Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Elsevier hereby grants permission to make all its COVID-19-related research that is available on the COVID-19 resource centre - including this research content - immediately available in PubMed Central and other publicly funded repositories, such as the WHO COVID database with rights for unrestricted research re-use and analyses in any form or by any means with acknowledgement of the original source. These permissions are granted for free by Elsevier for as long as the COVID-19 resource centre remains active.
Has COVID-19 lockdown impacted on aged care energy use and demand?

Aaron Liu *, Wendy Miller, Glenn Crompton, Sherif Zedan

Queensland University of Technology (QUT), 2 George St, Brisbane QLD4000, Australia

ARTICLE INFO

Article history:
Received 26 September 2020
Revised 23 December 2020
Accepted 13 January 2021
Available online 26 January 2021

Keywords:
Care home
Data analysis
Electricity
Energy audit
Energy management
Distributed energy resource
Health
Investment planning
Key performance indicator
Peak demand
Renewable
Resilience
Tariff

ABSTRACT

In late March to April 2020 residential aged care facilities (RAC) in Australia were under COVID-19 lock- down. This paper explores whether the resultant restrictions on entry and exit and elimination of site group activities within RACs impacted on the total energy use, peak demand and electrical load profiles. Six RACs in four different climate zones are analysed, comparing historical electricity load and demand profiles with the lockdown period. The facilities in warm regions showed largest reductions in energy use and peak demands. There was a peak demand timing shift in temperate regions and hot regions’ changes were negligible for energy use or peak demands.

This study revealed the limitations of using aggregate data as the key performance indicator (KPI) – energy use per bed. Also, KPIs in relation to cooling degree days (or total cooling and heating degree days) have been examined and are not recommended for temperate regions or temperate seasons. The potential CO2 emission reduction from onsite renewable generation is quantified.

Further research is to investigate energy use changes at circuit levels under lockdowns, and develop more nuanced KPIs that include the rate of energy use and the timing of that use.

1. Introduction

Evidence is emerging that lockdowns associated with strategies to reduce the impact of COVID-19 have reduced network level energy use and power demand in Australia, US, Brazil and many European countries[1–3]. Residential energy use under COVID-19, however, may have increased [1,4].

Residential aged care communities (RAC) are care homes for elderly persons who require full time care due to age related health issues. These facilities are typically owned and operated either by not-for-profit organisations, charities, government authorities or private enterprise. RACs are somewhat unique ‘building typologies in that they combine some of the features of homes, businesses and healthcare facilities. In modern Australian RACs, these features can include: (i) residents’ private rooms with ensuites; (ii) shared spaces for all residents (e.g. a dining hall, activity rooms, library etc); (iii) clinical and personal care services provided by onsite nursing staff; (iv) a range of additional healthcare services (onsite treatment rooms with visiting practitioners; (v) administrative functions of the operating agent; (vi) site-wide commercial services (e.g. catering and laundry); and (vii) assorted retail operators (e.g. florist, hairdresser, café etc).

Countries with ageing populations and increased service demands for that demographic are seeing increased financial pressures on providing appropriate levels of care services. Reducing energy cost overheads, such as through energy efficiency and renewable energy, are potential ways in which thermal comfort can be improved and budgetary pressures can be reduced [5].

Achieving this in a cost effective and systematic way, however, requires a better understanding of how and when RACs use energy. This requires the use of appropriate and meaningful benchmarks and key performance indicators [6].

Very little literature explicitly addresses these issues for care homes. The EU’s Save Age project [7] analysed the energy consumption patterns and energy efficiency measures of 100 residential care homes in 10 countries, as the EU’s first move to establish energy benchmarks for this sector. Space heating accounted for 40 + % of total energy use, while space cooling was not common. Four key performance indicators (KPIs) relating to energy use intensity (EUI) were reported: (i) kWh/m2/yr; (ii) kWh/resident/yr; (iii) kWh heating/m2/yr; and (iv) kWh heating / resident/yr [8,9]. In
Australia, grey literature suggests that energy use in RACs be presented by energy service (e.g. heating, cooling, lighting, hot water) evaluated against facility size (m²) or number of beds, on an annual or daily basis (e.g. kWh/bed/day) [10,11]. There are research considering heating degree days (HDD) or cooling degree days (CDD) in relationship to healthcare EUI [12]. However, there is not currently any widely-utilised KPI that considers energy demand.

There is not yet publication on RAC’s energy use, peak demand and demand profiles in the current COVID-19 context globally. At the time of writing (Aug 2020), two thirds of COVID-19 related deaths in Australia have been in RAC facilities [13] and a high number of COVID cases and deaths have also occurred in RACs in European countries [14,15], U.S. [16] and Canada [17].

This paper contributes to knowledge of how RACs use energy by:
- Quantifying the impact of COVID-19 in aged care facilities’ total energy use and peak demand across four climate zones
- Quantifying the correlation between temperature and energy use/peak demands in lockdown
- Quantifying renewable’s impact on RAC in lockdown
- Demonstrating the effectiveness and limitations of existing KPIs

The next section explains the data analysis methods and tools used, followed by case study and discussion sections. Our further research direction is discussed in the conclusion before acknowledgements and references.

2. Method

The overarching method employed is exploratory data analysis and case studies. Several different data analysis and analytical tools have been used to analyse or visually present energy uses, peak demands and demand profiles:

1. Because temperature is a highly correlated factor with energy use and peak demands [18,19], Kolmogorov-Smirnov 2-sample hypothesis test and temperature boxplots are implemented to examine temperature distribution between 2020 lockdown period and the same period in previous years.
2. Temperatures in different years are plotted and compared with boxplots to show visually show temperatures’ distribution and variations.

3. Pearson Correlation Coefficients (PCC) have been calculated to study the correlation between temperature and daily energy use/peak demands.

