the same time convention as for solar.
- The Energy Plus Weather (EPW) format:
  - Devised by the US National Renewable Energy Laboratory (NREL);
  - In wide use worldwide including the EnergyPlus open source software;
  - Incorporates cells for precipitation data for the <u>hour leading up to</u> the time stamp.
- Until the early 2000's, most observations were daily totals

Estimating Half-Hourly from Daily Totals: Markov Chain using TPM

- The model generates a sequence of random variables (or states) where the current value is probabilistically dependent only on the value of the prior variable.
- These probabilities are represented in a Transition Probability Matrix (TPM) format that is readable by the algorithm.



Current State	Next State						
	0	**0.2**	**0.4**	**...**	**38.2**	**38.4**	**38.6**
0	0.917	0.043	0.01	...	0	0	0
0.2	0.697	0.102	0.062	...	0	0	0
0.4	0.383	0.181	0.135	...	0	0	0
.				.			
.				.			
.				.			
38.2	0	0	0	...	0	0	0
38.4	0	0	0	...	0	0	0
38.6	1	0	0	...	0	0	0

$$TPM = \begin{array}{c} \\ s_1 \\ . \\ s_i \\ . \\ s_n \end{array} \begin{array}{c} \begin{array}{ccccc} s_1 & . & s_j & . & s_n \end{array} \\ \begin{pmatrix} p_{11} & . & . & . & p_{1n} \\ . & . & & & . \\ . & & p_{ij} & & . \\ . & & & . & . \\ p_{n1} & . & . & . & p_{nn} \end{pmatrix} \end{array}$$

Monte Carlo Markov Chain (MCMC) Model utilising simulating annealing

- This model utilises the observed properties of precipitation series.
- The optimisation technique used is called simulated annealing which works on the Metropolis-Hastings algorithm.
- This technique keeps iteratively modifying the hourly precipitation signals til the differences between the desired correlations and obtained correlations are below a certain threshold value.

Correlation analysis and Case Studies

- For our study, we used the historic data for Canberra, where the hourly weather data including precipitation was available from 2010 to 2019.
- To obtain a statistical relationship between precipitation and other weather elements, we perform a correlation analysis.

Analysis based on		Correlation Between	Value
Rain Days	Onsets		
	✓	P(t) and variance(DBT(t-1:t))	0.5
	✓	P(t) and variance(DBT(t-2:t))	0.48
	✓	P(t) and variance(RH(t-1:t))	0.45
	✓	P(t) and variance(RH(t-2:t))	0.43
✓		P(t) and P(t-1)	0.41
		.	
		.	
		.	
✓		P(t) and P(t-2)	0.23

