Extreme Climate Data Files for Design Resilience

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Energy consumption from buildings comprises 20-40% of the total final energy demand in developed countries (Pérez-Lombard et al. 2008). Therefore, to reduce building energy use and associated greenhouse gases, it is imperative to improve building energy efficiency. Heating, Ventilation and Air Conditioning (HVAC) systems are the largest contributor to building energy usage, accounting for 40-70% of the total energy consumption in commercial buildings (Ghenai and Salameh 2018). To improve energy efficiency in buildings while maintaining the required human comfort and health, building energy performance modelling is necessary to understand the optimal sizing and operation of HVAC systems.

While most simulation work focuses on evaluating building performance under ‘typical’ climatic conditions, there is a good potential to use simulations to develop insights into building energy performance under a range of likely future climatic conditions. These analyses would benefit greatly from a characterisation of ‘extreme’ climate as an input to the simulations.

Previous work has characterised extreme climate as it applies to solar PV (Hameed et al. 2020; Jain et al. 2021), and indicative extreme climate datasets are available for this application from a range of sources. However, our research shows that these extremes do not correlate well with extremes of building HVAC performance. In this paper, we present the development of an eXtreme Meteorological Year for building HVAC (XMY_{HVAC}). In a similar way that Reference Meteorological Year (RMY) represents the average (and historically expected) climate for a typical year, XMY_{HVAC} represents conditions that produce an extremely high or low building energy consumption across an entire year, and can be generated for any agreed degree of likelihood or ‘extremity’ (Lee et al. 2022).

Historical weather data from 1990 to 2017[1] for Canberra (NCC CZ7) and Brisbane (NCC CZ2) were run through a series of EnergyPlus simulations to calculate heating and cooling energy data for the three archetype NCC compliant buildings: Supermarket, 3-storey and 10-storey office buildings. Analysis of the energy data was conducted – for heating and cooling separately and combined, for individual building types and as a collective of buildings, over yearly and monthly time periods – to assess whether the “extreme” year for one building type is valid for all commercial building types. Results show a clear trend over time of increasing average cooling load and decreasing heating, which are indicative of a warming climate (Figure 1). Over 30 years, there is an observed increase of more than 20% in the cooling load demand for the same building types, and it is imperative to incorporate the likely future increase in cooling loads due to climate change impact into building energy simulations. The analysis also shows a reasonable correlation between the three building types (Figure 2 and Figure 3).

[1] The latest available at the time of writing. The final presentation is expected to be based on 1990-2021 data.

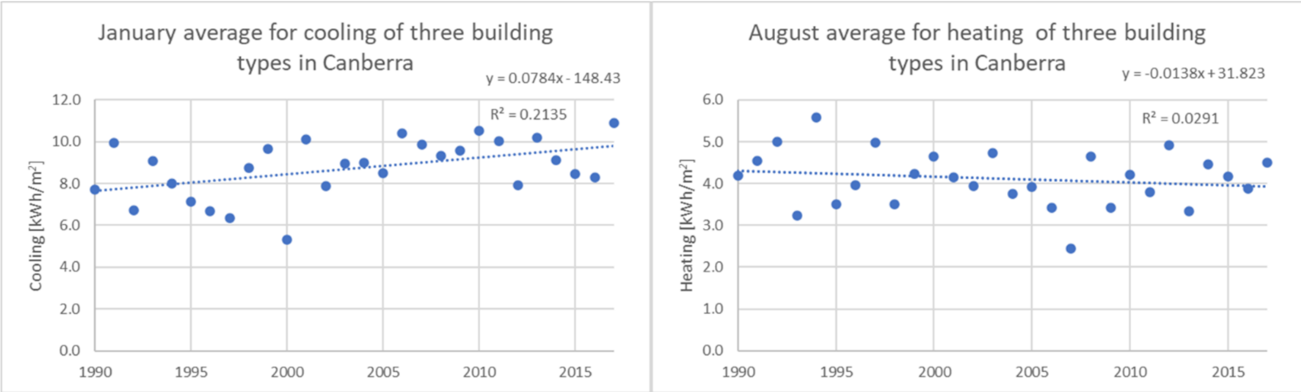

Figure 1. The trends of cooling and heating loads from 1990-2017 in Canberra show increasing cooling and decreasing heating, indicating a warming climate