Table 1
RAC Community case studies.

| No. | Communities | Climate | Number of beds (2020) | Style | Demographics |
|-----|-------------|---------|-----------------------|-------|--------------|
| 1   | Brisbane    | Warm humid summer, mild winter (Zone 2) | 116 | Single storey buildings, private rooms with ensuites; public shared spaces with central air conditioning | Similar demographic; typical mean age of residents is 75 and above; similar gender distribution (female to male ratio: 1.3 to 1 [21]) |
| 2   | Logan       | Warm humid summer, mild winter (Zone 2) | 60  |                                   |
| 3   | Cairns      | High humidity summer, warm winter (Zone 1) | 132 | similar medical/care equipment for each bed; |
| 4   | Townsville  | High humidity summer, warm winter (Zone 1) | 102 |                                   |
| 5   | Toowoomba   | Warm temperate (Zone 5) | 80  | Two storey building |
| 6   | Sydney      | Mild temperate (Zone 6) | 120 |                                   |

Table 2
Key energy and demand statistics comparisons for Brisbane and Logan RACs.

| No. | Climate | Number of beds (2020) | Brussels | Logan |
|-----|---------|-----------------------|----------|-------|
|      |         |                       | 2016     | 2018  | 2020 VS 2016 | 2020 VS 2018 | 2016     | 2018  | 2020 VS 2016 | 2020 VS 2018 |
| (a) | PCC daily max temperature VS peak demand | 0.82 | 0.83 | 0.72 | 0.73 | 0.81 | 0.53 | -13% | -13% | -28% | -35% |
| (b) | PCC daily max temperature VS energy use | 0.73 | 0.78 | 0.59 | 0.73 | 0.71 | 0.54 | -24% | -24% | -26% | -24% |
| (c) | Median daily min temperature (°C) | 17.3 | 17.0 | 16.6 | 17.3 | 17.0 | 16.6 | -4% | -3% | -4% | -3% |
| (d) | Median daily max temperature (°C) | 29.5 | 28.1 | 28.9 | 29.5 | 28.1 | 28.9 | -2% | 3% | -2% | 3% |
| (f) | Max daily peak demand (kW) | 268 | 240 | 232 | 172 | 169 | 156 | -9% | -8% | -9% | -8% |
| (g) | Median daily peak demand (kW) | 212 | 206 | 160 | 136 | 128 | 114 | -16% | -11% | -16% | -11% |
| (h) | Min daily peak demand (kW) | 149 | 127 | 104 | 77.6 | 85.4 | 84.0 | 8% | -2% | 8% | -2% |
| (i) | SD for daily peak demand (kW) | 31.8 | 30.0 | 27.9 | 22.9 | 18.5 | 17.8 | -22% | -4% | -22% | -4% |
| (j) | Max daily energy use (kWh) | 3561 | 3687 | 3093 | 2541 | 2623 | 2349 | 8% | -10% | 8% | -10% |
| (l) | Median daily energy use (kWh) | 3024 | 2943 | 2328 | 2133 | 2031 | 1726 | -19% | -15% | -19% | -15% |
| (k) | Min daily energy use (kWh) | 2358 | 2291 | 1826 | 1517 | 1546 | 1433 | -6% | -7% | -6% | -7% |
| (l) | SD for daily energy use (kWh) | 384 | 387 | 312 | 276 | 281 | 243 | -12% | -14% | -12% | -14% |
| (m) | Mean daily energy use (kWh) | 2947 | 2912 | 2400 | 2084 | 2028 | 1763 | -15% | -13% | -15% | -13% |
| (n) | Mean daily energy use per bed (kWh/bed) | 27.5 | 26.2 | 20.7 | 34.7 | 33.8 | 29.4 | -15% | -13% | -15% | -13% |
| (o) | CDD24 | 8.6 | 6.6 | 6.3 | 8.6 | 6.6 | 6.3 | -27% | -5% | -27% | -5% |
| (p) | Mean daily energy use per bed per CDD (kWh/bed/CDD) | 3.20 | 3.97 | 3.28 | 4.04 | 5.12 | 4.66 | 15% | -9% | 15% | -9% |
4. Boxplots, scatterplots and histograms are used to have visual presentation and comparison for daily energy uses and peak demands in lockdown.

5. Descriptive statistics are used to describe energy use and peak demand magnitudes, such as minimum, maximum, mean, median and standard deviations (SD).

6. Energy KPIs are calculated and analysed critically, such as kWh/bed, kWh/bed per cooling degree day (kWh/bed/CDD), kWh/bed per heating degree day (kWh/bed/HDD).

7. Multi-scenario case studies have been conducted to understand the environmental impact of renewable energy, such as onsite rooftop solar photovoltaic system (PV) and its impact to CO₂ emission.

The above method 1 and 2 can ensure weather parameters, specifically temperatures, were considered in selecting years of similar temperature distribution to compare with the 2020 COVID lockdown period data.

The above methods have been applied to six RACs which are owned and operated by the same not-for-profit organisation. They purchase energy from the same energy retailer. Their site total energy uses have been measured with high accuracy utility revenue meters (Australian Standard 62,052 and 62,053). The energy datasets were obtained from the energy retailer’s data downloading services. The energy data are in half-hourly resolution. There are varied durations for the data available. For the Sydney RAC (Table 1), its data go back to 2018, while other RACs have data since 2015. The characteristics of the six communities are summarised in Table 1.

The RACs are identified by the city in which they are located, rather than by name. The RACs are similar in their accommodation type, i.e. individual private rooms with ensuites, and shared spaces for functions, exercise or entertainment. Five of the sites are single-storey brick veneer buildings, while the 6th site (Sydney) has 2-storey concrete buildings. The six RACs have similar demographics over the study period and the typical mean age of residents is 75 and above. The female to male ratio is 1.3 to 1 over the period. For energy services, there have been very limited changes in how thermal comfort or food is prepared for those RACs in Australia for the past five years. The historical data for the number beds for each site were obtained and used for calculating item (n) and item (p) in Tables 2 and 4, item (n) and item (r) in Table 3. Those RACs have not got PV onsite. The six sites are in four climate zones as designated by the Australian Building Codes Board (Fig. 1 [20]).

The period of analysis is 40 days from 22nd March 2020 to the end of April 2020, the period that RACs across Australia were under official COVID-19 lockdown where visits to RAC facilities were restricted [22]. Group activities were not organised in the period. This lockdown period occurred during Australia’s autumn so it did not include peak heating or cooling months. Autumn in these locations, however, is still a cooling dominant season. As such, the six RACs were analysed based on three climate types that represent the 40 autumn days weather conditions:

- Warm regions: Brisbane and Logan (median daily maximum temperature: 28–29 °C for the lockdown period)
- Hot regions: Cairns and Townsville (median daily maximum temperature: 30–31 °C for the lockdown period)
- Temperate regions: Sydney and Toowoomba (median daily maximum temperature: 25–26 °C for the lockdown period)

The following sections present climate and energy analysis data for the RACs in these three regions respectively.

