Report #LS1_Baseline

Living Labs Educational Sector Energy Baseline and Key Performance

27 May 2022

University of Wollongong

About i-Hub

The Innovation Hub for Affordable Heating and Cooling (i-Hub) is an initiative led by the Australian Institute of Refrigeration, Air Conditioning and Heating (AIRAH) in conjunction with CSIRO, Queensland University of Technology (QUT), the University of Melbourne and the University of Wollongong and supported by Australian Renewable Energy Agency (ARENA) to facilitate the heating, ventilation, air conditioning and refrigeration (HVAC&R) industry's transition to a low emissions future, stimulate jobs growth, and showcase HVAC&R innovation in buildings.

The objective of i-Hub is to support the broader HVAC&R industry with knowledge dissemination, skills-development and capacity-building. By facilitating a collaborative approach to innovation, i-Hub brings together leading universities, researchers, consultants, building owners and equipment manufacturers to create a connected research and development community in Australia.

This Project received funding from ARENA as part of ARENA's Advancing Renewables Program. The views expressed herein are not necessarily the views of the Australian Government, and the Australian Government does not accept responsibility for any information or advice contained herein.

[i-Hub Educational Sector Energy Baseline and Key Performance Indicators]

The Educational Sector Energy Baseline and Key Performance Indicators: addendum to the sector-wide baseline benchmarking report, present a comparison and analysis of a newly created database of energy use in Australian government primary schools across most states and territories (excluding WA, SA, and NT)

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1. INTRODUCTION

1.1. Background

The Educational Sector Energy Baseline and Key Performance Indicators report (iHub,2021) presented a baseline of the education sector energy consumption, drawing on existing literature from Australia and internationally, and a small data source from ACT schools. During preparation of that report, the project team engaged in a substantial data collection exercise, with discussion and requests for data being presented to each Australian State and Territory. As a result of this, a substantial new database of energy consumption in schools across Australia was compiled. However, there was insufficient time or resource to appropriately analyse the data during the initial project period.

1.2. Aim

The aim of this addendum report is to present the analysis of this newly collated database, incorporating data collected with various frequencies and methodologies from 3,701 schools, covering 82% of the Australian population. The aim is to use this large data resource to develop simple benchmark reference value for energy consumption in schools, and thereby enhance the ability to undertake large-scale assessment of the value proposition of renewable energy technologies.

1.3. Data collection

Data had to be obtained from each jurisdiction separately, and requests were made to each education department for access to school energy consumption data. Where existing contacts were not available, or initial requests were not successful, formal Freedom of Information requests were submitted to the relevant departments.

Specifically, each department was asked to provide information for every state primary school regarding:

- Location (postcode);
- Enrolment numbers per school;
- Gross floor area per school (if available);

- Energy use (gas and electric), annual at a minimum, and preferably monthly, or 15-minute smart meter data as available; and
- Solar or other renewable energy generation at each school.

Data was requested for at least one continuous 12-month period prior to the COVID-19 pandemic, to avoid confounding factors due to associated school closures.

1.4. Data processing

In response to these data requests, information was received for 3,701 state run primary schools from 5 of 8 Australian states and territories, covering 82% of the Australian population, 80% of all public primary schools. Data was not received for Western Australia, South Australia and Northern Territory. In all cases where data was not provided, the project team were informed that the requested information was not held in a central database.

Received data covered different time periods, had different temporal resolution and different levels of detail. In most cases gas consumption data was supplied for schools with a gas connection, however, for Queensland schools only gas expenditure (manual data entry by the school principal) was available, which was of limited value without knowledge of tariffs. For all states but Queensland, information was provided to indicate whether a school had solar PV installed, and PV generation data was provided by 3 states. All Victorian schools with solar PV were net metered, meaning that the magnitude of PV generation was not available, and consumption could not therefore be determined definitively. A summary of the received data is presented in Table 1.

Table 1. Summary of data collected (n is the number of schools for each relevant parameter).

State	n	Period	Temporality	Gas data	n_{Gas}	Schools with PV identified	PV Generation data available	n_{Solar}
New South Wales (NSW)	1561	Jul 18-Jun 19	Monthly	Y	548	Y	Y	1139
Victoria (Vic)	1074	2019	15 min	Y	514	Y	N	515
Queensland (Qld)	896	2014-2020	Annual	$	23	N	N	Unknown
Tasmania (Tas)	121	Jul 19- Jun 20	Monthly	Y	1	Y	Y	64

Australian Capital Territory (ACT)	49	2015-2021	15 min	Y	48	Y	Y	17*

***note: ACT schools with net metered solar PV generation that did not result in any export during the analysed year may not have been identified as having solar PV.**

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The data received from each state education department was compiled differently, with all requiring processing and aggregation to obtain a usable dataset. In some instances, initial datasets were consistent, requiring little processing, while others had multiple methods of saving data with multiple energy retailers, requiring significant processing and validation to obtain a coherent and usable dataset. The processing removed incomplete or irrelevant data (e.g. removing high schools, public education centres etc.), and linked electricity meters with school data (i.e. enrolment numbers, gross floor area, etc.). Valid data was retained for 3,701 schools, or 95% of all public primary schools in the various jurisdictions. Additional data was obtained from the Australian Bureau of Statistics (socioeconomic data, remoteness index), Australian Building Codes Board (boundary of climate zones), and the Nationwide House Energy Rating Scheme (NatHERS) (boundary of climate zones). These additional datasets were linked to energy use data using school postcodes. A simplified breakdown of the processing of data can be seen in Figure 1.

