Enhancing our Weather and Climate Data Services for Facility Management

Presenter: David Ferrari

Managing Director
Exemplary Energy

exemplary ENERGY

IBTech@ARBS
INTELLIGENT BUILDINGS TECHNOLOGY

Learning outcomes

- The session will equip attendees with an understanding and knowledge of:
  - real-time and extreme weather & climate data;
  - the use of real-time weather data in weather/energy indices;
  - applying this to facilities management;
  - opportunities to use simulation as a tool for energy management and optimisation of building operations;
  - potential use of extreme climate data to evaluate risks relating to extreme climatalogical events; and
  - opportunities to incorporate precipitation data into moisture modelling.

Outline

- Introduction to weather and climate data for design resilience and facility management
- Background: Sourcing timely data
- Part I: Benchmarking real-time building and solar PV performance
- Part II: Characterising extreme climatic conditions
- Part III: Precipitation data for modelling moisture

Background: Weather and Climate Data Tools for Design Resilience and Facility Management

- Historical weather and the Australian Climate Data Bank (ACDB)
- Reference Meteorological Years (RMY)
- Typical Meteorological Years (TMY)
- Real-time (Meteorological) Years (RTY)
- The Exemplary Weather and Energy (EWE) Index
- eXtreme Meteorological Years (XMY)
- Ersatz Future Meteorological Years (EFMY)

Background: Weather and Climate Data Tools for Design Resilience and Facility Management

- Data sets include weather elements such as solar (GHI, DNI, DIF), Humidity, Wind Speed and Direction, Cloud Cover, Temperature and Pressure
- These can be provided in Typical Meteorological Year (TMY), Energy Plus Weather (EPW), and Australian Climate Data Bank (ACDB) formats for more than 200 locations.

Background: Applications of Weather and Climate Data

- New build: Demonstrating compliance with design regulations e.g. NCC Section J (RMY or TMY)
- Commissioning (RTY + model calibration)
- Energy retrofits: Measurement and verification (RTY)
- Performance benchmarking and monitoring (RTY and EWEI)
- Risk assessments to understand performance under extreme conditions (XMY) and future climate (EFMY)

Weather and Climate Data Services: challenges and opportunities

- Timely sourcing and dissemination of weather data
- Validating benchmark (archetype) models
- Meaningful and timely updates to RMY or TMY data
- Defining “extremes” in the XMY
- Sourcing other elements (e.g. precipitation)

Recent Developments:
A New Real-Time Solar Radiation Data Source

- Following the suspension of the dissemination of satellite solar data from BOM in August 2019, timely data was made available to us for Brisbane, Canberra, Perth, and Sydney by arrangements with QUT, CSIRO, Murdoch University and the NSW Department of Planning and Environment.
- While BOM launched a New Solar Radiation Data package via its Real Time Data Service in August 2021, several alternatives are available from commercial providers.

Recent Developments:
A New Real-Time Solar Radiation Data Source

- Our provider hosts a global solar database which is produced using high-resolution (1-2km) imagery from a range of geostationary meteorological satellites.
- The gridded solar data is produced by their in-house radiation model which uses observations from the advanced imager onboard the Himawari-8 satellite.
- The resulting estimates are also bias-corrected against a network of terrestrial stations.

Recent Developments: Incorporation into modelling datasets

- We combine these solar observations with terrestrial observations of other weather elements (dry-bulb, humidity, windspeed, air pressure, …) from the BOM's real-time service to produce our Real-Time Year (RTY) data product
- Disseminate in Typical Metrological Year (TMY2/3), Energy Plus Weather (EPW), and Australian Climate Data Bank (ACDB) formats

Weather and Climate Data Services: Format differences create challenges

Most simulation software uses hourly data , but different timestamp conventions require half-hourly data to fulfil both.

The Australian Climate Data Bank (ACDB) format:

- Solar irradiation data convention of the hour centred on the time stamp;
- No explicit cells for precipitation values, but spare cells at the end of each hour row.

The Energy Plus Weather (EPW) format:

- In wide use worldwide including the EnergyPlus open-source software;
- Incorporates cells for solar and precipitation data for the hour leading up to the time stamp.

Recent Weather Data

- Also known as Real Time Year (RTY) file, is a collection of historical real-time weather data acquired from the Bureau of Meteorology (BOM) or other sources.
- This data set includes weather elements like GHI, DNI, DIF, Humidity, Wind Speed, and Direction, Cloud Cover, Temperature and Pressure.
- We have the capability to provide this data set in Typical Metrological Year (TMY), Energy Plus Weather (EPW), and Australian Climate Data Bank (ACDB) formats for more than 200 locations.

Applications of the RTY

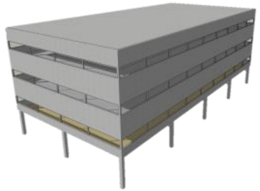
- Model calibration
- Measuring actual output or consumption in the previous 12 months or month relative to RMYs
- Building or energy system monitoring which helps to identify underperformance and take early restorative actions
- Renewable energy generator monitoring
- The Exemplary and Weather Energy (EWE) Index

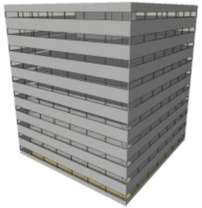
Exemplary Weather and Energy (EWE) Index

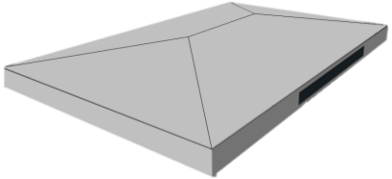
- A monthly free public service provided to understand how the RTY weather compares with the long-term average (RMY) and, for energy simulations, also with the medium-term future (EFMY-2050) climates
- Published through the "Exemplary Advances" e-newsletter since November 2014 and on our blog since October 2021.
  See exemplaryenergy.wordpress.com
- This service benchmarks three archetype commercial buildings (3-Storey, 10-Storey and Supermarket) and a 5kW solar PV system against RMY conditions

EWE Index: Building and PV Performance

- The building performance is compared for 3-storey office building, 10-storey office building and a ground-level supermarket.
- The building services (primarily cooling and heating) energy consumptions are compared by simulating the building models in EnergyPlus.
- EnergyPlus is a software developed by the US Department of Energy (DOE) and the US National Renewable Energy Laboratories (NREL).





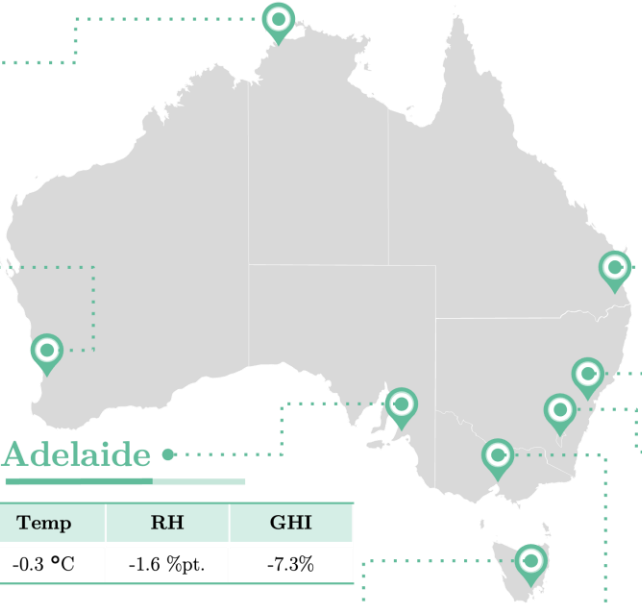


EWE Index: Building and PV Performance

- Current PV owners can monitor their system performance against our benchmark to identify underperformance and take early corrective actions.
- Prospective PV owners can get an idea of how much energy production they can expect. This can help them in making a better-informed decision.
- Similarly, Green Star, SmartScore, NatHERS and NABERS rated building owners can also compare their heating and cooling energy utilisations against our simulated benchmarks and conduct corrective actions if their building is underperforming.