3. RAC in warm regions

Fig. 2 contains the boxplots for the Brisbane and Logan RAC’s daily maximum temperature, daily peak demands and energy use for the same period across six years (22nd March to 30th April). The red horizontal dashes inside each blue box are median values.
The top edge of each blue box is the 75th percentile and the bottom edge of each blue box is the 25th percentile. When there are no outliers, the top end of the whisker above each blue box is the maximum value; the bottom end of the whisker below each blue box is the minimum value. The red crosses are outliers.

The weather data for the lockdown period was compared with weather data from the previous five years (the extent of the RAC energy use data availability). The median values and distribution of the 2020 daily maximum temperatures were similar to those in 2016 and 2018 in the same period (Two-sample Kolmogorov-Smirnov distribution test with 0.01 significance level cannot reject \( H_0: \) they are from the same distribution). As a result, it was considered appropriate to compare the 2020 energy use with 2016 and 2018 data. The key statistics of Fig. 2 are summarised into Table 2.

As shown in Table 2, the general trend was a wide spread of reduction in daily peak demand in kW and energy use in kWh for the two sites. Rows (a) and (b) show the relationship between maximum temperature and energy demand and energy use respectively; rows (c) and (d) – temperature; rows (e) to (h) compare peak demand; rows (i) – (l) compare daily energy use, and rows (m) to (p) present the information in typical KPIs, such as daily energy use (kWh) and energy use per bed (kWh/bed) or energy use per bed per cooling degree day (CDD). Note row e maximum peak demand is often a system level KPI [23], especially in discussion with network connection or congestion. Key statistics discussed in the following paragraphs have been highlighted in bold red fonts. In this paper, 24 \(^\circ\)C have been used to calculate CDD and 18 \(^\circ\)C have been used to calculate HDD in this paper based on Australian Bureau of Meteorology standard [24].

For the Brisbane RAC in comparison with previous years, row (a) shows its 2020 Pearson Correlation Coefficients (PCC) between daily maximum temperature and peak demands dropped by 13% and row (b) shows its PCC between daily maximum temperature and energy use dropped by 24%. However, those PCCs are still high above 0.5. In terms of temperature, the Brisbane and Logan community experienced similar mean daily minimum temperatures and maximum temperatures with difference less than 4% compared to previous years.

The Brisbane community's maximum daily peak demand, median daily peak demand, minimum daily peak demands and standard deviation (SD) for peak demands all dropped at various levels from 4% to 30%. Among all statistical comparisons between 2020 and 2016, and comparisons between 2020 and 2018, the peak demand related change percentages (row e to h) showed largest differences between “2020 VS 2016” and “2020 VS 2018”. For example, 2020 maximum peak demand dropped 13% compared to 2016 and dropped by only 4% compared to 2018. A possible reason was that it was a cooling needed period (no HDD) and the 2020 period had 27% decrease in CDD compared to 2016 and a smaller 5% decrease in CDD compared to 2018 (row o). The SD for peak demands dropped by 12% compared to 2016 and 7% compared to 2018 and this downward trend in SD for peak demands was in line with most of other communities.

The Brisbane community's energy statistics in row i to l had 13% to 23% drop. The median and minimum daily energy use dropped by 21% or more compared to the same period in 2016 and 2018. The SD for daily energy use dropped 19% compared to 2016 and 2018. This indicated less variation in the way or amount in using energy and the possibility of having more similar energy use patterns in everyday of the lockdown period.

In terms of KPIs, the mean daily energy use per bed was reduced by 25% compared to 2016 and 21% compared to 2018. They were
quite significant reduction amounts and similar to the reduction in median daily energy use in row j and minimum daily energy use in row k. In terms of mean daily energy use per bed per CDD, the Brisbane community had 3% increase compared to 2016 and 17% decrease compared to 2018.

Similar to the Brisbane RAC, the Logan RAC has observed large reductions in peak demands statistics, energy use statistics, SDs for peak demands and energy use, and energy use per bed. Compared to the Brisbane RAC, the Logan RAC had lower level of PCC between temperatures and peak demands, and between temperatures and energy uses. The PCC between temperature and peak demands dropped to 53% in 2020 for the Logan RAC which is the lowest PCC value in the table. Also compared to the Brisbane RAC, the Logan RAC observed higher level of SD reduction for peak demands comparing 2020 to 2016 in row h. In the interest of saving audience reading time and space, other Logan RAC’s power demand and energy use statistics are not described here since they were quite similar to the Brisbane RAC’s statistics.

A limitation of the analysis so far is that it doesn’t well explain peak demand and demand profiles. Hence the 30-minute interval demand profile analysis follows to discuss peak demands magnitudes and timing of peak demands.

Fig. 3 presents 30 min interval power demand profiles for the Brisbane and Logan RAC in the same period in 2016, 2018 and 2020. This figure is useful for analysing the timing and distribution of electricity demand. The Brisbane RAC’s median peak demand values were more than 200 kW for 2016 and 2018, but the median peak demand in 2020 was around 160 kW (Fig. 3a). The Logan RAC’s median peak demand values were reduced in 2020, compared to 2016 and 2018 but the reduction amount and percentage were not as large as the Brisbane RAC. There were no significant changes in the timing of daily peak demand in either the Brisbane or the Logan RAC and the peak demand tended to happen around midday to afternoon periods in the same period across these years.

Fig. 4 shows scatter plots and distribution plots for maximum daily temperature and peak demand (plot a and c), and for maximum daily temperature and energy use (plot b and d) for the same period 22nd March to 30th April 2020. For all subplots in Fig. 4, the horizontal coordinates are daily maximum temperatures. For plots (a) and (c), the vertical coordinates are daily peak demands. For plots (b) and (d), the vertical coordinates are daily energy use. The distribution plots of daily maximum temperature for 2016, 2018 and 2020 are plotted under each horizontal axis. The distribution plots of peak demands or energy use are presented vertically besides each vertical axis.

These distribution plots on the left of the vertical axis show that there were more occurrences of lower daily peak demand and more occurrences of lower daily energy use in 2020, compared to 2016 and 2018. The relationship between daily maximum temperature and peak demand, or daily maximum temperature and energy use were more linear in 2016 and 2018, compared to 2020. This is in line with the 2020’s PCC reduction in Table 2.