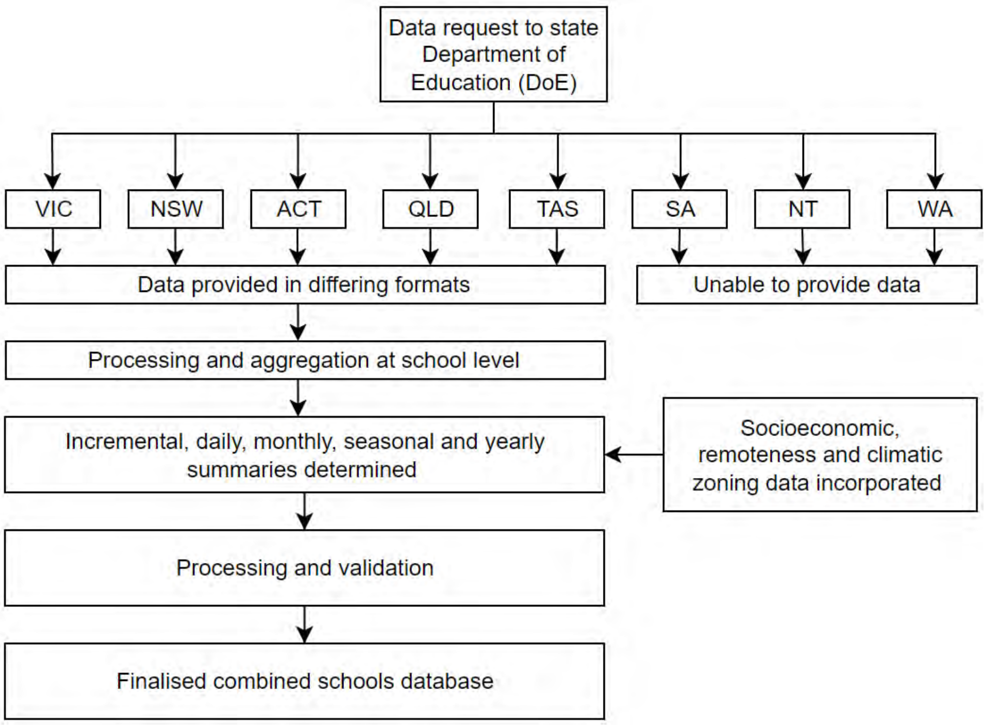

Figure 1: Process of developing energy usage database for Australian primary schools.

1.4.1. Climate zones

In Australia, there are two common definitions used to represent climate zones. The National Construction Code (NCC) describes 8 climate zones covering all Australia, based on the average humidity at 3pm and average maximum temperature in January, average July temperature, and average annual number of heating degree days. The NCC zones are also adjusted for ease of administration to match jurisdictional boundaries, local topographical features, and local construction practices (ABCB, 2019). The Nationwide House Energy Rating Scheme (NatHERS) describes 69 local climate zones to represent climate diversity across Australia, with the climate zone boundaries linked to postal areas. However, it is not clear by which exact measures and methods climate zones are differentiated in the NatHERS scheme [1]. Each school in the database was assigned an NCC and NatHERS climate zone based on the postcode of the school. The matching of NCC climate zones to postcodes was undertaken using shape file overlays from the Australian Housing Database [2]. A summary of the climate zones used in the current report is provided in Table 2.

Table 2. *Basis of the NCC climate zones, including the NatHERS climate zones captured by each NCC zone, and corresponding Koppen climate classification* [3].