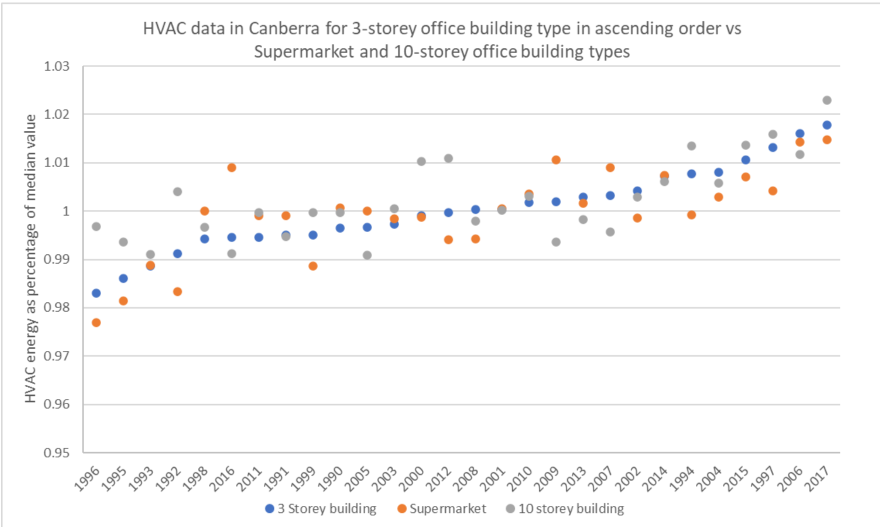

Figure 2. Correlation of HVAC energy use between the three building archetypes in Canberra from 1990 to 2017

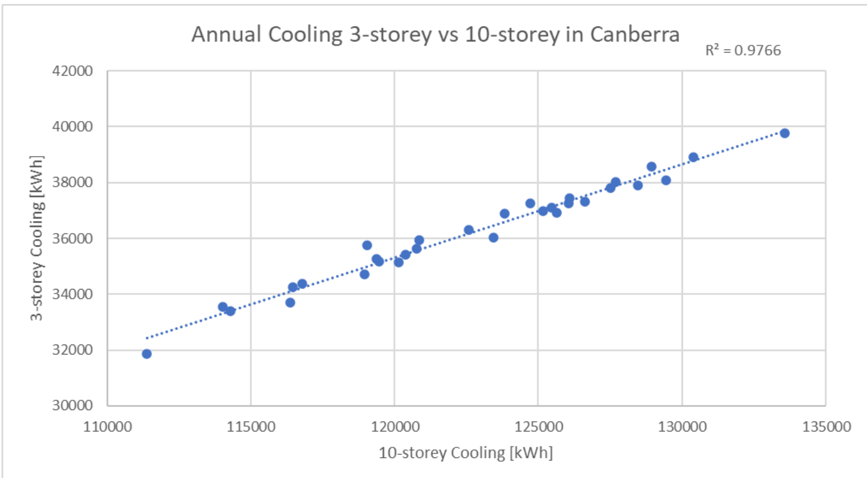

Figure 3. Pairwise comparison of the annual cooling energy use between the 3-storey and 10-storey office buildings in Canberra from 1990 to 2017

The results fit a rough Gaussian distribution (bell curve, Figure 4), indicating that standard statistical techniques can be applied to the analysis. When performing statistical analyses, probability values (P-values) provide an insight into the statistical likelihood of a dataset or event. In our study, P-values of annual HVAC energy consumption were calculated by applying each calendar year of historical weather to estimate the average energy consumption across the three building archetypes in Canberra and Brisbane, then calculating the mean and standard deviation of the result. Using the empirical rule, 68% are expected to fall within one standard deviation of the mean, 95% within two standard deviations of the mean and 99.7% within three standard deviations of the mean. The P01, P10, P90 and P99 data are those years that would result in energy consumption that is expected to exceed 1%, 10%, 90% and 99% of the cases (respectively) in a temporal sample, so a year in which energy use exceeds the P01 value can be described as a "1 in 100 year event" and so on.[2]