4. RAC in temperate regions

The same analytical process of the previous section has been applied to the Sydney RAC and Toowoomba RAC. The Toowoomba RAC has six years of half hourly electricity demand data available
(2015–2020) whereas the Sydney RAC half hourly data availability was limited to 2018 to 2020. Different years are used for comparison purposes for these two RACs. For the lockdown period, the mean daily maximum temperature for Sydney was similar to 2018 and 2019 with less than 2% difference. The median daily peak demands and daily energy use were similar to 2018 and 2019. However, from the length of the blue boxes in the middle and bottom plots of Fig. 5(a), the variation of daily peak demands and energy use have been reduced by a large ratio. For the Toowoomba RAC, its 2020 median value and distribution of daily maximum temperatures were similar to its 2016 and 2018 temperatures. Therefore, for the Toowoomba RAC, its 2020 lockdown period energy use and demand profiles’ comparisons are made with 2016 and 2018 in the following sections.

Overall, there were general trends but no consistent large reduction in terms of peak demand or use for the two RACs. The difference in peak demands and energy use between 2020 and their corresponding comparable years are smaller compared to the Brisbane and Logan communities. The key statistics of Fig. 5 are contained in Table 3.

The two temperate region RACs had some similar and some different levels of change when comparing their peak demands and energy use in the 2020 lockdown period to the same period in previous years (Table 3). For the Sydney RAC,

- PCCs in row a and b dropped by more than 50%, leading PCC below 0.4. This indicates temperature was no longer highly correlated with peak demands or energy use. This did not happen for the Toowoomba community. This may indicate a large reduction in temperature related or thermostat-controlled load, or different energy use patterns (amounts) for a 2-storey building compared to a single storey building. Further investigation is required to understand the reason(s).

- In row h in Table 3, the peak demand SD dropped by 66% compared to 2018 and dropped by 46% compared to 2019.

### Table 3

| No. | Description                                                                 | Sydney |                  |                  | Toowoomba |                  |                  |
|-----|-----------------------------------------------------------------------------|--------|------------------|------------------|-----------|------------------|------------------|
|     |                                                                             | 2018   | 2019             | 2020             | 2020 VS   | 2016             | 2018             |
|     |                                                                             |        |                  |                  | VS 2018   | 2018 VS 2016   | 2018 VS 2018   |
| (a) | PCC daily max temperature VS peak demand                                    | 0.91   | 0.81             | **0.23**         | -74%      | 0.66             | 0.48             |
|     |                                                                             |        |                  |                  | -71%      | 0.62             | -7%              |
| (b) | PCC daily max temperature VS energy use                                     | 0.92   | 0.81             | **0.40**         | -56%      | 0.62             | 0.41             |
|     |                                                                             |        |                  |                  | -50%      | 0.69             | 12%              |
| (c) | Median daily min temperature (°C)                                           | 16.9   | 15.0             | 15.1             | -10%      | 15.5             | 15.5             |
|     |                                                                             |        |                  |                  | 1%        | 14.9             | -4%              |
| (d) | Median daily max temperature (°C)                                           | 25.7   | 25.8             | 25.2             | -2%       | 25.7             | 24.7             |
|     |                                                                             |        |                  |                  | -2%       | 25.4             | -1%              |
| (e) | Max daily peak demand (kW)                                                  | 129    | 121              | 103              | -20%      | 74.7             | 84.3             |
|     |                                                                             |        |                  |                  | -15%      | 81.5             | 9%               |
| (f) | Median daily peak demand (kW)                                               | 94.0   | 88.2             | 90.6             | -4%       | 62.6             | 61.8             |
|     |                                                                             |        |                  |                  | 3%        | 64.4             | 3%               |
| (g) | Min daily peak demand (kW)                                                  | 77.4   | 74.8             | 80.0             | 3%        | 51.5             | 47.0             |
|     |                                                                             |        |                  |                  | 7%        | 51.3             | 0%               |
| (h) | SD for daily peak demand (kW)                                               | 16.1   | 10.2             | 5.4              | -66%      | 5.9              | 8.2              |
|     |                                                                             |        |                  |                  | -46%      | 7.9              | 33%              |
| (i) | Max daily energy use (kWh)                                                  | 1895   | 1761             | 1573             | -17%      | 1282             | 1282             |
|     |                                                                             |        |                  |                  | -11%      | 1268             | -1%              |
| (j) | Median daily energy use (kWh)                                               | 1477   | 1455             | 1434             | -3%       | 1059             | 1092             |
|     |                                                                             |        |                  |                  | -1%       | 1075             | 2%               |
| (k) | Min daily energy use (kWh)                                                  | 1295   | 1334             | 1315             | 1%        | 931              | 896              |
|     |                                                                             |        |                  |                  | -1%       | 925              | -1%              |
| (l) | SD for daily energy use (kWh)                                               | 162    | 97.3             | 57.4             | -65%      | 89.4             | 81.3             |
|     |                                                                             |        |                  |                  | -41%      | 84.9             | 5%               |
| (m) | Mean daily energy use (kWh)                                                 | 1522   | 1470             | 1434             | -6%       | 1078             | 1084             |
|     |                                                                             |        |                  |                  | -2%       | 1088             | 1%               |
| (n) | Mean daily energy use per bed (kWh/bed)                                     | 12.7   | 12.2             | 12.0             | -6%       | 13.8             | 13.9             |
|     |                                                                             |        |                  |                  | -2%       | 13.6             | -2%              |
| (o) | CDD24                                                                       | 16.0   | 1.4              | 0.0              | NA       | 0.0              | 0.0              |
|     |                                                                             |        |                  |                  | NA       | 0.45             | NA               |
| (p) | HDD18                                                                       | 4.6    | 13.5             | 10.3             | **126%**  | 3.2              | 8.0              |
|     |                                                                             |        |                  |                  | -23%      | 1.6              | -49%             |
| (q) | TCHDD=CDD24 + HDD18                                                         | 20.5   | 14.8             | 10.3             | -50%      | 3.2              | 8.0              |
|     |                                                                             |        |                  |                  | -30%      | 2.1              | -35%             |
| (r) | Mean daily energy use per bed per THDD (kWh/bed/TCHDD)                       | 0.62   | 0.83             | 1.16             | **88%**   | 4.4              | 1.7              |
|     |                                                                             |        |                  |                  | -40%      | 6.6              | 51%              |
- In terms of its energy use, its maximum daily energy use (in row i) dropped by 17% compared to 2018 and dropped by 11% compared to 2019. Its SD for daily energy use (in row l) dropped by very high percentages, 65% compared to 2018 and 41% compared to 2019.
- In row n, the mean daily energy use per bed for the Toowoomba RAC had a 2% drop compared to 2016 and 2018.