Climate zone	Description	Average 3 pm January water vapour pressure	Average January maximum	Average July mean	Average annual heating degree days	NatHERS Climate zones	Corresponding Koppen zone (approximation)	Primary location of schools in Dataset
1	High humidity summer, warm winter	≥ 2.1 kPa	≥ 30°C	-	-	1, 2, 5, 29, 30, 31, 32, 33, 34, 37	Tropical *(Aw - Savanna)*	Regional, Far north Queensland
2	Warm humid summer, mild winter	≥ 2.1 kPa	≥ 30°C	-	-	7, 9, 10, 11, 15, 35, 36	Temperate *(Cfa - Humid subtropical)*	Brisbane, regional coastal Queensland and northern NSW
3	Hot dry summer, warm winter	< 2.1 kPa	> 30°C	≥ 14°C	-	3, 4, 6, 19, 38, 39, 40	Dry *(Bsh - Hot semi-arid and Bwh - Hot desert)*	Inland regional Queensland
4	Hot dry summer, cool winter	< 2.1 kPa	≥ 30°C	< 14°C	-	8, 13, 14, 20, 27, 41, 42, 44 45, 46, 47, 48, 51, 55, 59	Dry *(Bsh - Hot semi-arid, Bsk - cold semi-arid and Bwh - Hot desert)*	Inland regional NSW and Victoria
5	Warm temperate	< 2.1 kPa	< 30°C	-	≤ 1,000	12, 13, 15, 16, 17, 47, 50, 52, 53, 54, 56, 57	Temperate (*Cfa - Humid subtropical, Cfb- Oceanic, and Bsk - cold semi-arid)*	Sydney, Wollongong and Newcastle, Coastal urban NSW.
6	Mild temperate	< 2.1 kPa	< 30°C	-	1,000 to 1,999	14, 18, 21, 22, 28, 47, 49, 54, 56, 57, 58, 60, 61, 62, 63, 64	Temperate *(Cfb - oceanic, and Csb - Warm summer Mediterranean)*	Melbourne, Regional costal NSW and Victoria
7	Cool temperate	< 2.1 kPa	< 30°C	-	≥ 2,000 other than Alpine areas	23, 24, 25, 26, 65, 66, 67, 68, 69	Temperate *(Cfb - Oceanic)*	Canberra, Hobart. Inland regional NSW, Victoria and Tasmania
8	Alpine	Alpine area are areas 1200m or more above Australian Height Datum (AHD) for New South Wales, Australian Capital Territory and Victoria, and 900 m or more above AHD for Tasmania				69	Temperate *(Cfc- Subpolar oceanic)*	Alpine regions

1.4.2. Australian Bureau of Statistics Data

Two additional datasets were sourced from the Australian Bureau of Statistics (ABS) to assist in the analysis of energy consumption in schools. The ABS Australian Statistical Geography Standard Remoteness Structure [4] divides Australia into 5 classifications of remoteness on the basis of relative access to services, namely Major Cities, Inner Regional, Outer Regional, Remote and Very Remote. A remoteness category is provided for each postcode, which allowed the dataset to be linked with the school energy use database. Similarly, the Socio-Economic Indexes for Areas (SEFIFA) [5] ranks areas in Australia according to relative socio-economic advantage and disadvantage based on census responses. SEIFA provides an index for relative disadvantage, as well as of relative advantage and disadvantage, for each postcode. These indices provide a measure of “people's access to material and social resources, and their ability to participate in society” [5]. Given the role of Parents and Citizens Associations in fundraising for school equipment, it is reasonable to assume that schools in relatively more or less disadvantaged communities may have different access to energy related systems (i.e. Solar PV, air-conditioning, etc.).

2. RESULTS

Results presented below are for a common base year (2019) where possible, although NSW data was only provided for the period from July 2018 to June 2019, and Tasmania for the period July 2019 to June 2020, which caused some issues in comparability. First, a consideration of the size of schools in terms of gross floor area (GFA) and number of students is presented. Energy data is then analysed, with results presented for annual energy consumption, annual greenhouse gas (GHG) emissions, and the breakdown of energy source.

Additional exploration and statistical analysis of determinants of energy consumption in school, including climate zone, geographical location, socio-economic status of the suburb, and the impact of solar and gas will be available in a forthcoming article [6].

2.1. Australian school stock characteristics

Information supplied regarding the individual schools was limited to gross floor areas, student enrolment numbers and locations. School size (in terms of both gross floor area and enrolment number) strongly influences energy usage, with a greater amount of energy being required in larger schools. A direct comparison of energy usage is of limited utility due to this variation, so normalisation by area (kWh/m^2/yr) or enrolment (kWh/student/yr) is necessary to better aggregate and compare schools of differing size.

A summary of the GFAs and enrolments are provided in the figures below. It can be seen in Figure 2 that considering both size and number of students, there is a high proportion of smaller schools (22% were less than 1000 m^2, and 19% had fewer than 50 students). This was relatively similar for each jurisdiction within the database, as shown in Figure 3, although the ACT was notably for having few small schools (i.e. only approximately 20% of ACT schools had fewer than 400 students, compared with approximately 65-85% for other states). Considering the student density (m^2 per student) shown in Figure 4, there is much less variation, with the great majority of schools having between 5 and 20 m^2 per student.