Metropolis-Hastings Algorithm

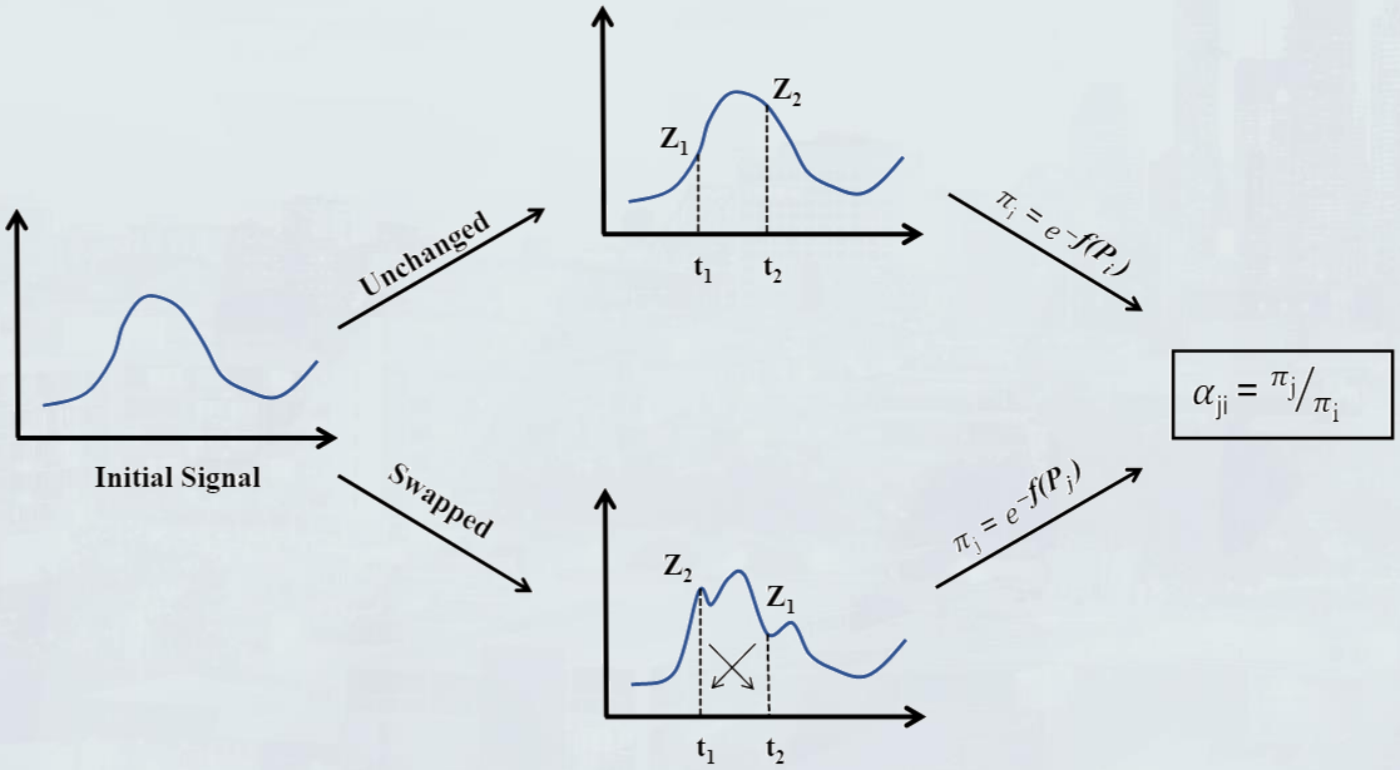
- Consider two signals P1 and P2 and assign the conditional probabilities to them:
  - $\pi_1 = P(P1 | P = P1 or P2)$
  - $\pi_2 = P(P2 | P = P1 or P2)$
- Based on this algorithm, an acceptance ratio is defined for the two considered series P1 and P2, as follows:
  - $\alpha_{21} = \pi_2 / \pi_1$

$$\begin{cases} \text{Accept the candidate } P_2 & \text{if } \alpha_{21} \geq 1 \\ \text{Accept the candidate } P_2 & \text{if } u \leq \alpha_{21} < 1 \\ \text{Reject the candidate } P_2 & \textit{otherwise} \end{cases}$$

  - Where u is a uniformly generated random number between (0,1)