EWE Index: Results

Weather index– monthly means



Darwin

Temp	RH	GHI
-1.7 °C	+0.6 %pt.	-2 %

Perth

Temp	RH	GHI
+1.3 °C	-1.9 %pt.	-10 %

Adelaide

Temp	RH	GHI
-0.3 °C	-1.6 %pt.	-7.3%

Hobart

Temp	RH	GHI
-0.5 °C	+7.7 %pt	+1.9 %

Brisbane

Temp	RH	GHI
—	+5.4 %pt.	-17.5 %

Sydney

Temp	RH	GHI
—	+13 %pt.	-21 %

Canberra

Temp	RH	GHI
+0.5 °C	—	-0.8 %

Melbourne

Temp	RH	GHI
-1.3 °C	+8.1 %pt.	-2.9 %

EWE Index: Results

Weather Index (monthly means)

Temperature (°C)		
Min	Avg	Max
-1.3	+0.6	+2.2

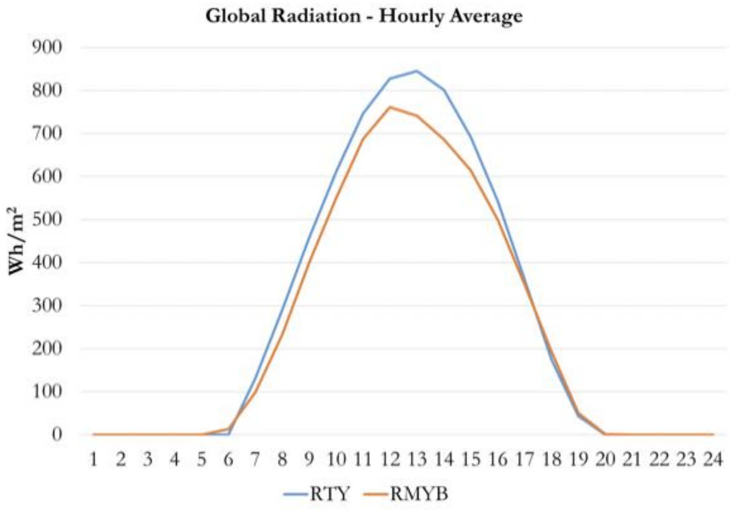
Relative Humidity (%pt)		
Min	Avg	Max
-7	-0.5	-6

Energy Index (%)

10-Storey		3-Storey		Supermarket	
Heat	Cool	Heat	Cool	Heat	Cool
-	+6	-	+2	-	+1

Solar PV
-24 %

EWE Index: Results



Weather Index (monthly means)

Temperature (°C)

Min	Avg	Max
+0.6	-0.2	-0.5

Relative Humidity (%pt)

Min	Avg	Max
+7	-1	-3

In Canberra, temperatures and humidity were mostly comparable to the long term average in February, with slightly higher minimum values. The solar insolation was slightly higher throughout the day, which caused the solar PV simulation output results to be 3.3 % higher.

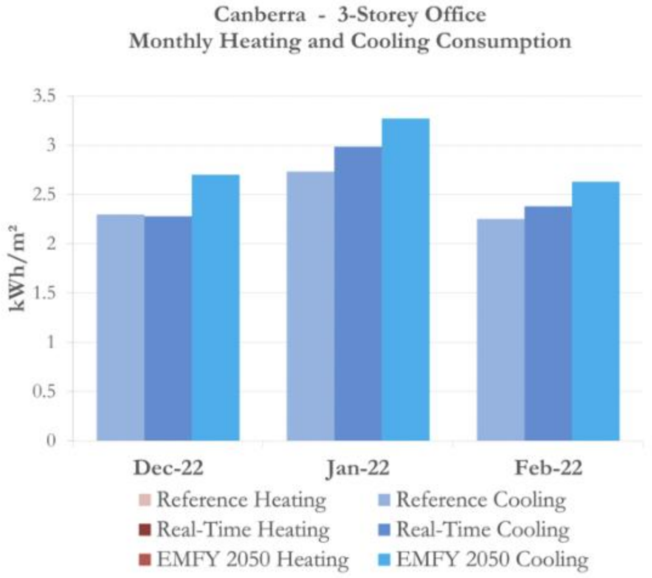
EWE Index: Results

Energy Index (%)

10-Storey		3-Storey		Supermarket	
Heat	Cool	Heat	Cool	Heat	Cool
-	+5	-	+6	-	-11

Solar PV
+8.9 %

All the building archetypes had higher cooling requirements compared to the long term average. The west-facing and north-facing zones of the 10-storey building had 15 % higher cooling consumption, while for the east-facing and south-facing zones the cooling consumption was, respectively, 14 % and 7.5 % higher.



EWE Index: Future developments

- Modelling other non-residential building archetypes, extending the analysis to the whole range used in the ABCB regulatory impact statement.
- Enhancing the presentation of results, including a database of historic results, to offer the possibility to look at a wide range of historic data for all 8 capital cities.

Part II: Characterising "Extreme" Climate as eXtreme Meteorological Years (XMY)

IBTech@ARBS
INTELLIGENT BUILDINGS TECHNOLOGY

XMY: eXtreme Meteorological Year

- Hypothetical data set representing an extreme year of weather, i.e. representing conditions that produce extremely high or low energy consumption/generation across the entire year

Uses of XMY – in design and financial applications like:

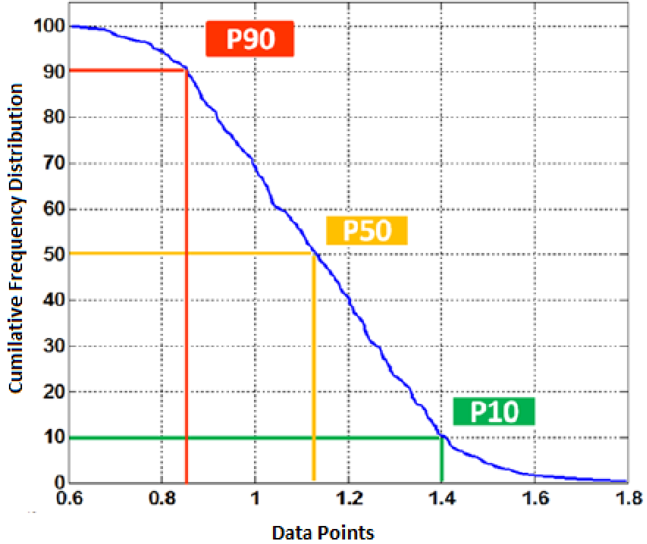
- Understanding building energy performance in extreme year
- Best Year Data – to calculate USE (unserved energy)
- Worst Year Data – to manage risk of variability of renewable sources by determining factors like DSCR (Debt Service Coverage Ratio)

Previous work: defining XMY for fixed flat-plate solar PV

- From literature survey, most XMY data were defined based on dry bulb temperature and solar irradiation.