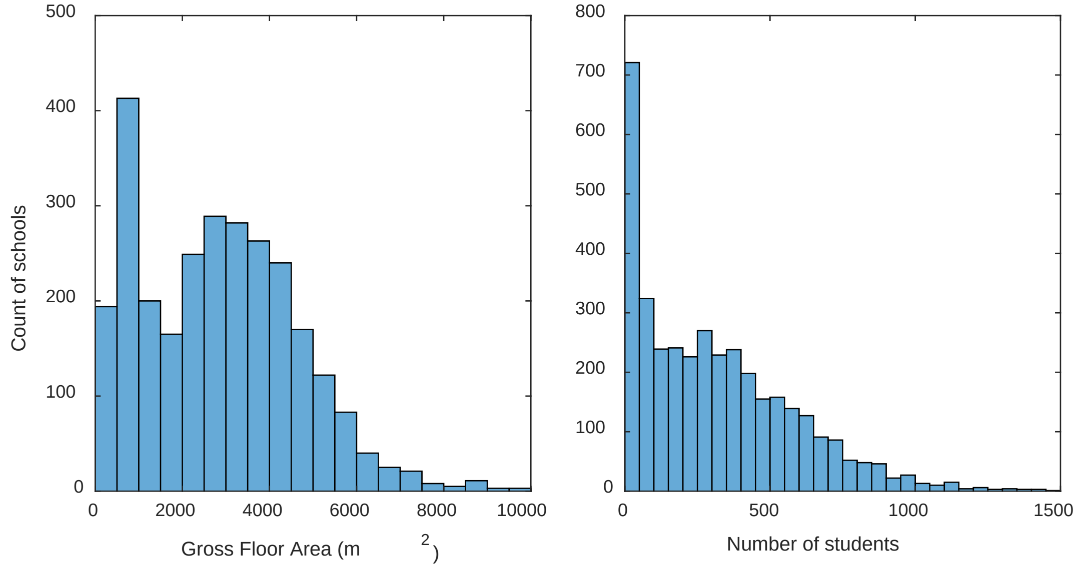

Figure 2. Summary of i) gross floor area and ii) student numbers for Australian primary schools captured within the database. Note: GFA information was not available for Queensland schools.

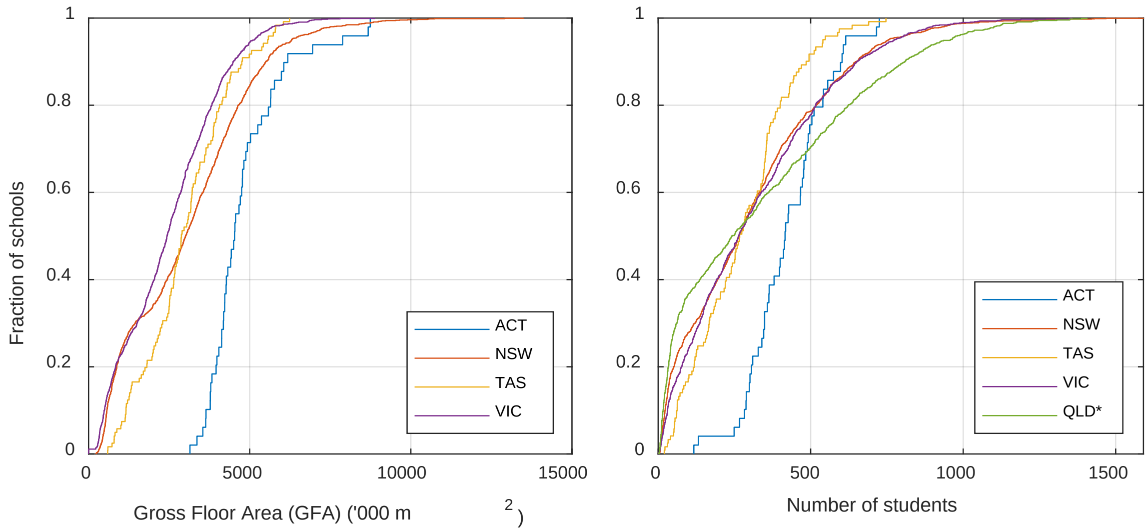

Figure 3. Cumulative distribution function plot of i) gross floor area and ii) enrolment number for the reference year for each state. Note: GFA data for Queensland was not available.

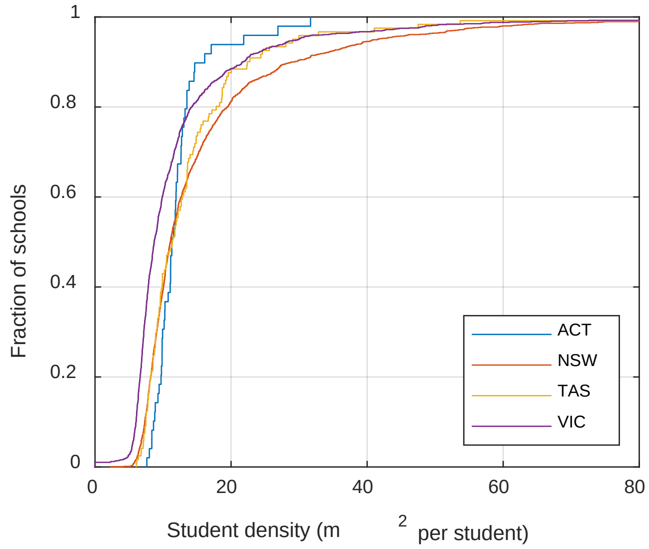

Figure 4. Cumulative distribution of student density for each state. Note: GFA information was not available for Queensland schools.

As noted in the introduction, there is some debate regarding whether the use of area based or student based normalisation is the most appropriate metric by which to benchmark school energy consumption. As GFA data was not available for Queensland, the default normalisation for the current report will be on a per student basis, however, an exploration of the impact of the normalisation method is included where relevant. These two normalisation options are highly correlated, as can be seen in Figure 5, where the adjusted R^2 for the regression was 0.73.