Simulated Annealing

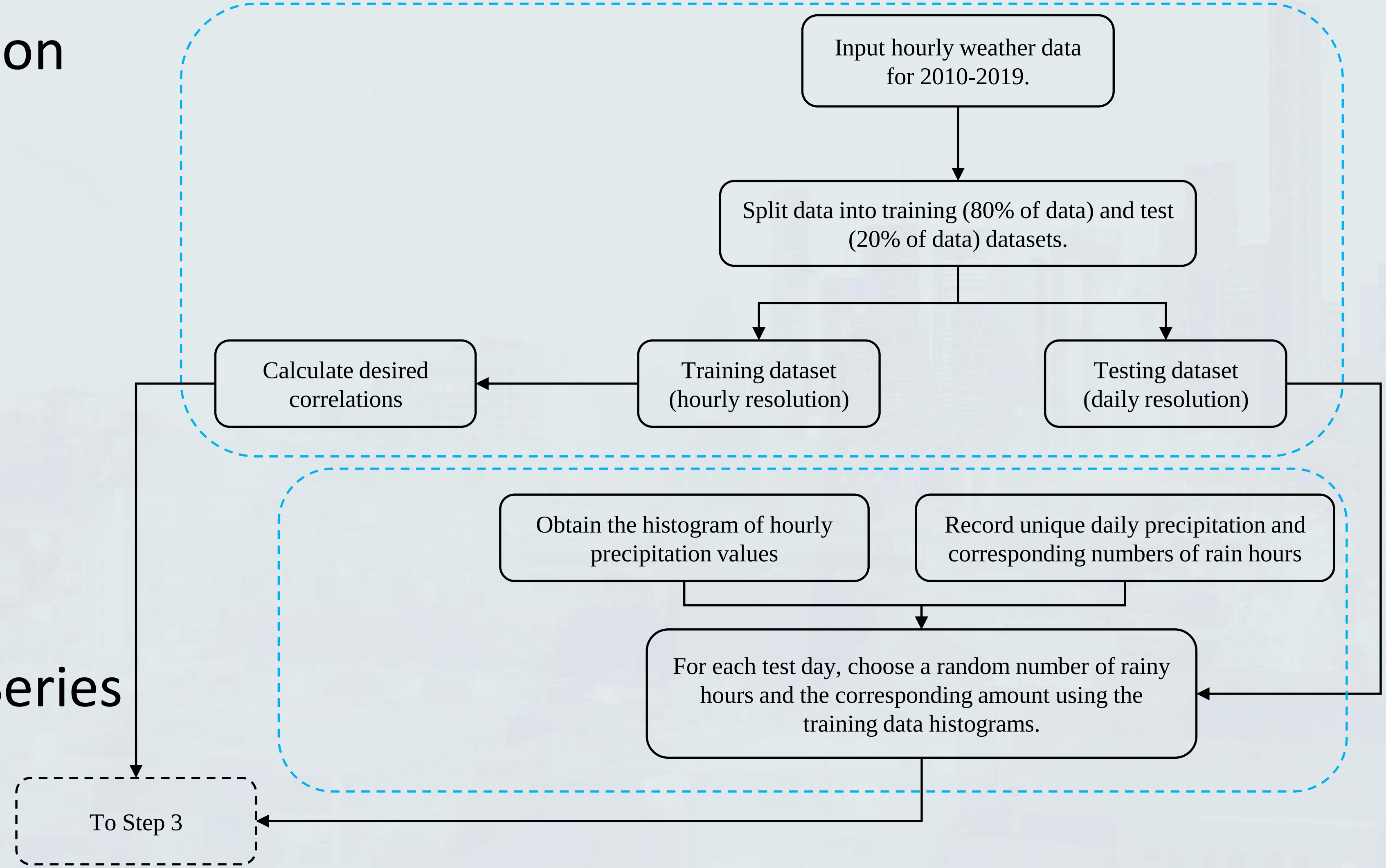
- We randomly choose d days and for each day, two times $t_1 \neq t_2$ are selected to swap their hourly rain values. This process is called resampling and generates a new time series.