Probabilistic Approach

- P01, P10, P90 & P99 data in statistics: a value expected to exceed 1%, 10%, 90% and 99% of cases in a given temporal sample respectively
- Can be done using Monte Carlo simulation[1]



[1]Dobos, A. P., Gilman, P., & Kasberg, M. (2012). P50/P90 analysis for solar energy systems using the system advisor model. National Renewable Energy Lab. (NREL), Golden, CO (United States)

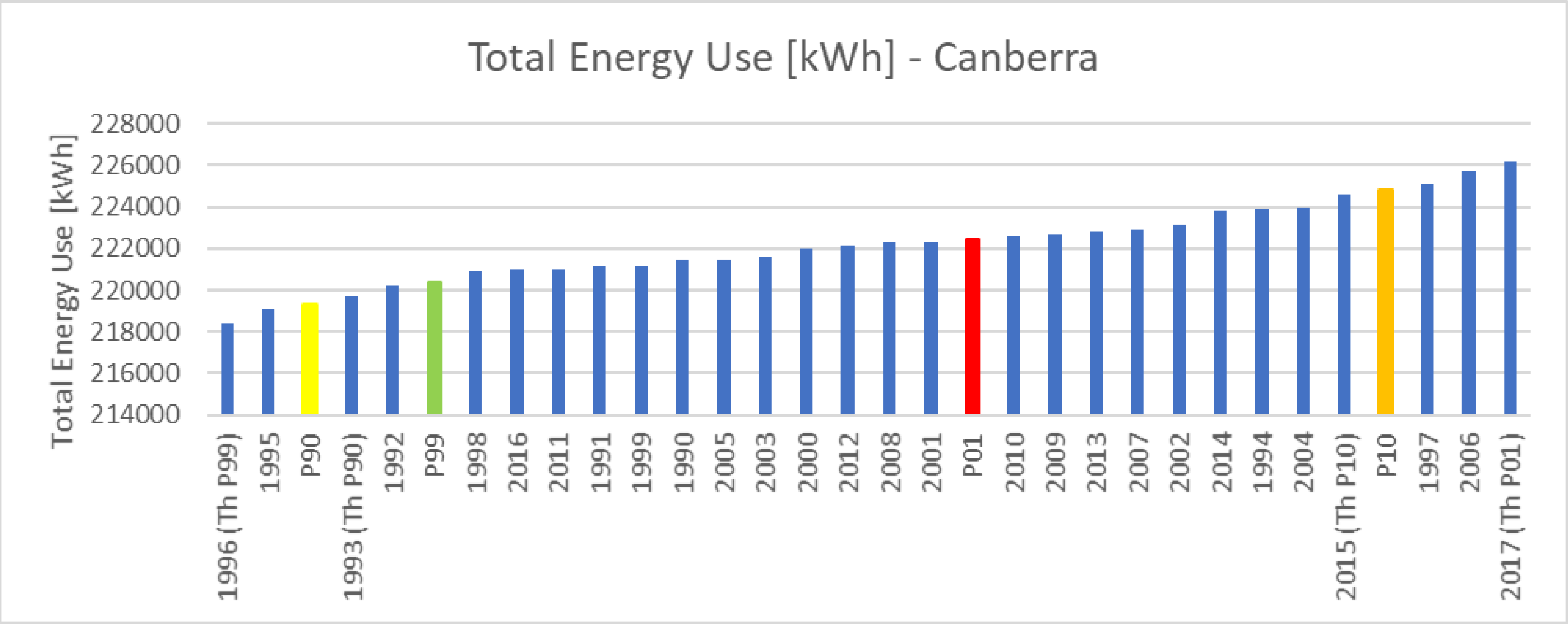
Previous work: defining XMY for fixed flat-plate solar PV

- **System Advisor Model (SAM)** – free, readily available NREL software
- **ClimateCypher** - Exemplary Energy's in-house software package
- **EnergyPlus** - open-source building energy performance simulation software developed by the US Department of Energy
- Generated P01, P10, P90 and P99 weather files in ClimateCypher by concatenating the most appropriate 12 historic calendar months such that synthesised year closely matches the 1st, 10th, 90th and 99th percentile criteria respectively for a PV system output.
- Conducted for all eight Australian Climate Zones in the National Construction Code, and results were presented at the APSRC 2020 and 2021.

New developments: defining XMY HVAC

- Extremes are important for building energy simulations
- Analysed the validity of applying the existing XMY_{PV} data to building HVAC
- The total building energy consumption was computed for Brisbane and Canberra for each year from 1990-2017 for the 3-storey building archetype
- Total and end-use component energy consumptions corresponding to hypothetical P01, P10, P90 and P99 weather data from ClimateCypher were also computed
- As expected, results of this analysis show that the extreme weather data defined in this way proves to be incapable of correctly representing the extremities of energy consumption or demand of a building

Applying XMY_{PV} to HVAC

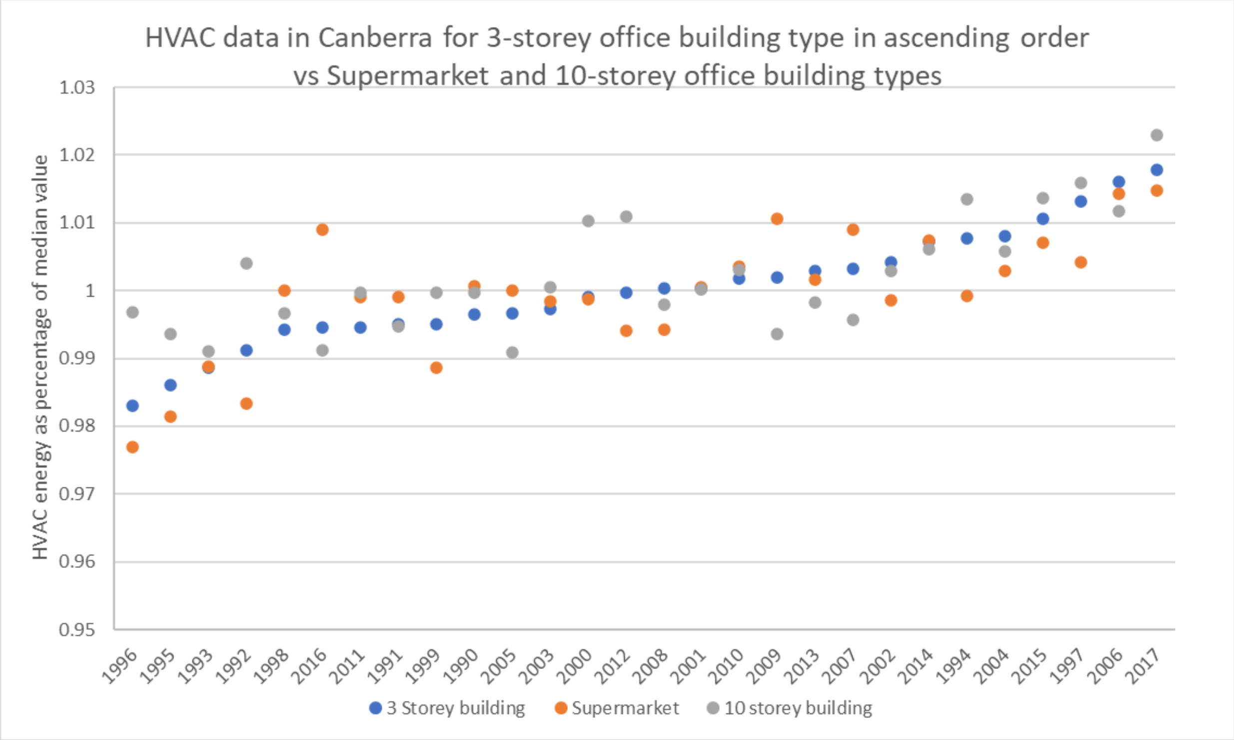


IBTech@ARBS
INTELLIGENT BUILDINGS TECHNOLOGY

Recent work: towards XMY (HVAC)