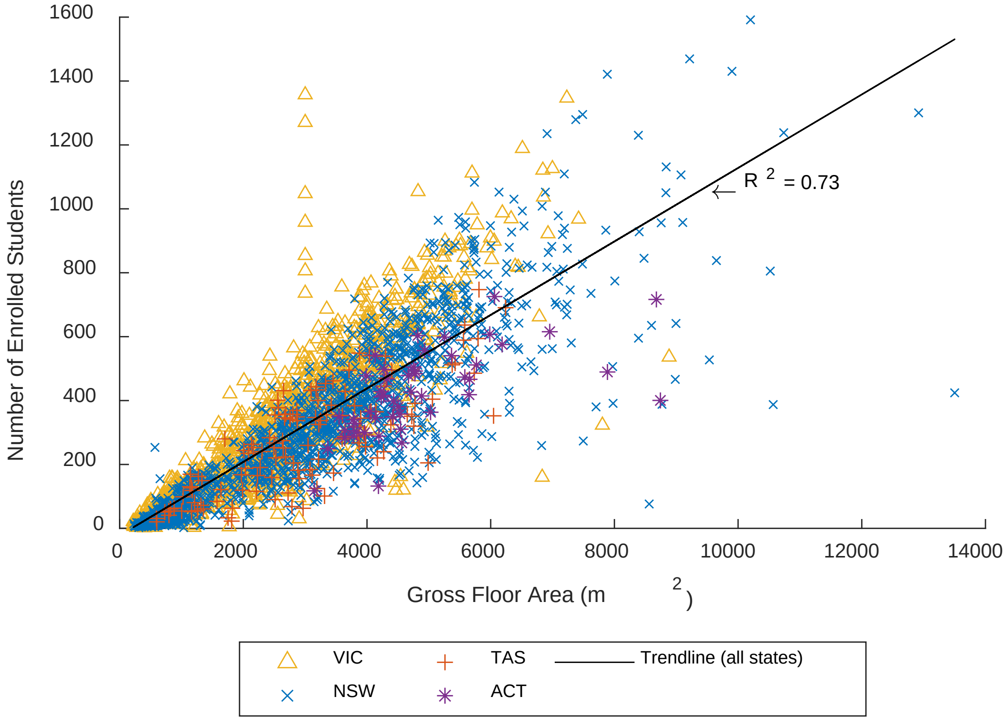

Figure 5. Relationship between number of enrolled students and gross floor area. Note: GFA information was not available for Queensland schools.

In line with findings in previous literature, we found that energy use in schools is moderately correlated with school size, in terms of both GFA and enrolments. The regressions shown in Figure 6 show that within the current database both measures of school size are positively correlated to energy usage, with both measures having adjusted R^2 values of approximately 0.6. Given that both measures are similarly correlated to school energy use, this analysis indicates that area based and enrolment based normalisation methods are equally useful; which is perhaps not unexpected given the correlation between these measures in Figure 5.

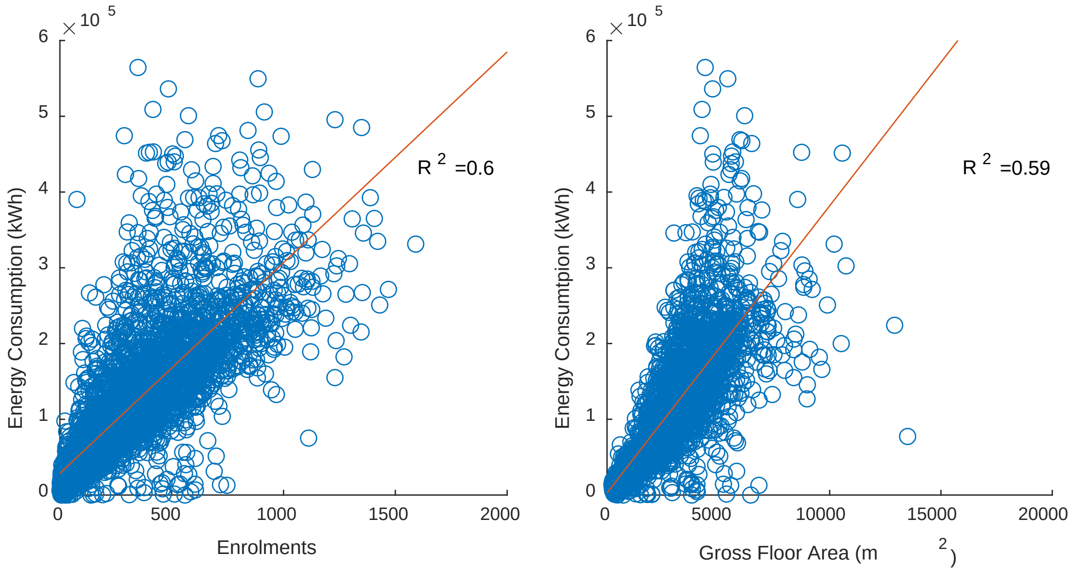

Figure 6. Regression of school energy consumption against i) enrolments and ii) gross floor area. Note: GFA information was not available for Queensland schools.