Steps of Algorithms

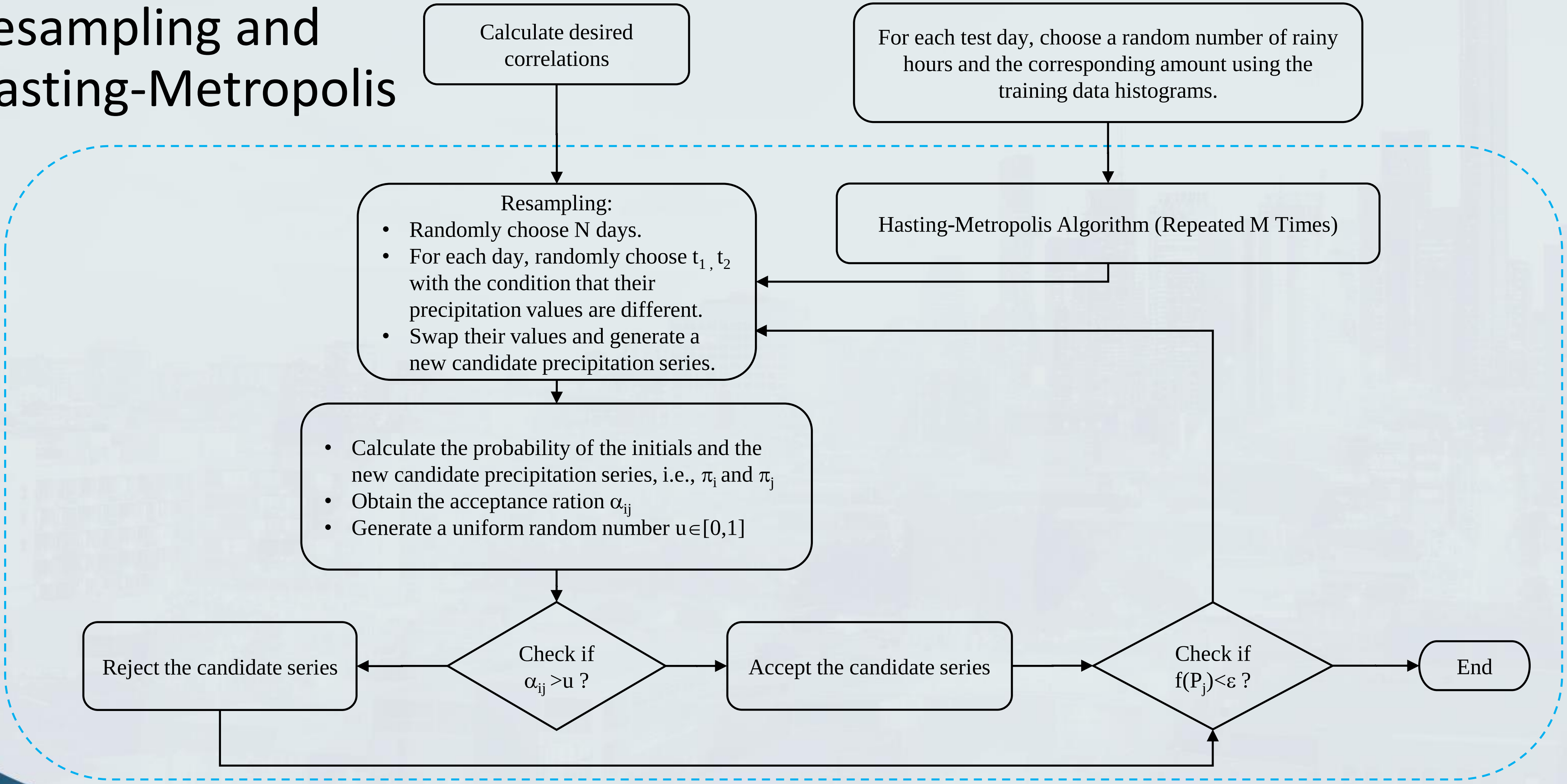
1. Data Preparation Process.