For the Toowoomba RAC,

- PCCs in row a and b remained high above 0.62 for the 2020 period.
- Its maximum daily energy use (in row i) dropped by 1% compared to previous years.

Row o to row r are CDDs, HDDs, and related energy use KPIs for the two communities. There had been some CDD for the two RACs however, that was not always the case for the same period across the three years in row o in Table 3. The two communities’ HDDs tended to decrease as a general trend. Row q shows the total cooling and heating degree days (TCHDD) for the two communities. TCHDD had over 30% reduction for both communities compared to previous years. A likely reason was reduction of HDDs (due to limitation, no longer term temperature data are available for the Sydney community.).

Looking at mean daily energy use per bed per TCHDD in row r, their 2020 figures had 40% to 280% increase compared to previous years’ figures. It may be arguable that for RACs in temperate climate (or seasons), KPI in relationship to degree days may be misleading because:

- RACs’ energy use may not be highly relevant to air conditioning use or other factors may play a bigger role in energy use.
- the KPI values in relationship to degree days may be inflated
- this type of KPI cannot inform how to manage energy in relationship to air conditioning.

As with the previous discussion on the Brisbane and Logan RACs, a more detailed demand profile analysis is required to better understand the peak demands and timing of peak demands, which is in the following.

Fig. 6 presents the boxplots for the Sydney and Toowoomba RAC’s 30 min interval electricity demand profiles. For the Sydney RAC, peak demands were in the late afternoon to early evening in 2018 and 2019 as shown in the top and middle plot of Fig. 6 (a). However in 2020, the blue boxes (quartile ranges) of larger values appear much earlier in the day, slowly decrease until about 16:00, then further decrease to the base demand level. Without large temperature differences in the morning (daily minimum temperatures) to the previous years, the Sydney RAC in 2020 tended to have more morning peak demands. The Sydney RAC demands were between 60 kW and 90 kW in the 6am to 9am time block across the three years. One key difference for the 2020 Sydney RAC morning demands was that the demand ramp up rate during the 6am to 9am was higher than 2018 and 2019. The reduction of energy use later on during the day further emphasised the morning demands. The morning demands in this community are likely due to a certain pattern of use that is not in the other communities (which could be because of cooler morning coinciding with early activities).

The demand profiles of the Toowoomba RAC were reasonably flat during daytime hours for the 2016 and 2018 periods. Its 6am to 9am demands boxplots seemed to be slightly higher in 2020, however, the morning demands were not as outstanding as the Sydney RAC’s in 2020.
For the Sydney RAC, a comparison of Fig. 7(a) and (c) shows the 2020 daily maximum temperature distribution was similar to its 2019 distribution. Daily peak demand and energy use were both peakier in 2020, compared to the previous two years. This was also seen previously in the Sydney RAC’s SD reduction in Table 3. Fig. 7(a) and (c) also show the reduction of PCC, as the 2020 scatter plots are flatter compared to previous years in.

For the Toowoomba RAC, a comparison of Fig. 7(b) and (d) shows the 2020 daily maximum temperature distribution was similar to its 2018 distribution. The distribution curve of its energy use in 2020 was slightly lower than 2018’s energy use distribution curve. No major reduction was observed for daily energy use or daily peak demand for the Toowoomba RAC. There was also no significant change in the load profile (peakiness).

5. RAC in hot regions

Temperature data from the lockdown period in 2020 were compared with temperature data for the previous five years. As with the Brisbane and Logan case studies, the 2020 median values and distribution for median daily temperature maximums, were similar to the 2016 and 2018 temperature data. Hence 2016 and 2018 datasets (temperature and energy) were used for comparative purposes. The key statistics of Fig. 8 are presented in Table 4.

Compared to warm regions, the hot region communities did not experience consistent large reduction in daily peak demands or in daily energy use.

A consistent change was the reduction of PCC between daily maximum temperatures and energy use. However, the PCC was still at 0.5 for the Cairns community in 2020 and at 0.44 for the Townsville community.

Another two consistent and noticeable changes were the reduction of standard deviation for both daily peak demand and energy use. The Cairns RAC had more than 20% reduction in daily peak demands SD and more than 29% reduction in daily energy use SD compared to the previous years. The Townsville community had more than 12% reduction in daily peak demands SD and more than 19% reduction in daily energy SD.

Both communities are in tropical region and they have no HDD. In Table 4, row 0 shows increased need for cooling, as CDD increased by more than 10% for the Cairns RAC and more than 7% for the Townsville RAC. However, for their EUI in relation with CDDs, the Cairns RAC observed more than 8% decrease in mean energy use per bed per CDD and the Townsville RAC had more than 19% drop in mean energy use per bed per CDD. This indicated the two RAC in hot regions probably had less energy use per bed for air conditioning even though there were more CDDs needed in 2020. Lockdown rules in visit restriction and onsite activities probably had impact on the air conditioning use for RACs in hot regions. Degree days and related EUI calculation seem to be meaningful show lockdown changes for RACs in hot regions (or seasons).

Demand profiles of the Cairns and Townsville communities were plotted in Fig. 9. There were no changes in terms of peak demand timing. For the two communities, daily peak demands tended to occur around midday. Comparing 2020 to 2018, both communities recorded higher demands around middays. For the Cairns community, there were more occurrences of demands around 280 kW to 300 kW in 2020 compared to 2016. The two communities’ demand profiles were quite similar to typical daily solar radiation curves, especially for the Cairns community’s demand profile.
Fig. 10 presents the scatterplots and distribution plots for the Cairns community and the Townsville community in the same period. The scattered circles for 2020 energy uses and peak demands were more condensed for both communities and their distribution curve also were peakier in 2020. This indicates less variations in daily peak demands and energy uses were observed for both communities, which was in line with the SD changes in Table 4. One reason could be that during COVID lockdown, the use of buildings became more consistent. For example, the same number of occupants follow the same daily routine.

For the Cairns community, its 2020 daily energy use distribution curve was slightly below 2018’s (Fig. 10c). However as shown in Fig. 10a, its 2020 daily peak demand distribution curve was slightly above other years (2% increase in median values in Table 4).