2.2. Annual Energy Consumption

Summary visualisations of the annual energy consumption of each school for the various jurisdictions in the database are shown in Figure 7 and Figure 8. Binned energy data shown in Figure 7 shows that, when considering total energy consumption, there is a large number of schools that use relatively little energy, corresponding to the large number of smaller schools in Figure 2. Energy consumption per m^2 shows a close to normal distribution, with a slight positive skew, with a mean of 38.0 kWh/m^2/yr and median of 35.7 kWh/m^2/yr. This is significantly lower than the value reported by COAG [7] of 48 kWh/m^2/yr, however, it must be noted that this COAG report i) has internal inconsistencies, and also reports figures as high as 109 kWh/m^2/yr, and ii) does not differentiate between primary and secondary schools. The energy consumption per student in the current database is positively skewed, approaching a log-normal distribution with a mean of 542 kWh/student/yr and a median of 392 kWh/student/yr.

Considering the variation between jurisdictions shown in Figure 8, on a per school basis, median energy consumption at ACT schools was substantially higher than other jurisdiction at 367 MWh/school/year (380% greater than the median of the rest of the dataset). Considering normalised energy consumption (per m^2 or per enrolment) the relative differences between jurisdictions was reduced, although schools in the ACT were still the largest consumers with a median of 873 kWh/student/yr (225% greater), and 77.2 kWh/m^2/yr (250% greater).

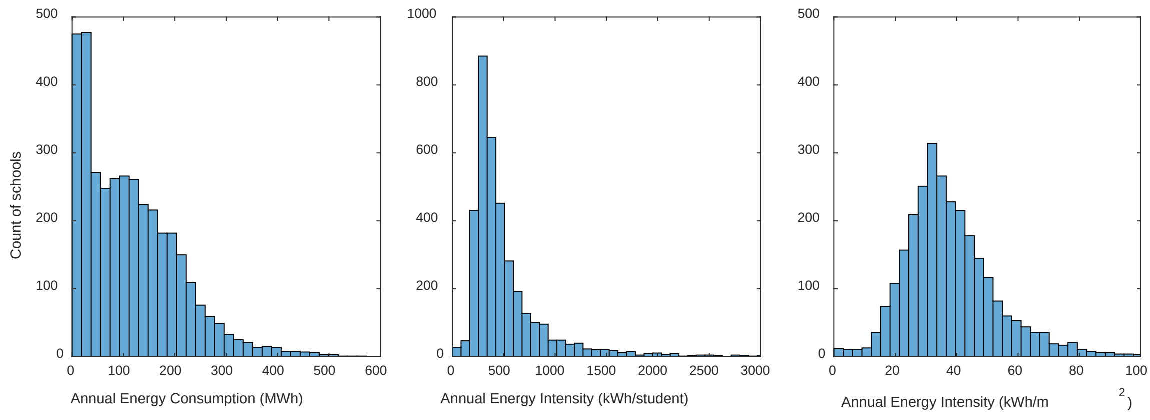

Figure 7. Histogram of annual energy consumption for all schools in the database, showing energy use i) per school, ii) per student and iii) per m². Note: GFA information was not available for Queensland schools. While outliers are not included in this figure they are shown in detail in the Figure 8 below.

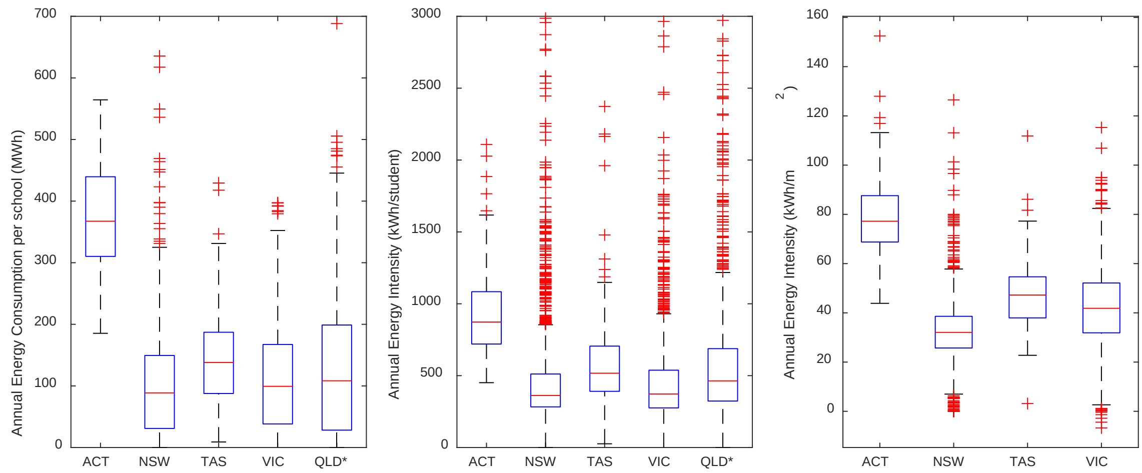

Figure 8. Boxplot of annual energy consumption per school for each state in the database, showing i) total energy consumption, ii) energy consumption normalised by floor area, and iii) student numbers. Note: GFA information was not available for Queensland schools, and gas consumption information was deemed unreliable, therefore the small number of schools with gas supply in Queensland are not included in these figures.