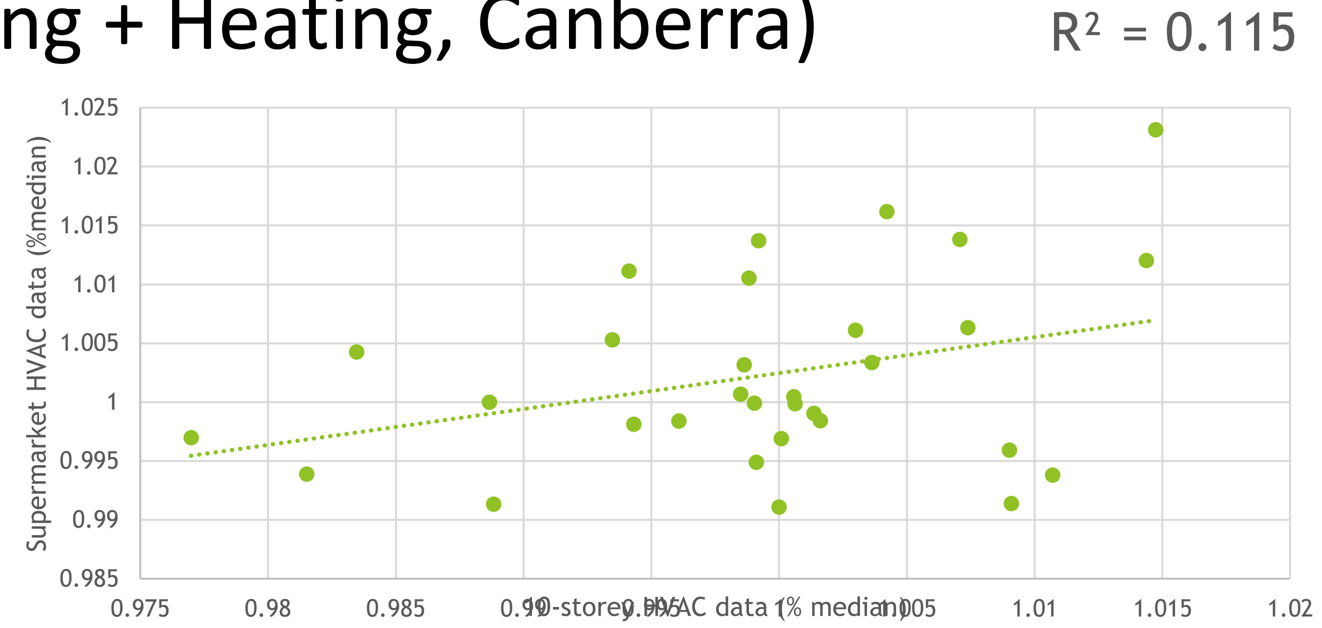
- New technique: run historical yearly weather data through EnergyPlus to generate heating and cooling energy data for our three archetype buildings - Supermarket, 3-storey and 10-storey office buildings
- We assessed whether the “extreme” year for one building type is valid for all commercial building types
- Confirmed correlation between building types
- Descriptive statistics (max, min, mean, standard deviation, z-scores)
- Early work found that results fit a rough Gaussian distribution (bell curve) and therefore standard statistical techniques can be applied to the analysis

Correlation of HVAC energy use between building types



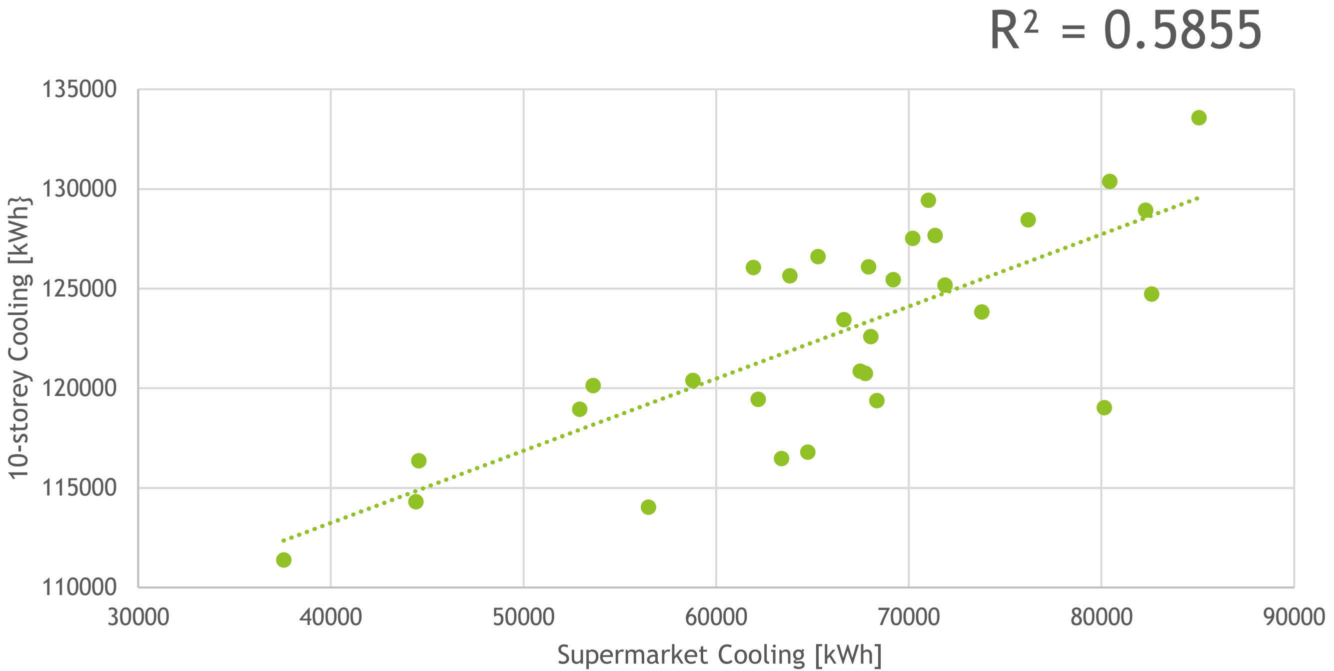
Defining “extremes” in the XMY

- Supermarket vs 10-storey: Annual Total HVAC (Cooling + Heating, Canberra)



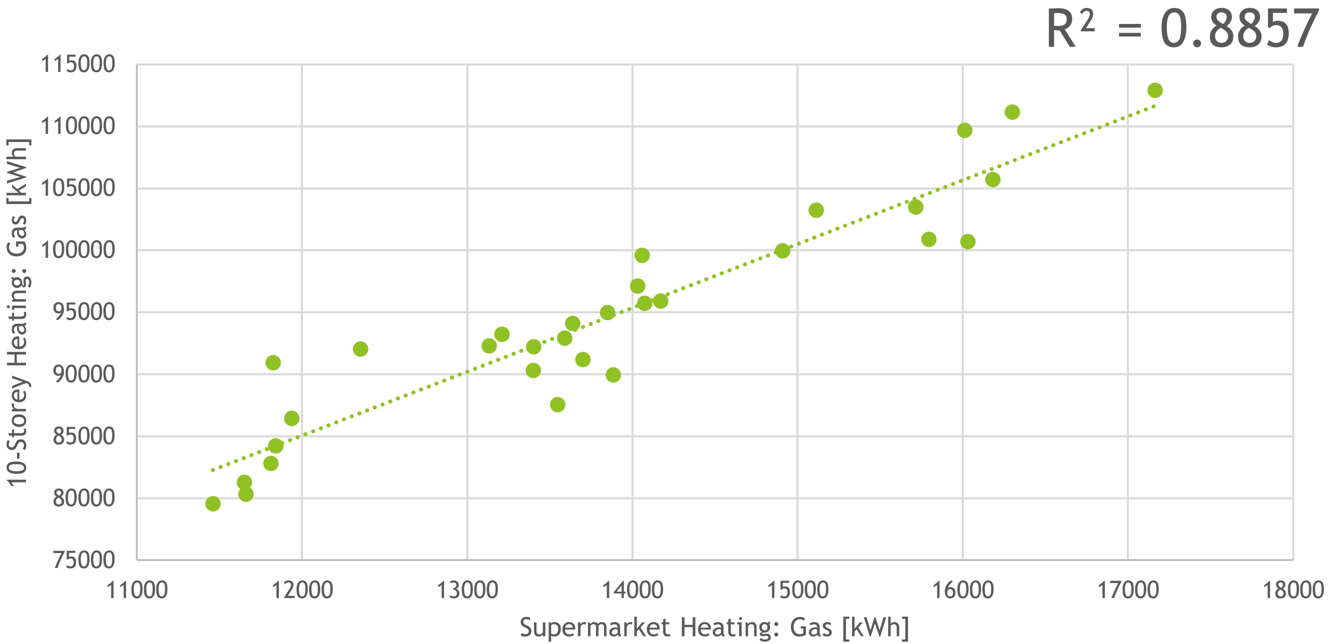
Defining “extremes” in the XMY

- Supermarket vs 10-storey: Annual Cooling (CBR)