For the Townsville community, its 2020 peak demands and energy use distribution curves moved upwards compared to its 2018 curves, meaning more occurrences of higher peak demands and energy use. A possible reason was that its 2020 temperatures tended to be higher than its 2018 temperatures (i.e. daily max temperature distribution curves in Fig. 10b and d, and CDD figures in Table 4).

Table 5 summarises the ranges for the six RACs’ total daily energy use, daily energy user per bed, energy use per bed per degree day, daily peak demands, and peak demand timing across three climate types. The ratios for RACs in each climate type tend to stay in a similar band. For example, for the total energy use, the Sydney RAC has a 1:1.46 ratio and the Toowoomba RAC has a 1:1.43 ratio. In terms of peak demands, the Cairns RAC has a 1:1.64 ratio and the Townsville RAC has a 1.70 ratio.

When the EUI KPIs are in relation to degree days (either CDD or TCHDD), these KPIs can be inflated and not meaningful in guiding energy operation or management in temperate climate zones or temperate seasons, such as for the Sydney and Toowoomba communities (more details in Section 6). However, these KPIs can be helpful for understanding the energy performance of RACs for hot regions, such as for the Cairns and Townsville communities (more details in Section 7).

In terms of peak demand magnitudes, RACs in hot regions had the highest range of peak demands, followed RACs in warm regions. RACs in temperate regions registered lowest range of peak demands. These peak demand magnitudes seemed to be temperature related. In terms of peak demand timing, all six communities had high probabilities of peak demands appearing around midday.
6. Impact of renewables

To improve the energy resilience of RAC or reduce the energy risk exposure of RAC, distribution renewable generation can help [25,26]. As a form of distributed renewable energy, rooftop solar photovoltaic inverter systems (PV) are a very common and cost-effective renewable energy investment option for many parts of Australia. By July 2020, more than 36% of dwellings in the states of Queensland and South Australia had rooftop PVs [27]. The average size of these PV systems exceeded 5 kW in 2015 [28], equating to approximately 1.5 kWp per bedroom (assuming 3 bedrooms residences).

PV has been quite common in distribution network and at customers’ end in Australia [29,30] however, none of the case study communities in this paper have rooftop PV installed. As we have previously seen, the energy use and peak demand appears to be highly climate correlated, and the distribution of peak demand is mostly during daylight hours for the case study. This suggests that rooftop solar could be a viable energy management option for RACs.

For this section, three different test values of kWp per bed PV systems were proposed for each site, to determine to what extent rooftop solar could impact on the observed daily energy use, and associated greenhouse gas emissions (Table 6). The three PV system sizes are 1 kWp per bed, 1.5 kWp per bed and 2 kWp per bed.

The PV generation outputs for each location are estimated based on real PV output data from research institutes [31] and daily solar exposure from governmental weather stations [32]. CO₂ emission calculations are based on the Australian Energy Market Operator’s 2019 statistics [33]: 0.790 kg CO₂/kWh grid electricity for the Sydney community and 0.773 kg CO₂/kWh grid electricity for all other communities.

With the same amount of renewable PV investment per bed, Cairns has the highest amount of generation and Logan has the lowest generation amount. However, due to Sydney and Toowoomba’s temperate climate, their mean daily electricity use is not high. As a result, their CO₂ emission reduction percentages are higher than other RACs with higher renewable generation amounts.

The maximum daily benefits for all six RACs are estimated based on the assumption that all PV generation is used for self-consumption to replace grid import. $0.12 AUD is used as the grid import price for each kWh. The Cairns and Townsville RACs have the highest benefits mostly due to its solar radiation amount (related to climate and geographical location).

7. Discussion

The first finding from this study, is that the COVID-19 lockdown had different impacts on RACs in different temperature regions.

For the warm region, the Brisbane and Logan RACs experienced similar impacts:
- 2% to 4% temperature changes compared to the same period in previous years
- 11% to 23% reduction in median daily energy use and peak demands
- 4% to 19% less variation for daily energy use or peak demands
- 13% to 25% less energy use per bed

This could suggest that, for these RACs, energy uses were impacted by operational changes.
For the temperate region, Sydney and Toowoomba RAC had different levels of impact. Some similarities include:

- more morning peak demands, rather than evening peak demands. This may be due to their comparative cooler mornings and certain energy use behaviour in that climate, along with the reduction of energy use thru the day during lockdowns.
- 2% to 6% less energy use per bed

For the hot regions, Cairns and Townsville RAC had:

- 1% to 3% temperature changes when comparing 2020 lockdown period with the same period in 2016 and 2018
- no consistent visible change in daily energy use or peak demand in COVID lockdown.
- 12% to 36% less variation (standard deviation) for daily energy use or peak demands. This may suggest their loads may be heavily weather dependent (such as heavily reliant on air conditioning) and therefore less impacted by occupant routine changes.

The second finding is that, for these RACs, there was a general trend of a lower level of correlation between temperature and energy use during lockdown. The energy use in 2020 was not as linear as other years, which means energy use did not follow the same increase/decrease pattern of temperature, or followed it but with less intensity (flatter curve). A plausible reason for this is, during lockdown, these facilities ceased group activities and reduced utilisation of shared spaces, therefore decreasing the air conditioning use in these spaces. There were also less visitors to the facilities, reducing the internal heat loads. As a result of this, air conditioning energy use may have dropped to the point that other energy use became more influential.

Further analysis of median daily maximum temperatures (Fig. 11(a)) and mean daily electricity use per bed (Fig. 11(b)) can provide more insight.

The third finding, from Fig. 10(b) is that climate is a significant factor in terms of general levels of energy use per bed, even in the relatively mild autumn season. RACs in the warmest climate generally have the highest kWh/bed, and those in the coolest climate have the lowest kWh/bed. An anomaly is Logan (in the warm climate). This may be because Logan is the smallest facility (60 beds).