The figures above include both gas and electricity data in total energy consumption, however, annual GHG emissions are of greater importance from the point of view of environmental impacts. In Australia, different states have different energy generation profiles, leading to associated variations in carbon intensity of energy generation. Conversion of electricity and gas consumption was completed using the National Greenhouse Accounts Factors [8]. Nationally the emission intensity factor for natural gas was taken to be 51.4 kg CO2-e/GJ (equivalent to 0.19 kg CO2-

e/kWh). The emission intensity factors for electricity generation varied widely across the different states; ranging from 0.17 kg CO2-e/kWh for Tasmania, through 0.81 kg CO2-e/kWh for ACT, NSW and QLD, to 0.98 kg CO2-e/kWh for Victoria. In 2020, the ACT sourced 100% of its energy from renewable energy generators [9], however, the NGER factors are based on average emission intensity for a connected grid, and the impact of these renewables purchasing agreements are shared across the grid.

A comparison of the results presented in Figure 8 and Figure 9 shows that it is important to use the emissions intensity factors of the various energy sources to provide a realistic measure of the environmental impact of greenhouse emissions related to energy use in schools. Figure 9 shows that Tasmanian schools, which are predominately powered by electricity from a network with a high proportion of hydro power, produce substantially lower emissions than schools in other states. NSW and Victorian schools have similar CO_2 emissions on a per student basis, with ACT and Queensland schools being slightly more emissions intensive (noting that the NGER emissions factors do not attribute ACT renewable purchasing to the ACT supply). On an area basis, for which Queensland GFA data was not available, ACT and Victorian schools were the most emissions intensive.

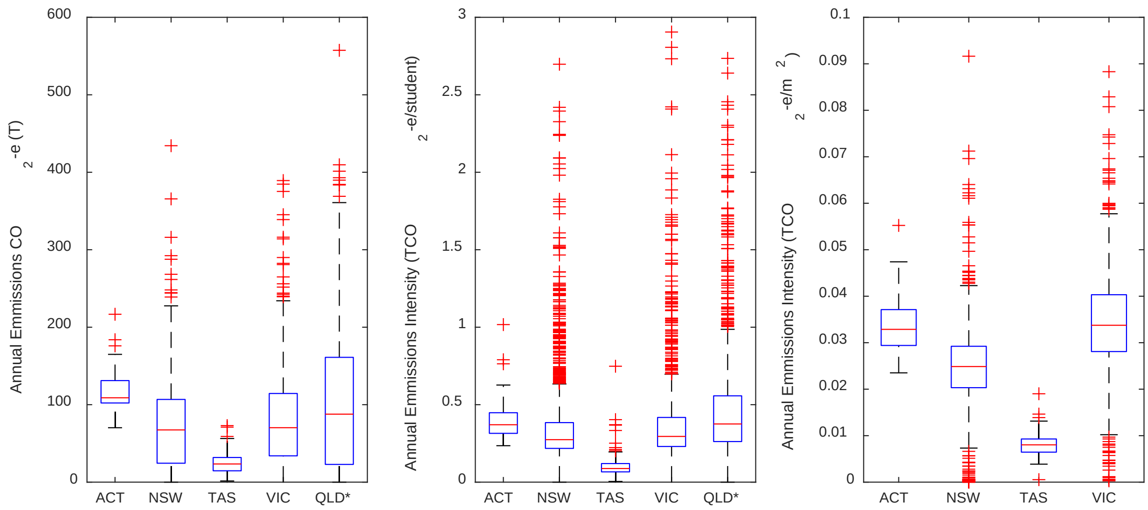

Figure 9. i) Annual greenhouse emissions, ii) emissions intensity per student and iii) emissions intensity per m² for Australian schools. Note: gas consumption and GFA was not available for Queensland schools

The difference between total energy consumption and associated greenhouse emissions is in part explained by the different emission intensity conversion factors of energy sources, and that schools in each state supply different proportions of their energy demand from gas and electricity.

The ratio of median Annual Energy Intensities in ACT and Victoria (Figure 8iii), is double that for the ratio of Annual *Emissions* Intensities (Figure 9iii), for example, and this is primarily because of the different proportion of school total energy supplied from natural gas in each state (Figure 10). Natural gas currently has a lower emissions factor than grid electricity, and gas accounted for 60% of total energy consumption in ACT schools and 26 % in Victorian schools. This compares with 11% for NSW and a negligible contribution in Queensland and Tasmania.

It is worth noting that the Queensland data in Figure 10 was based on expenditure rather than consumption data for both gas and electricity, as consumption information was not available for gas. In Queensland 3% of primary schools had a gas connection or used bottled gas, however, only 1% (n=11) of schools had gas costs greater than 1% of total energy costs.

