The Innovation Hub

for Affordable Heating and Cooling

Report #LS1_Baseline

Living Labs Educational Sector Energy Baseline and Key Performance Indicators

20 May 2021

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.

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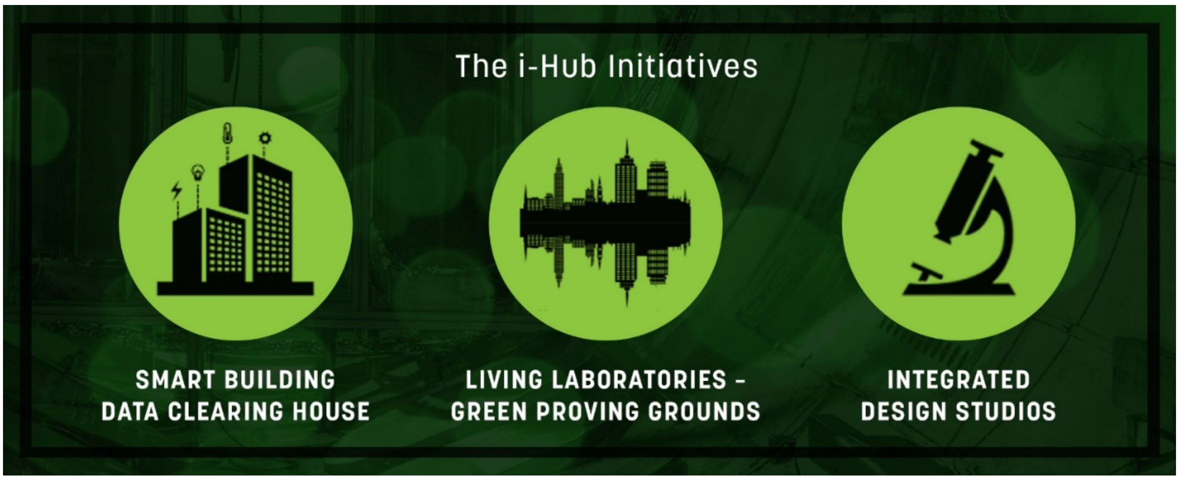

[i-Hub Educational Sector Energy Baseline and Key Performance Indicators]

The Educational Sector Energy Baseline and Key Performance Indicators project will quantify education sector energy consumption, identify the potential for renewable energy technologies to reduce sector energy consumption and cost for HVAC in particular, and propose requirements for optimal integration of renewable energy technologies.

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1.0	21/04/2021	Released for comment by AIRAH and ARENA	L Ledo	D Daly, G Kokogiannakis
2.0	**20/05/2021**	**Added discussion of new data sources (section 2.3), and calculation of REETSEF KPI's for ACT Schools (Section 2.3.2)**	**D Daly**	**G Kokogiannakis**

Please note, this a living document that will be iteratively updated during the establishment and operation of the foundation living laboratories. The above table only tracks major published updates. Please download the latest version from Note: Insert Public Link After Major Feedback from AIRAH and ARENA Implemented.

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1 INTRODUCTION

1.1 Background

Education facilities (schools) are characterised by high levels of energy consumption, which represent a large percentage of the facilities running cost. In the US, for example, schools constitute 8% of the total commercial buildings energy use and their energy bills are the second-highest operating expense, following the salaries. In addition, electricity demand in school buildings is expected to rise in the near future due to higher student numbers and a more intensive use of technologies as pedagogical tools.

The education facilities covered in this report include schools of different levels from preschools to high schools (secondary school), together with special schools and colleges (years 11 and 12).

1.2 Aim

The aim of this report is to collate a range of existing energy KPIs and data for the education sector domestically and internationally. These KPIs will establish a point of reference to benchmark the Australian school's energy consumption, enabling the assessment of the value proposition of renewable energy technologies.

1.3 Scope

The Baseline Report for education facilities presents electricity and gas consumption data assembled through a review of published literature (government and sector reports as well as academic publications) together with an analysis of data provided by the senior director of infrastructure and capital works for the education department in the ACT Government.

This review provides existing KPIs already employed in the literature. The existing KPIs are evaluated in terms of their effectiveness in enabling renewable energy or energy efficiency technologies, reducing peak demand and energy use. Recommendations on principles to select KPIs are provided at the end of the report before the conclusion section.

The current report update includes information on data sourcing activities aimed to assemble a substantial data resource for schools energy consumption (included in Section 2.3), as well as calculation of a number of the Renewable Energy and Enabling Technology Service Evaluation Framework Key Performance indicators (REETSEF KPI's) for all ACT schools to serve as a benchmark for the living laboratory baseline and technology evaluations (Section 2.3.2).