2. General Initial Random Precipitation Series



Steps of Algorithms

3. Resampling and Hasting-Metropolis

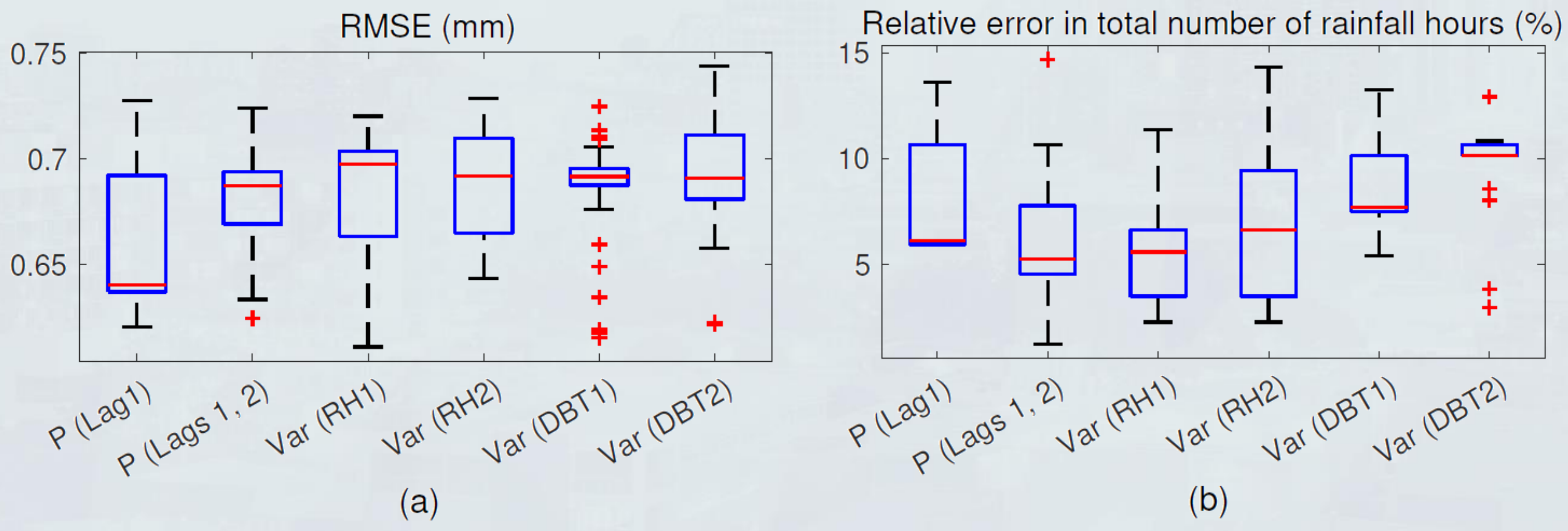


Results

- We performed the following six different experiments.
  I. P (Lag1): considering only Lag 1 of the precipitation and
  II. P (Lags 1, 2): considering Lag 1 and Lag 2 of the precipitation,
  III. Var (RH1): considering variance of relative humidity during the past hour,
  IV. Var (RH2): considering variance of relative humidity during the past two hours,
  V. Var (DBT1): considering variance of dew point temperature during the past hour, and
  VI. Var (DBT2): considering variance of dew point temperature during the past two hours.