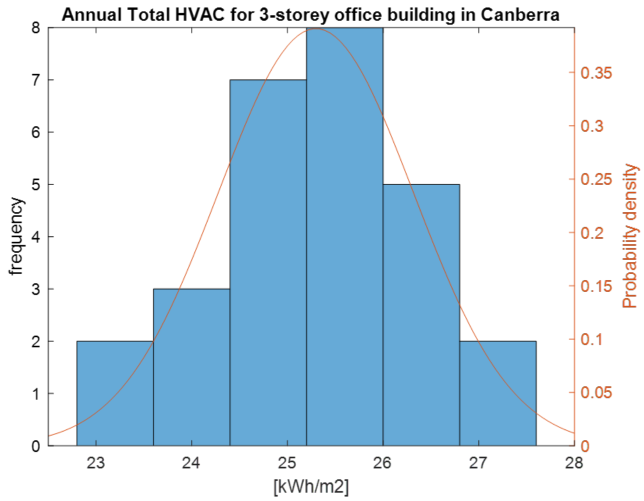

Figure 4: The annual total HVAC data for 3-storey office building in Canberra from 1990 to 2017 roughly fitting a Gaussian distribution (bell curve)

In Figure 5 we have plotted the ranked annual energy use (averaged across the three archetypes) from lowest to highest and inserted P-values that arise from this distribution (green, yellow, orange and red bars).

One option for creating a representative P-value climate data set is to take the historical year that most closely matches the target. For example, the P90 year results in slightly more than 20 kWh/m^2 (averaged across the three archetypes); the closest historical year is 1992, which resulted in marginally less consumption than the P90 target. In fact, for this distribution, the probability of exceeding the energy consumption of 1992 is 91.9 per cent. The closest historical data to the targeted P-values are listed below:

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

[2] For consistency, we have respected the statistical sense of the XMY_{PV} production of P01 being the high energy end of the weather spectrum (Hameed et al. 2020; Jain et al. 2021). However, because XMY_{PV} deals with energy production while the proposed XMY_{HVAC} deals with energy consumption, the PV P01 is extremely benign while the HVAC P01 is extremely challenging. The authors seek peer critique or concurrence of this proposed convention.

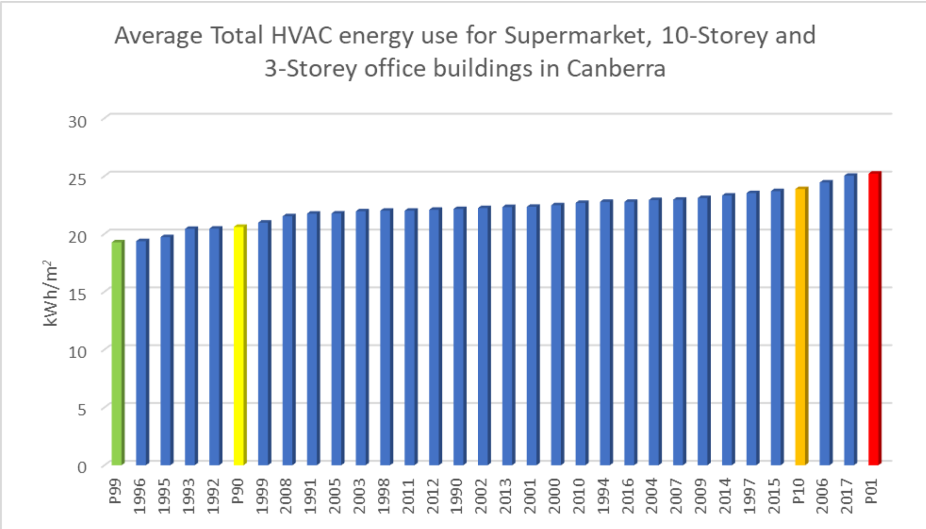

Figure 5. The average annual energy use across the three building archetypes from 1990 to 2017 in ascending order, with the targeted P01, P10, P90 and P99 values in coloured bars

The next step in this development will be to devise a technique to concatenate a series of months to create an artificial year of 12 months which more closely results in the target consumption at the P1, P10, P90 and P99 levels. In the process, we will remain alert for lessons indicating how best to synthesize years which may allow simulators to evaluate high heating months/seasons with high cooling months/seasons in the same 12 month simulation.

We also intend to investigate further the multivariate relationships between various metrics applied to the weather elements (e.g. average dry bulb temperature, average daily maximum dry bulb, average daily global solar radiation etc.) to establish relationships that can be used to determine an XMY_{HVAC} dataset without requiring the brute-force approach of applying each historical year to the set of archetype models. The XMY_{HVAC} weather files are expected to be available in early 2023.

XMY_{HVAC} data sets are important for building energy simulations and it can help us gain understanding on how a building performs in an "extreme" year or a year of extreme seasons. This work will serve to provide modellers and project proponents with insights into the probability of high (or low) energy costs for the forward lifetime of the building, and provide opportunities for optimisation to improve the resilience of the building system to extreme climate.

References

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