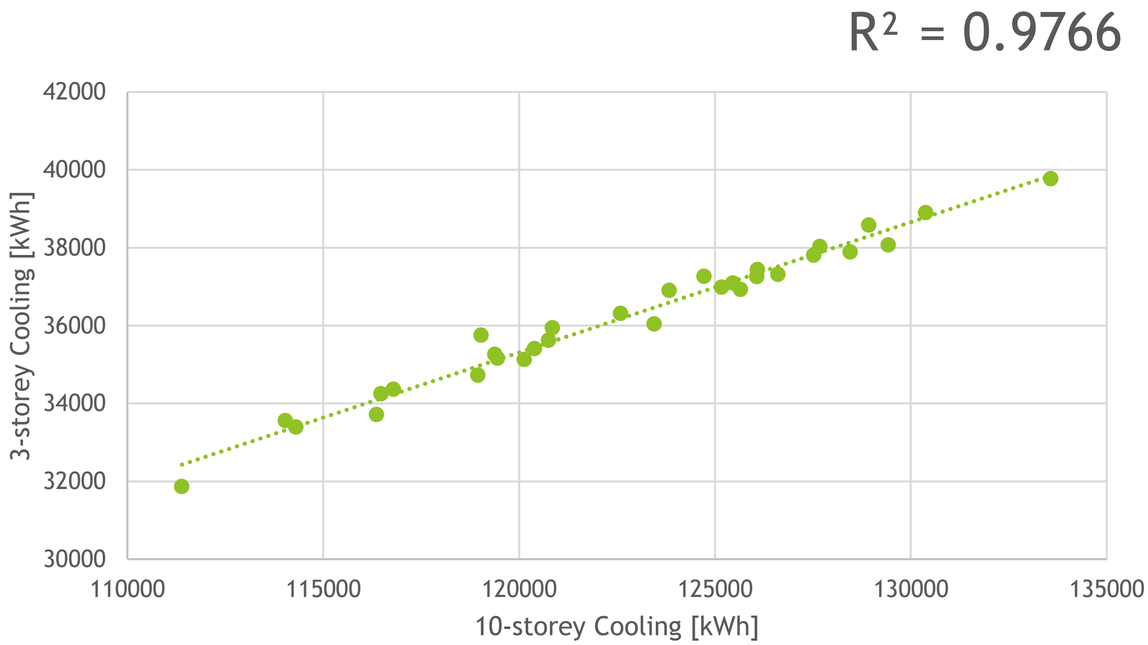
Defining “extremes” in the XMY

- Supermarket vs 10-storey: Annual Heating (CBR)

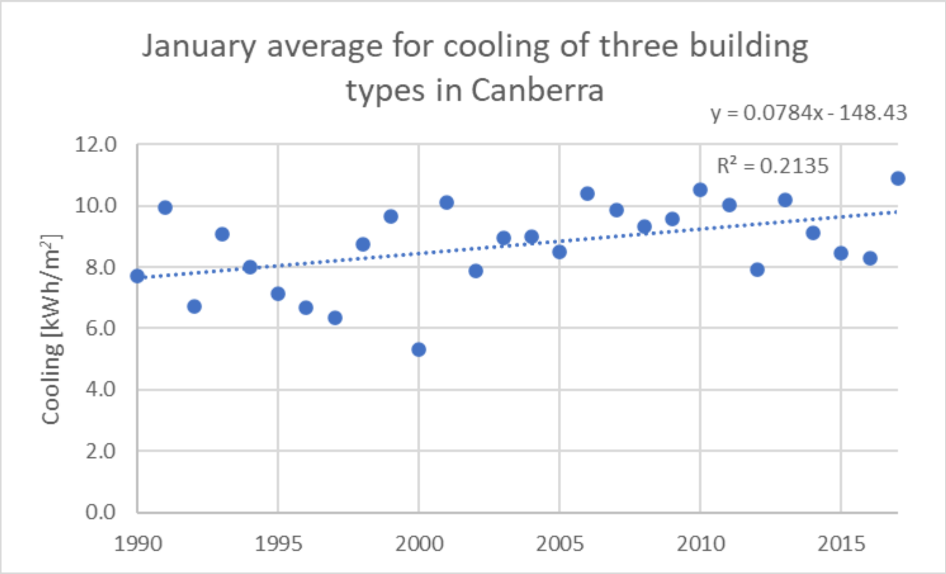


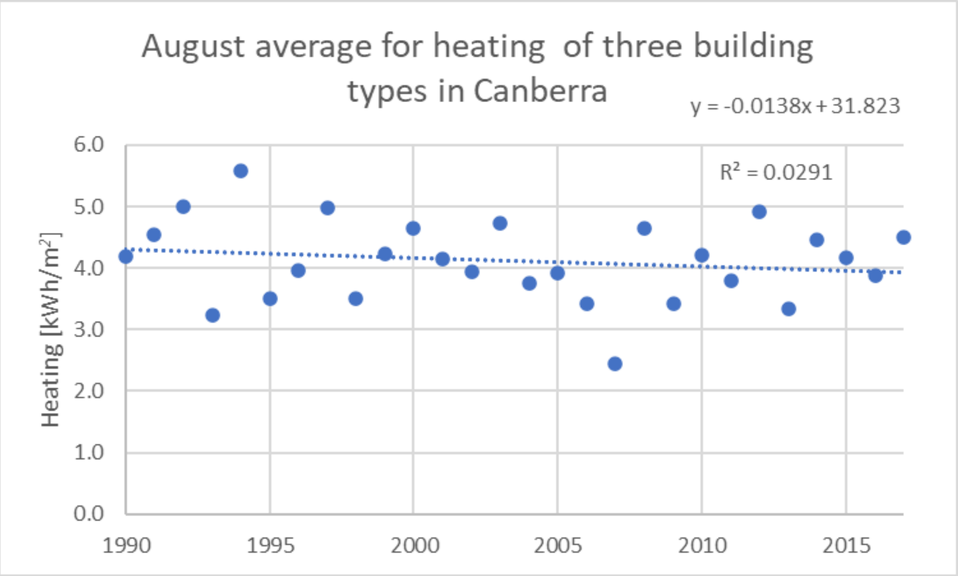
Defining "extremes" in the XMY

- 3-storey vs 10-storey: Annual Cooling (CBR)