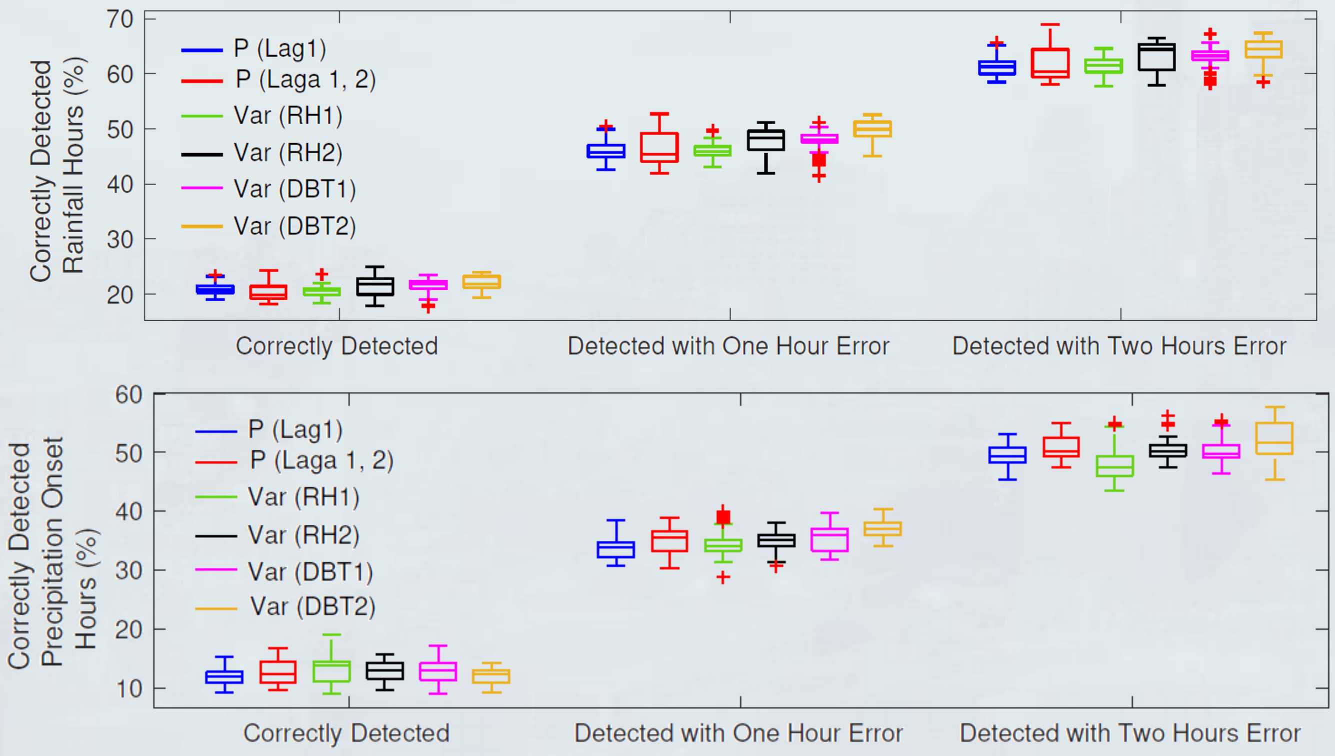
Results

- We repeated the MCMC algorithm 100 times, to account for the uncertain nature of this algorithm, and calculated RMSE between the generated and the actual precipitation series, and the relative error between the total number of rainfall hours in the generated series.



Results

- We observed that the MCMC algorithm detects at least 60% of the rainfall hours with less than two hours error. It also infers at least 50% of the precipitation onset hours with the same error.



Conclusions

- We have developed two algorithms based on Markov chains to generate hourly temporal resolution precipitation data in Australian locations based on the daily precipitation data recorded by the Bureau of Meteorology (BoM) before 2000's.
- The proposed algorithms use a combination of data recorded for weather elements like temperature, relative humidity and cloud cover, along with the precipitation data.
- We show that MCMC algorithm has a better performance compared to Markov chain model. We also observe improvements in the considered metrics when the other weather elements are integrated in the developed algorithms.
- However, the results are not assessed as good enough to allow us to use the synthesized half-hourly data in generating hourly data sets incorporating precipitation data in the time conventions of the respective formats.

Future Development

- Climate change can affect buildings in different ways by changing the energy demand and other stresses on buildings, as demonstrated in our eXtreme Meteorological Years (XMYs) presentation today.
- Subsequent work will need to concentrate on more recent years, addressing the quality of the precipitation data in the form of 30-minute precipitation accruing to 9am made available by the BOM, and updating climate data to incorporate precipitation (mostly rainfall).
- Producing eXtreme Meteorological Years for Water Penetration and Condensation (XMY_{WPC}) for façade and other componentry testing by simulation (e.g. WUFI® and UTas).
- BOM data cf Meteonorm data for WUFI®.
- Full enhancement of weather and climate data files for reliable simulation.