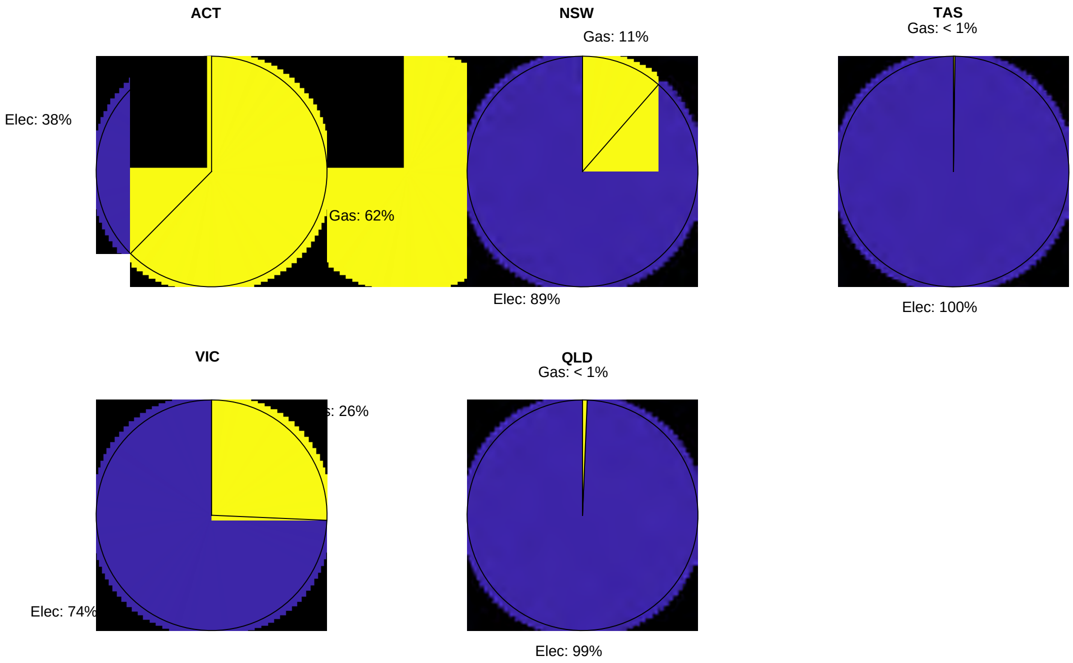

Figure 10. Proportion of total energy consumption in schools from natural gas and electricity for each state included in the database for which gas consumption information was available. Note: only gas expenditure data was available for Queensland schools; electricity data for Victorian schools with solar generation is net consumption.

3. CONCLUSIONS

This addendum report has summarised the compilation and analysis of energy use data for 3,701 public primary schools across five jurisdictions in Australia, covering approximately 82% of the population. Mean energy consumption was found to be 38.0 kWh/m^2/yr, or 542 kWh/student/yr. Substantial variations were identified between jurisdictions, although differences were lower when greenhouse gas emissions were considered, rather than energy use, due to substantial variation in the use of gas across states.

Of the schools in the database for which information on the presence of solar PV systems was available, 64% had a solar PV array installed against 37% that did not. Schools with solar PV had an average net energy usage 16% lower than schools without solar, suggesting existing PV systems were undersized. Gas was present in 31% of the schools in the current database, however, this varied significantly across the jurisdictions. Energy consumption was notably higher on a per m^2 basis for schools with gas present (mean of 45.3 kWh/m^2/yr vs 33.1 kWh/m^2/yr for schools without gas).

There are myriad different purposes this database could now be used in support of appropriate policy development and energy management in the schools sector. By way of example, this database can provide an initial energy intensity benchmark to support the development of a school energy performance rating tool. Table 3 presents a set of possible/hypothetical energy performance benchmarks for a simple 10-step star rating system based on the percentile energy performance of schools within the database.

However, the development of a practical star rating system to guide future school energy system design and operation would require further analysis, and ideally the addition of further data to substantially increase the breadth and robustness of our current database. Benchmarks may be more appropriately differentiated at a state or climate zone level, for example, and likely should account for urban regional geography. This would allow individual schools to better compare their performance against others of similar situations and characteristics. Information on the conditioned floor area, presence of cooling, cooling system types, heating system type, presence of high energy consuming facilities, and presence, size and metering configuration of solar PV and other renewable energy resources would allow much greater understanding of the drivers of energy consumption. Any such school energy star rating system would need to carefully consider how to value the provision of appropriate IEQ for improved learning performance so that schools are not encouraged to sacrifice IEQ for an improved energy star rating.

Table 3. An example of a hypothetical star rating schema that could be developed from the current database, showing EUI and energy consumption per student for various percentiles.

Star rating	Percentile	Maximum Energy Consumption per student (kWh/student/yr)	Maximum Energy Consumption per m^2 (kWh/m^2/yr)
9 star	10th	236	21
8 star	20th	276	26
7 star	30th	312	30
6 star	40th	348	33
5 star	50th	393	36
4 star	60th	452	39
3 star	70th	528	43
2 star	80th	661	48
1 star	90th	962	58

The new database that was developed and analysed in this report represents a significant contribution to benchmarking and understanding of energy use in Australian primary schools, including physical, geographic and jurisdictional variations in energy performance. It is expected to be utilised by organisations such as NABERS to develop rating tools for school buildings.

Additional exploration and statistical analysis of determinants of energy consumption in school, including climate zone, geographical location, socio-economic status of the suburb, and the impact of solar and gas has been undertaken and it will become available in a forthcoming article [6].

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