### Table 4

Key energy and demand statistics comparisons for Cairns and Townsville RACs.

| No. | Cairns | Townsville |
|-----|--------|------------|
|     | 2016   | 2018  | 2020 | 2020 | 2016 | 2018  | 2020 | 2020 | 2016 | 2018  | 2020 | 2020 |
| (a) | PCC daily max temperature VS peak demand | 0.81 | 0.63 | 0.51 | -38% | -19% | 0.65 | 0.50 | 0.54 | -18% | 8% |
| (b) | PCC daily max temperature VS energy use | 0.81 | 0.55 | 0.50 | -39% | -9% | 0.60 | 0.45 | 0.44 | -26% | -3% |
| (c) | Median daily min temperature (°C) | 22.3 | 22.8 | 23.0 | 3% | 1% | 22.4 | 22.6 | 22.8 | 2% | 1% |
| (d) | Median daily max temperature (°C) | 30.9 | 30.4 | 30.8 | 0% | 1% | 31.1 | 30.5 | 31.2 | 0% | 2% |
| (e) | Max daily peak demand (kW) | 312 | 278 | 303 | -3% | 9% | 270 | 217 | 232 | -14% | 7% |
| (f) | Median daily peak demand (kW) | 246 | 245 | 250 | 2% | 2% | 224 | 188 | 199 | -11% | 6% |
| (g) | Min daily peak demand (kW) | 192 | 190 | 211 | 10% | 11% | 196 | 159 | 172 | -12% | 8% |
| (h) | SD for daily peak demand (kW) | 25.9 | 25.3 | 20.3 | -22% | -20% | 17.0 | 14.9 | 13.1 | -23% | -12% |
| (i) | Max daily energy use (kWh) | 4888 | 4594 | 4664 | -5% | 2% | 4824 | 3586 | 3751 | -22% | 5% |
| (j) | Median daily energy use (kWh) | 3933 | 4059 | 3915 | 0% | 4% | 3918 | 3117 | 3241 | -17% | 4% |
| (k) | Min daily energy use (kWh) | 3248 | 3082 | 3471 | 7% | 13% | 3363 | 2539 | 2793 | -17% | 10% |
| (l) | SD for daily energy use (kWh) | 365 | 407 | 260 | -29% | -36% | 326 | 283 | 228 | -30% | -19% |
| (m) | Mean daily energy use (kWh) | 3920 | 3928 | 3956 | 1% | 1% | 3907 | 3087 | 3267 | -16% | 6% |
| (n) | Mean daily energy use per bed (kWh/bed) | 29.7 | 29.8 | 30.0 | 1% | 1% | 38.3 | 30.3 | 32.0 | -16% | 6% |
| (o) | CDD24 | 92.5 | 89.0 | 101.9 | 10% | 15% | 110 | 90 | 117 | 7% | 30% |
| (p) | Mean daily energy use per bed per CDD (kWh/bed/CDD) | 0.32 | 0.33 | 0.29 | -8% | -12% | 0.35 | 0.34 | 0.27 | -22% | -19% |
and may have a higher external surface area to internal volume than the other facilities. Another possibility is that this facility has a microclimate or urban heat island index that impacts on its space cooling load. A third possibility is that this facility has a lower thermal performance of its building envelope compared to the Brisbane facility.

The fourth finding, perhaps unsurprisingly, is that, within similar climate zones, RACs with more beds seem to be more energy efficient. For example, the Logan RAC tends to always have higher energy use per bed compared to the Brisbane RAC and the Townsville RAC tends to always have higher energy use per bed compared to the Cairns RAC. Perhaps, this is because shared services can be averaged across more residents when RACs are larger, or, as mentioned previously, the relationship could be due to the external surface area to internal volume ratios.

The fifth finding relates to the key performance indicators typically used in this sector. The most widely used KPI is kWh/bed/day, and it is effective in that the data required to report on this KPI is relatively easily gained. However, this EUI KPI has limited usefulness as an industry benchmark, and does not enable detailed evaluation of the energy efficiency of the site and its systems and services. It also doesn’t allow for evaluation of energy uses that contribute to peak demand, nor analysis of options for renewable energy and energy storage solutions.

The utilisation of 30-minute data and different analysis techniques exemplified in this study revealed more information about the nature and characteristics of energy use for a specific RAC, providing the basis from which an analysis of the potential benefits of onsite renewable energy systems (roof-mounted PVs) could be undertaken. For example, the 30-minute demand profile of Cairns and Townsville RACs are quite similar to daily solar radiation profile. For all these RACs, onsite renewable energy systems can be quite beneficial to the environment and operational cost containment.

The dataset is over a 5-year period and the data used for this study are for 40 days in 6 consecutive years (except the Sydney RAC). A limitation of this study is the not very long period of data used for comparison. This is because the lockdown period happened to be 40 days and COVID situation have been managed well in those areas since then.

8. Conclusion

This study used whole site electricity data from billing meters to quantify the impact of COVID-19 on energy use, peak demands, demand profiles and onsite renewable generation for six residential aged care communities. The analysis shows that energy use and peak demands magnitudes are highly relevant to climate situ-
The general trend of energy use and power demand was downwards in RACs in warm climate regions. There were negligible changes in energy use and peak demands in RACs in temperate and hot regions.

Distributed renewable energy resources, such as rooftop PV systems, can provide consistent CO₂ emission reduction in different climate regions over the year.

The different analysis techniques utilised provided nuanced understandings of energy use and demand. Distributed renewable energy resources, such as rooftop PV systems, can provide consistent CO₂ emission reduction in different climate regions over the year.
lockdown period. Further work could analyse circuit level data to establish changes made to daily routine and consumption patterns behind meters. This investigation could address why and how energy use patterns changed based on space types and load types for warm region RACs.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgment

The research is part of an Australian Renewable Energy Agency iHub project (www.ihub.org.au) funded by the Australian Government and Industry. The funding bodies had no input into the study design; collection, analysis and interpretation of data; the writing of the report or in the decision to submit the article for publication.

The authors sincerely thank Bolton Clarke for the case study demand data. Computational resources and services used in this work were provided by the HPC and Research Support Group, Queensland University of Technology, Brisbane, Australia.

References

[1] Energy Networks Australia, Commercial down v residential up: COVID-19’s electricity impact, (2020). https://www.energynetworks.com.au/news/energy-insider/2020-energy-insider/commercial-down-v-residential-up-covid-19s-electricity-impact/ (accessed August 1, 2020).

[2] IEA, COVID-19 impact on electricity, (2020). https://www.iea.org/reports/covid-19-impact-on-electricity (accessed August 25, 2020).
[3] H. Zhong, Z. Tan, Y. He, L. Xie, C. Kang, Implications of COVID-19 for the electricity industry: A comprehensive review, CSEE J. Power Energy Syst. 6 (2020) 489–495. https://doi.org/10.17775/CSEEJPES.2020.02590.