Future Development – scoping XMY_{WPC}

BOM data cf Meteonorm data for WUFI®

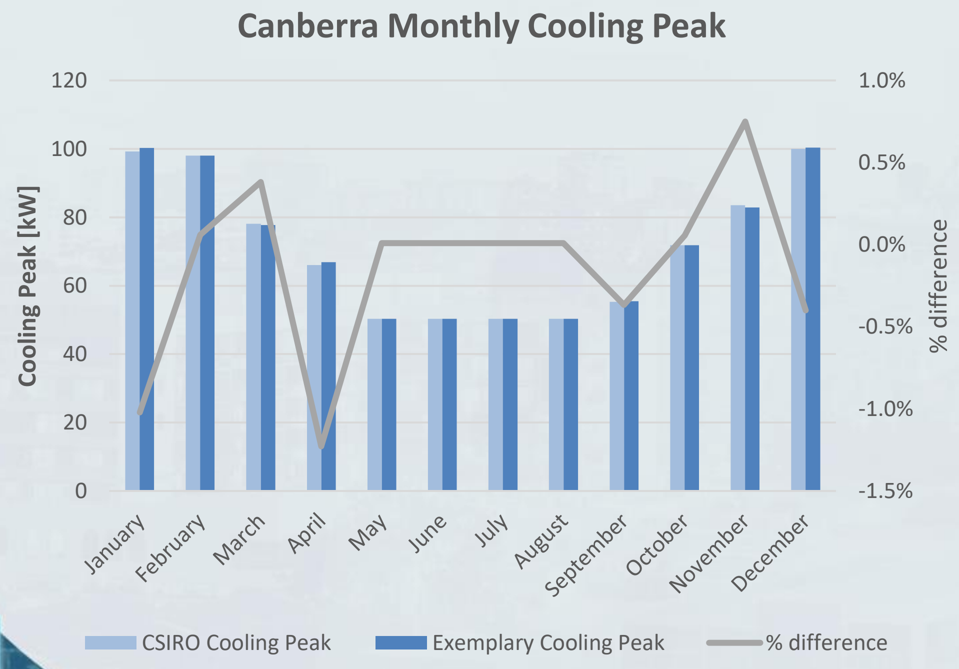
- Currently only compared for Canberra in collaboration with LAROS Technologies in Fyshwick ACT and University of Tasmania.
- Preliminary analysis of the data used by LAROS on the recommendation of WUFI® (sourced from Meteonorm) has these apparent characteristics:
- Mean Rain Days 101.2, Mean Annual Precip'n 592.8 (BOM 1990-2015)
- Rain Days 161, Annual Precipitation 494.0 (Meteonorm)
- See Freya Su's paper (UTas) later in the program.

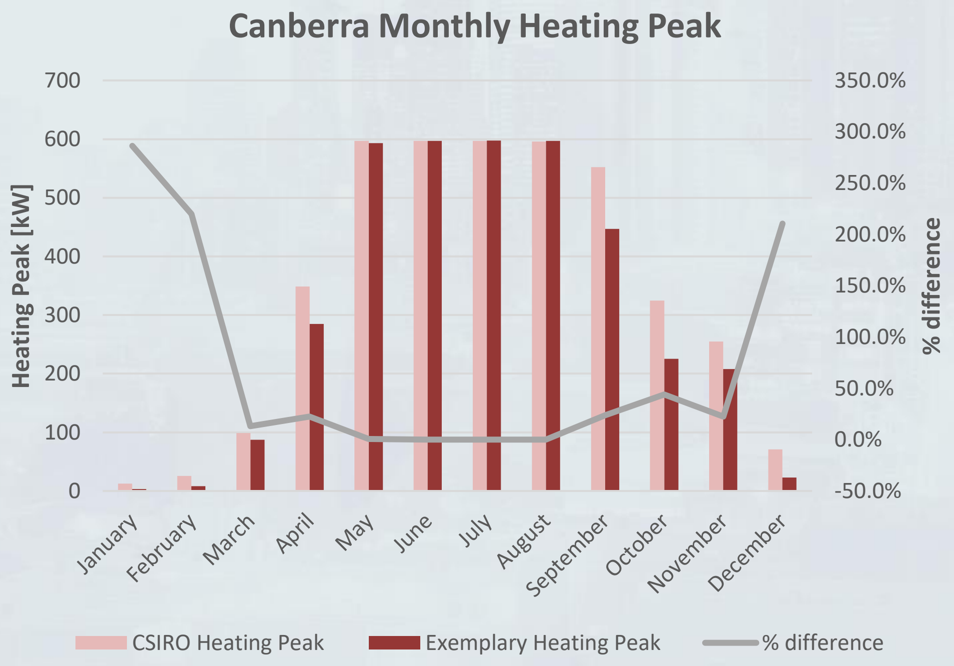
Future Development – scoping the full enhancement cf CSIRO

- Updating the weather record by 6 years for more current reflection of climate in the RMYs (CSIRO ends with 2015) – 1990 to 2021.
- Offering the full 32-year weather record for sale and peer review of our RMYs and XMYs.
- Adding precipitation data to the ACDB and EPW formats with the same time convention as the solar irradiation in each instance.
- Potential half-hourly data sets in EPW format for greater temporal precision.
- Correcting the 1-hour off-set built into the CSIRO data set in the incorrect transposing of data between the ACDB (0-23) format (NIWA) and EPW format.
- Correcting the half-hour off-set in the solar irradiation data, again built in by incorrect transposing of the ACDB to EPW formats.
- Possibly shortening the data period in the RMY production to incorporate half-hourly precipitation data and be more reflective of the changing climate.