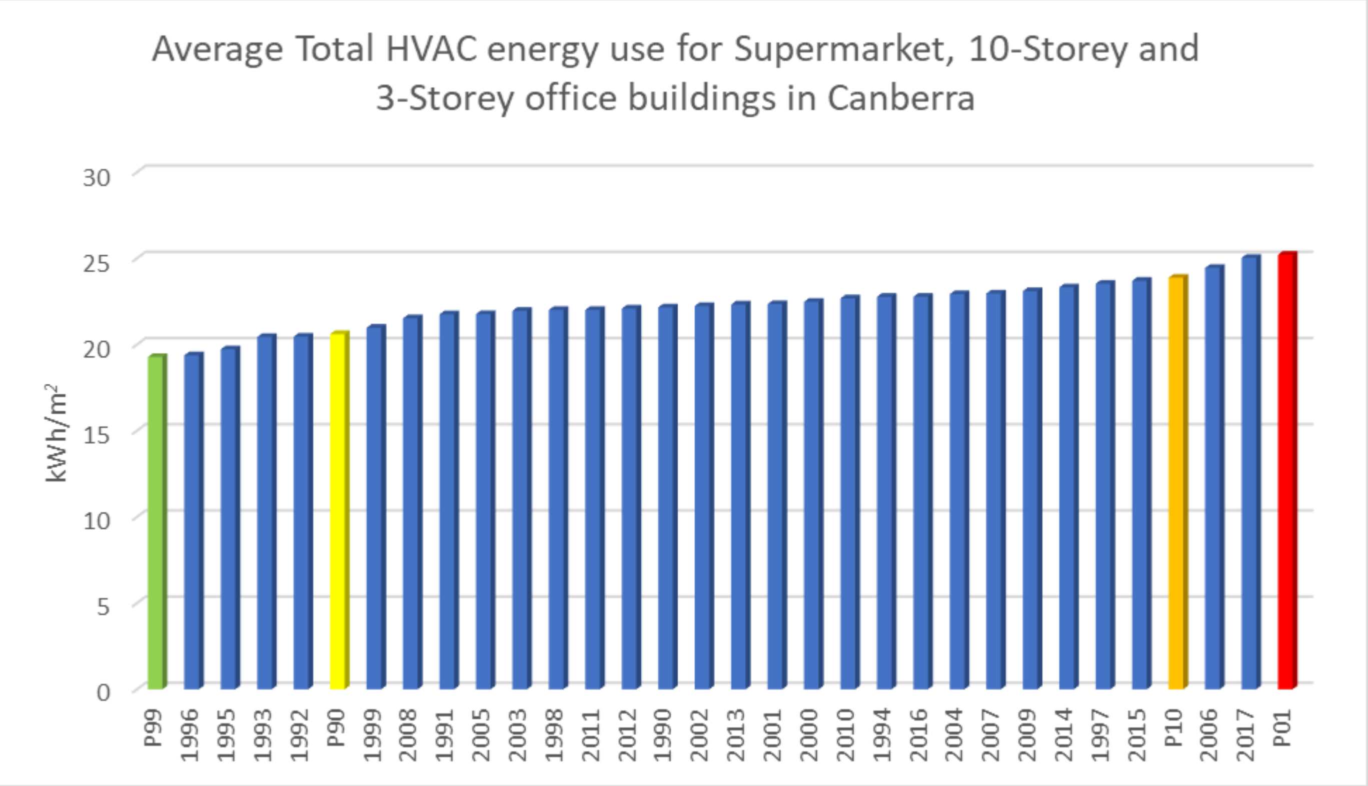


Trends over time





Results: P-values



Closest historical data to calculated P-values of:

- P99 is 0.988 (1996)
- P90 is 0.919 (1992)
- P10 is 0.127 (2015)
- P01 is 0.014 (2017)

Next Steps

- To develop a technique to concatenate a series of months to create an artificial year of 12 months representative of P1, P10, P90 and P99 years for simulation testing of the robustness of building designs
- Create XMY datasets for key locations in Australia
- Generalise the technique: Evaluate the multivariate statistical relationships between the various weather elements and the energy demand – to attempt a technique which bypasses the multi-year simulation when deriving the XMY and can this be applied to any location with ease

Part III: Precipitation data for modelling moisture

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.

A

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

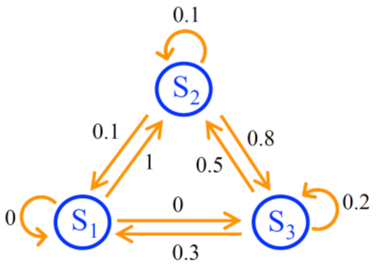
- A recent amendment introduced in 2019 details new provisions in the NCC that aims to minimize moisture impacts on building physics such as water ingress, condensation and mould formation, etc.
- Verification by simulation is permitted using accredited software such as WUFI®
- Climate files fitted to 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: high temporal resolution data

- Modelling software requires hourly (or higher) temporal resolution
- Until the early 2000's, most observations of precipitation were daily totals
- Proposed techniques for estimating half-hourly from daily totals:
  - Markov Chain using Transition Probability Matrix; and
  - Monte Carlo Markov Chain (MCMC) Model utilising simulating annealing

The need for Precipitation Data: high temporal resolution data

- 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.
- Probabilities are represented in a matrix 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

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

Correlation analysis and Case Studies

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

Analysis based on: Rain Days	Analysis based on: Onsets	Correlation Between	Value
	✓	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

Correlation analysis and Case Studies

Consider two signals P1 and P2 and assign the conditional probabilities to them:

$$\pi_1 = P(P1 \mid P = P1 or P2)$$

$$\pi_2 = P(P2 \mid P = P1 or P2)$$

Based on this algorithm, an acceptance ratio is defined for the two considered series P1 and P2, as follows:

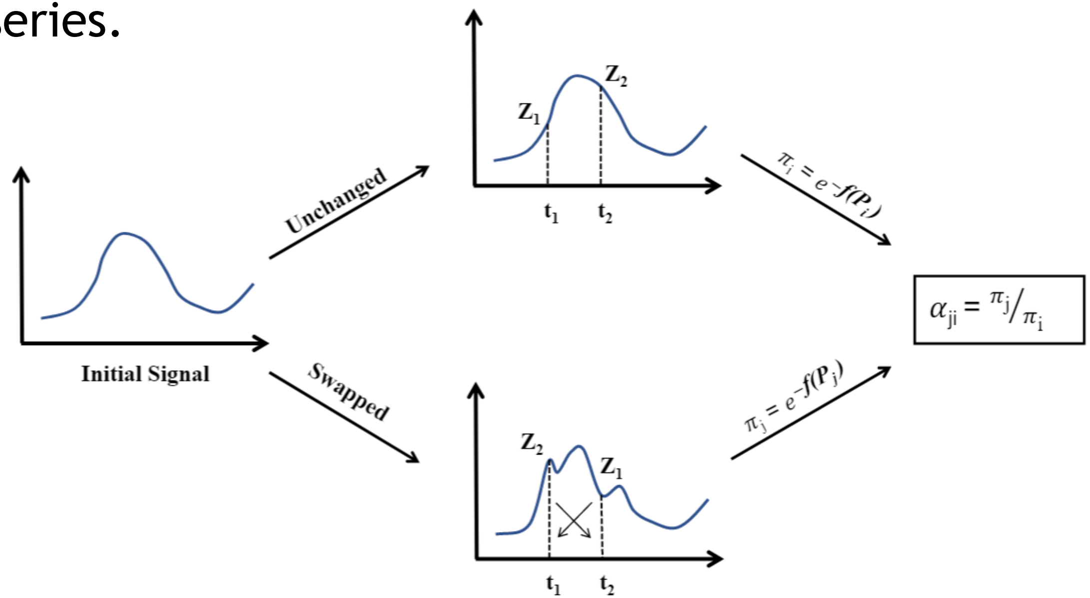
$$\alpha_{21} = \pi_2 / \pi_1$$

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

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

Simulated Annealing

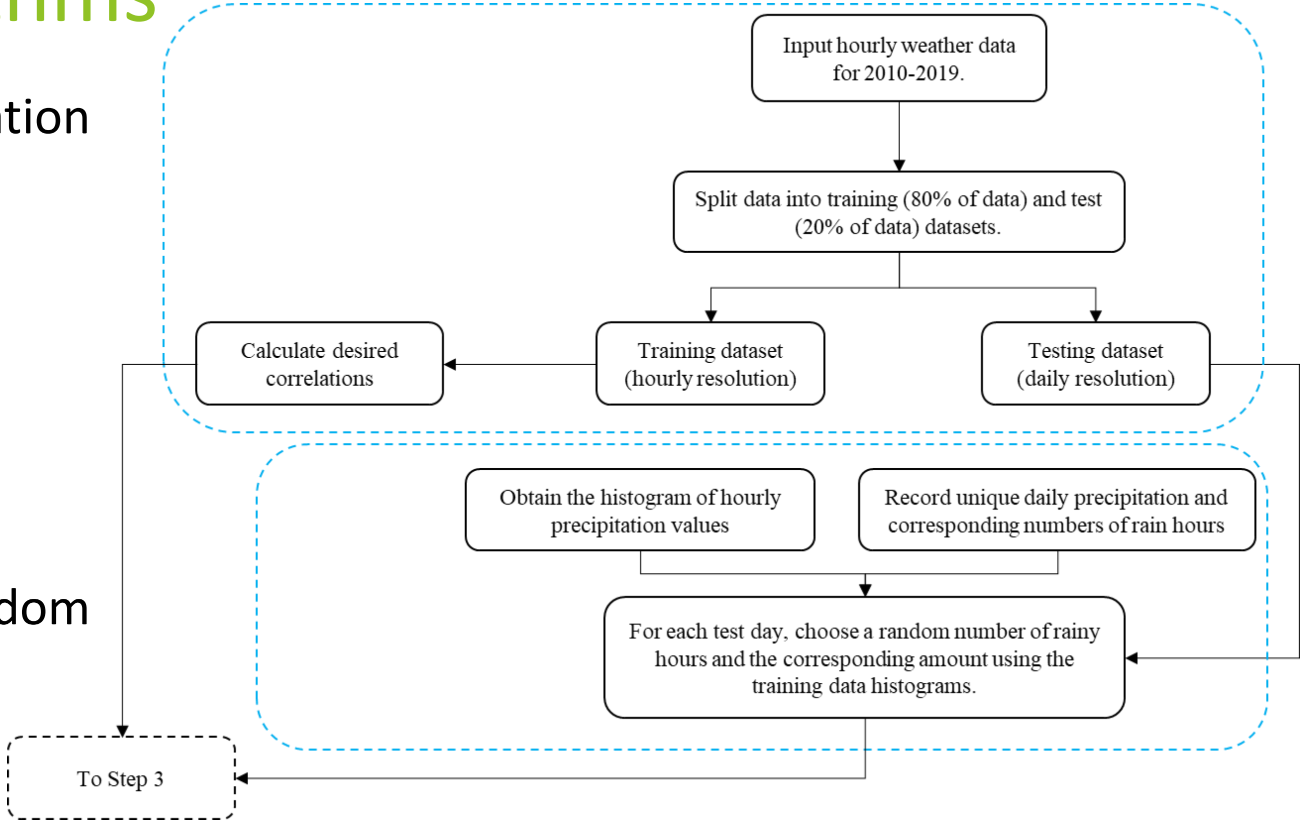
- We randomly choose d days and for each day, two times $t_1 \neq t_2$ are selected to swap their hourly rain values. This process is called resampling and generates a new time series.



Steps of Algorithms

1. Data Preparation Process

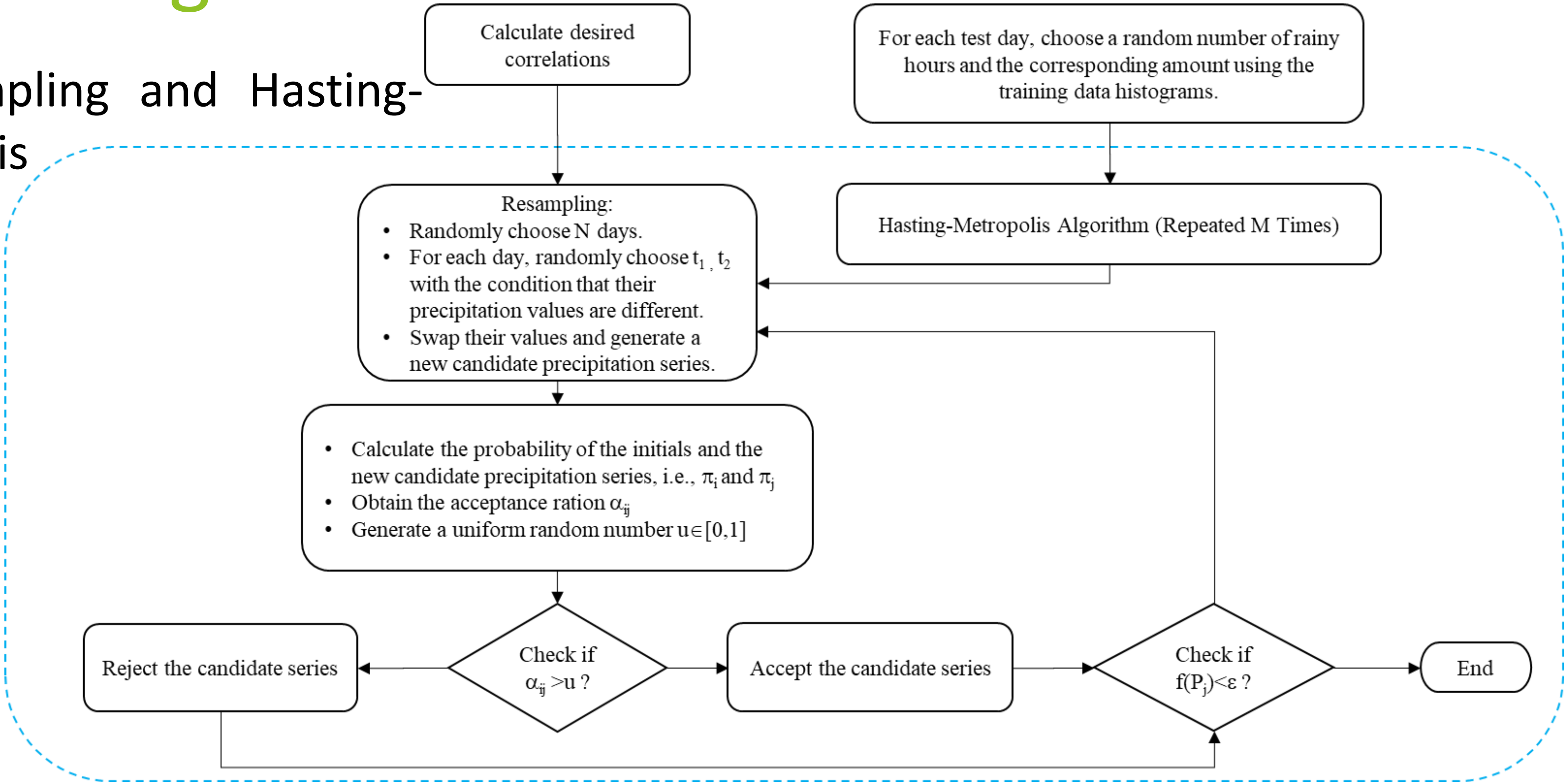
2. General Initial Random Precipitation Series