[4] C. Edmond, Working from home might not cut energy use as much as we'd hoped, World Econ. Forum, (2020). https://www.weforum.org/agenda/2020/06/remote-working-energy-use-coronavirus/ (accessed August 25, 2020).

[5] W. Miller, D. Vine, Z. Amin, Energy efficiency of housing for older citizens: Does it matter?, Energy Policy. 101 (2017) 216–224. https://doi.org/10.1016/j.enpol.2016.11.050.

[6] C. Li, T. Hong, D. Yan, An insight into actual energy use and its drivers in high-performance buildings, Appl. Energy. 131 (2014) 394–410, https://doi.org/10.1016/j.apenergy.2014.06.032.

[7] SAVE AGE: A Project on Energy and Cost Reduction in Care Homes for the Elderly, (n.d.). http://www.saveage.eu/.

[8] P. Fonseca, P. Esteves, L. Marques, A. Anibal, Analysis of total energy consumption in 100 care homes for elderly, 2011. http://www.saveage.eu/index.php/en/project-publications.

[9] T. Hong, M.A. Piette, Y. Chen, S.H. Lee, S.C. Taylor-Lange, R. Zhang, K. Sun, P. Price, Commercial Building Energy Saver: An energy retrofit analysis toolkit, Appl. Energy. 159 (2015) 298–309. https://doi.org/10.1016/j.apenergy.2015.09.002.

[10] N S W Office of Environment and Heritage, ed., Energy Saver Aged-care toolkit, (2014) 36.

[11] A. Vikstrom, R. Boyle, S. Harkness, J. Hargraves, J. Jarnath, E. Kinnon, Summary of Energy Audits (Level 2) – Aged Care Facilities, Hobart, 2015. https://d3n8a8pro7vhmx.cloudfront.net/slt/pages/original/1458625548/Summary_all_aged_care_facilities_210316.pdf?1458625548.

[12] EPA, Data trends - energy use in hospitals, Environmental Protection Agency - index.php/en/project-publications.

[13] M. Trabucchi, D. De Leo, Nursing homes or besieged castles: COVID-19 in northern Italy, Lancet Psychiatry. 7 (2020) 387–388, https://doi.org/10.1016/S2215-0366(20)30149-8.

[14] EPA, Data trends - energy use in hospitals, Environmental Protection Agency - index.php/en/project-publications.

[15] Australian Bureau of Meteorology, Heating and cooling degree days documentation, (2020) 2015. https://www.bom.gov.au/climate/data/
historical#4/-26.67/134.12 (accessed July 23, 2020).

[16] Australian Bureau of Meteorology, Heating and cooling degree days documentation, (2020) 2015. https://www.bom.gov.au/climate/data/
historical#4/-26.67/134.12 (accessed July 23, 2020).

[17] Australian Bureau of Meteorology, Heating and cooling degree days documentation, (2020) 2015. https://www.bom.gov.au/climate/data/
historical#4/-26.67/134.12 (accessed July 23, 2020).

[18] A. Liu, G. Ledwich, W. Miller, M.E. Chollette, A New Multi-dimension Clustering-based Method for Planning Sustainable Energy Investment, in: sdewes.org, Gold Coast, Queensland, Australia, 2020: pp. 1–14. https://www.goldcoast2020.sdewes.org/.

[19] T. Hong, M. Baran, S. Hisiang, D. Dickey, S. Fang, Short Term Electric Load Forecasting, North Carolina State University, 2010. http://www.lib.ncsu.edu/resolver/1840.16/6457.

[20] Australian Building Codes Board, Australia climate zone map, 2019.

[21] Australian Bureau of Statistics, Population - Queensland by sex and single year of age, (2020). https://www.abs.gov.au/statistics/people/population/national-state-and-territory-population/latest-release#data-downloads-data-cubes.

[22] J. Young, Aged care direction – Department of Health, (2020), https://www. health.qld.gov.au/system-governance/legislation/cho-public-health-directions-under-expanded-public-health-act-powers/revoked/aged-care-1.

[23] H. Li, T. Hong, S.H. Lee, M. Sofos, System-level key performance indicators for building performance evaluation, Energy Build. 209 (2020) 109703, https://doi.org/10.1016/j.enbuild.2019.109703.

[24] Australian Bureau of Meteorology, Heating and cooling degree days documentation, (2020) 2015. http://www.bom.gov.au/climate/map/heating-cooling-degree-days/documentation.shtml (accessed August 1, 2020).

[25] S. [Charani Shandiz], G. Foliente, B. Rismanchi, A. Wachtel, R.F. Jeffers, Resilience framework and metrics for energy master planning of communities, Energy. 203 (2020) 117856. https://doi.org/10.1016/j.energy.2020.117856.

[26] A. Liu, G. Ledwich, A Grid-friendly Sustainable Neighborhood Energy Trading Mechanism for MV-LV Network, IEEE Trans. Smart Grid. 3053 (2020) 1–10, https://doi.org/10.1109/TSG.2020.3045976.

[27] APVI, APVI Solar Map, Aust. PV Inst. (2020) 1–3. http://pv-map.apvi.org.au/open-access-data.

[28] W. Johnston, Australia average solar PV system size hits 5kW, (2015) 2–3. https://reneweconomy.com.au/graph-of-the-day-australias-average-solar-pv-system-size-hits-5kw-47293/.

[29] L. Wang, F. Bai, R. Yan, T.K. Saha, Real-time coordinated voltage control of PV inverters and energy storage for weak networks with high PV penetration, IEEE Trans. Power Syst. 33 (2018) 3383–3395, https://doi.org/10.1109/TPWRS.2018.2789897.

[30] W. Kong, Z.Y. Dong, Y. Jia, D.J. Hill, Y. Xu, Y. Zhang, Short-term residential load forecasting based on LSTM recurrent neural network, IEEE Trans. Smart Grid. 10 (2019), https://doi.org/10.1109/TSG.2017.2753802.

[31] UQ Solar Open Access Data, (2020). https://solar-energy.uq.edu.au/research/ open-access-data.

[32] Bureau of Meteorology Climate Data Online 2020 Commonw Aust http://www. bom.gov.au/climate/data/.

[33] Australian Energy Market Operator, AEMO CO2 equivalent intensity index, (2020). https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/market-operations/settlements-and-payments/settlements/carbon-dioxide-equivalent-intensity-index (accessed September 4, 2020).