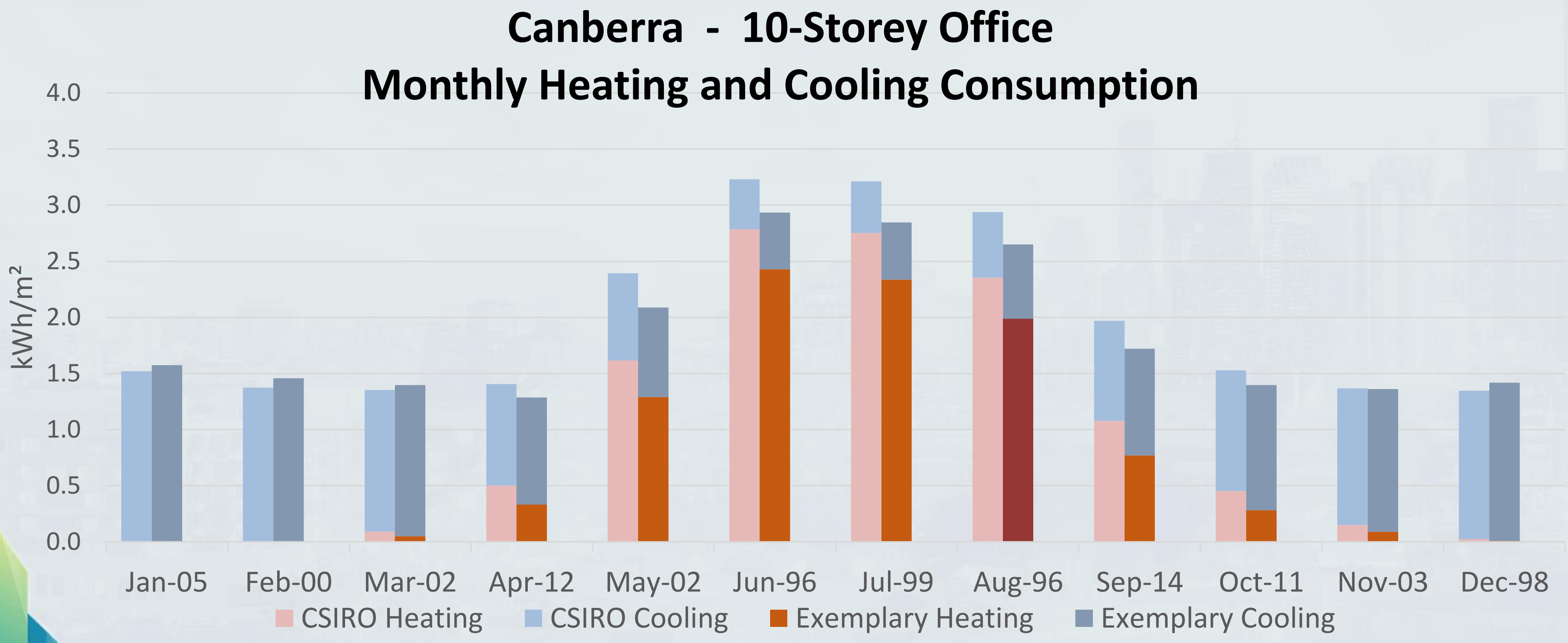
Future Development – scoping the full enhancement cf CSIRO

- We have used our long term weather records to replicate the CSIRO RMY (1990-2015) in EPW format by concatenating the same calendar months and simulating our 10-storey archetype with each file. Peaks little changed except for their “time”.





Future Development – scoping the full enhancement cf CSIRO



Q&A

AUSTRALASIAN BUILDING SIMULATION

AIRAH

International Building Performance Simulation Association Australasia

#BUILDSIM22