IBTech@ARBS
INTELLIGENT BUILDINGS TECHNOLOGY

Steps of Algorithms

3. Resampling and Hasting-Metropolis

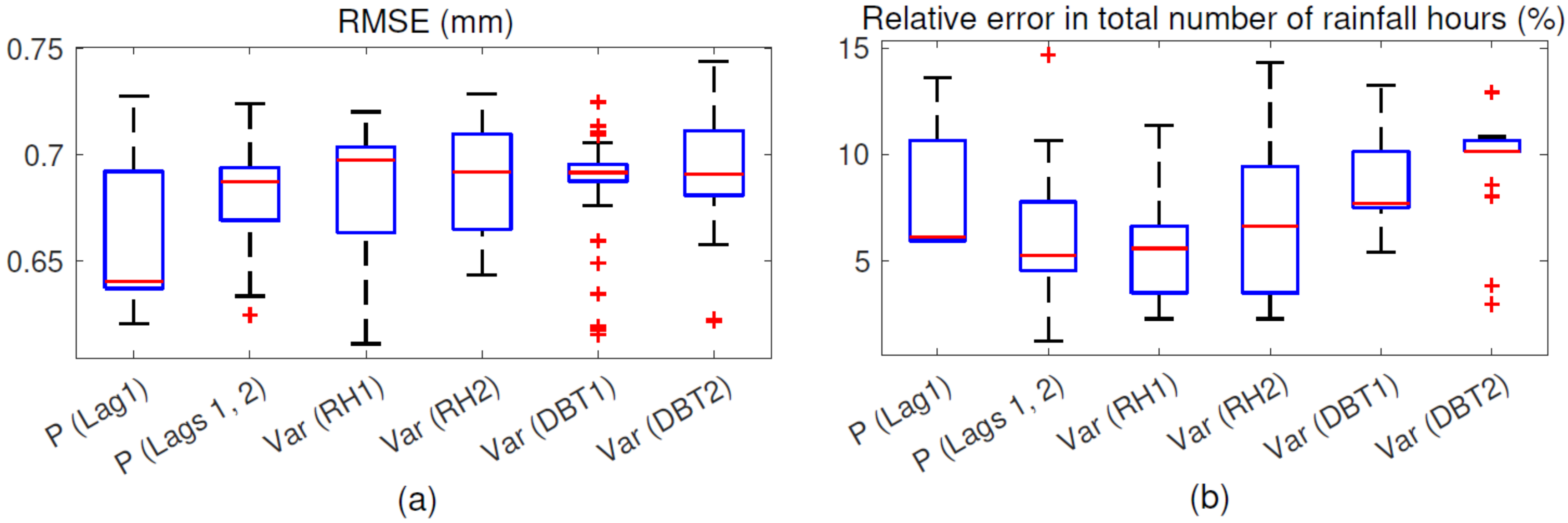


Results

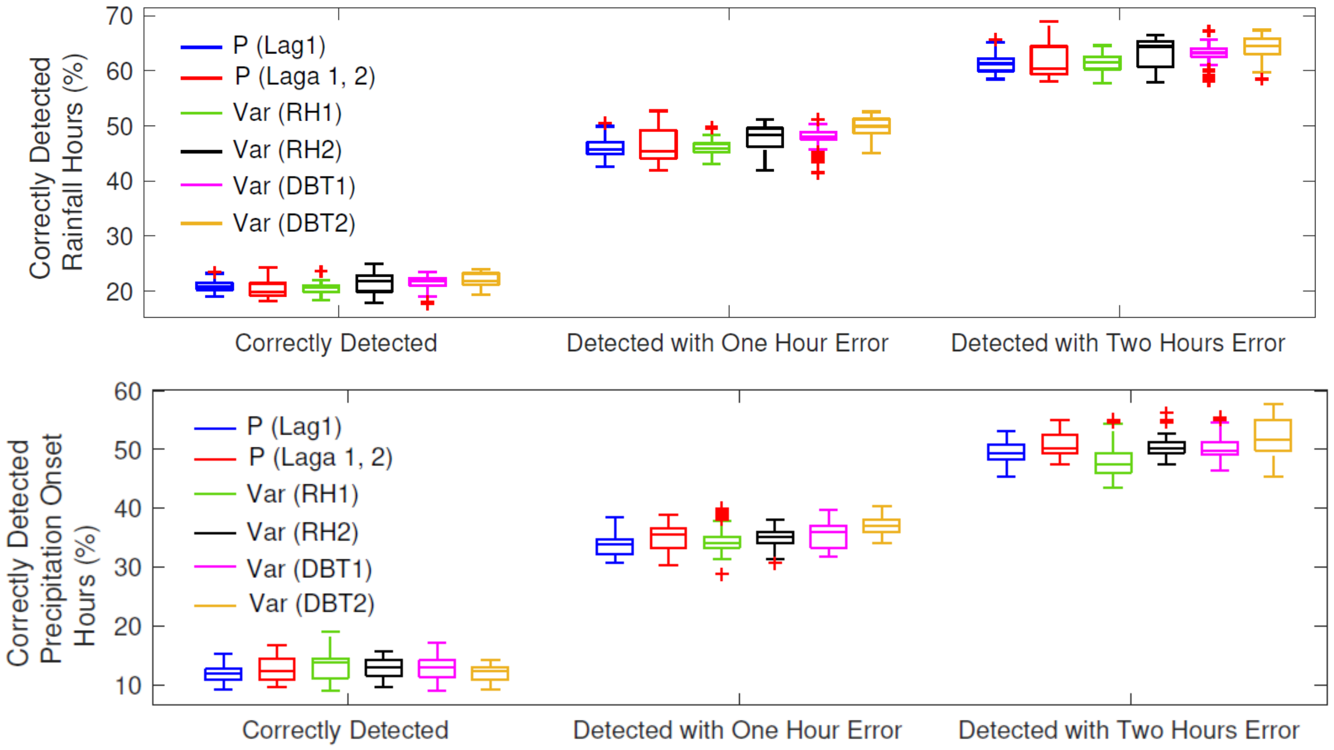
We performed the following six different experiments.

1. P (Lag1): considering only Lag 1 of the precipitation and
2. P (Lags 1, 2): considering Lag 1 and Lag 2 of the precipitation,
3. Var (RH1): considering variance of relative humidity during the past hour,
4. Var (RH2): considering variance of relative humidity during the past two hours,
5. Var (DBT1): considering variance of dew point temperature during the past hour, and
6. Var (DBT2): considering variance of dew point temperature during the past two hours.

Results


RMSE (mm)
0.75
0.7
0.65
P (Lag1)
P (Lags 1, 2)
Var (RH1)
Var (RH2)
Var (DBT1)
Var (DBT2)
(a)
Relative error in total number of rainfall hours (%)
15
10
5
P (Lag1)
P (Lags 1, 2)
Var (RH1)
Var (RH2)
Var (DBT1)
Var (DBT2)
(b)

Results



Correctly Detected Rainfall Hours (%)
70
60
50
40
30
20
P (Lag1)
P (Laga 1, 2)
Var (RH1)
Var (RH2)
Var (DBT1)
Var (DBT2)
Correctly Detected
Detected with One Hour Error
Detected with Two Hours Error
Correctly Detected Precipitation Onset Hours (%)
60
50
40
30
20
10
P (Lag1)
P (Laga 1, 2)
Var (RH1)
Var (RH2)
Var (DBT1)
Var (DBT2)
Correctly Detected
Detected with One Hour Error
Detected with Two Hours 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.

Conclusions

- 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).

Future Development

- 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	592.8mm	(BOM 1990-2015)
Rain days	161	Annual precip'n	494mm	(Meteonorm)

Thank you!

- Summary of the presentation:
  - Introduction to weather and climate data for design resilience and facility management
  - Challenges of sourcing of timely data
  - Part I: Benchmarking real-time building and solar PV performance
  - Part II: Characterising extreme climatic conditions
  - Part III: Precipitation data for modelling moisture

Thank you!
Let’s discuss…

Enhancing our Weather and Climate Data Service

Presenter: David Ferrari
Managing Director
Exemplary Energy

david.ferrari@exemplary.com.au

Enhancing our Weather and Climate Data Service

Presenter: David Ferrari
Managing Director
Exemplary Energy

david.ferrari@exemplary.com.au

exemplary ENERGY

IBTech@ARBS
INTELLIGENT BUILDINGS TECHNOLOGY