2 SCHOOLS ENERGY BASELINE

Baseline data of energy use in the schools building stock can be used to benchmark the performance of school buildings. A benchmark is a value of a performance metric, which indicates a point of reference [1]. Effective energy benchmarking identifies and employs key performance indicators (KPIs) to assess the energy performance. Understanding the factors influencing the energy performance is key for developing these KPIs.

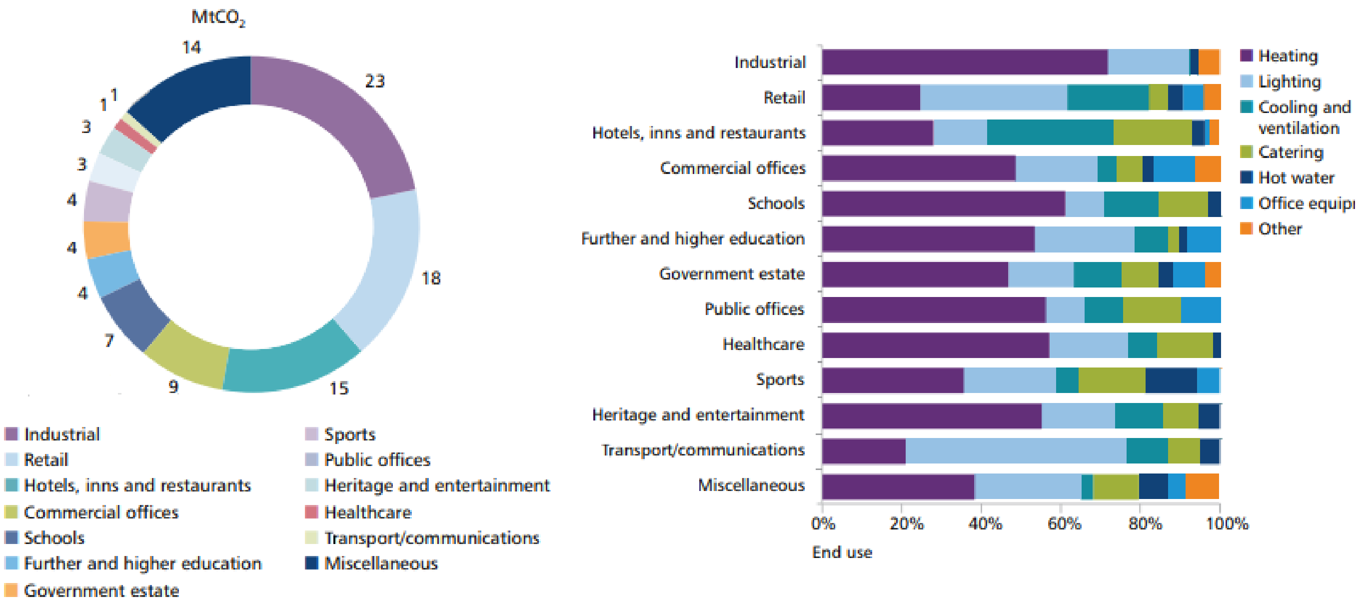
A technical guide on the energy performance of non-domestic buildings established that key factors influencing the non-domestic buildings energy performance were building design, systems, occupancy and climatic conditions [2]. Each of these factors was assessed for 40% the school building stock in England [3] showing that location, HVAC system and school density correlate with the energy use of the schools. Another study undertaken in 80 Italian schools [4] underlined the parameters that could be employed to characterise a school energy performance, these were: i) the school's level (i.e. preschool, primary or high school), ii) the geometric characteristics of the school via the ratio between its externals surface and heated volume and iii) the age of the building that is associated with the relevant building code regulations.

In Australia, no method for measuring the performance of school buildings, nor mandated targets for improvement exist in this sector.

The following sections first provide an overview of the energy reported in schools across the world. Then, an analysis on the energy consumption for the schools of the Australian Capital Territory is provided, with particular emphasis on the two living laboratories, Amaroo and Fadden schools. Finally, the typical KPIs used in the review of the literature are summarised

2.1 Energy use in schools

Due to the major social importance of school buildings, the energy performance of these facilities has been subject of interest from several researchers [5]. In the UK, schools represented one of the top carbon emitters for non-domestic buildings as seen in Figure 1a [6]. The highest energy end use in the schools corresponds to conditioning the spaces, i.e. heating, which is almost 60% of the total energy use, followed by cooling and ventilation (10%), as observed in Figure 1b.



(a) (b)

Figure 2-1 (a) Breakdown of non-domestic buildings CO_2 emissions in the UK by sector and; (b) end use in each sector from [6].

In the US, educational facilities use 12% of all the nation commercial buildings energy consumption, corresponding to the third highest user behind mercantile and services (e.g. malls and stores) and office buildings [7]. Similarly to the UK, most of the energy (66% in the US as per Figure 2) is used for conditioning the school via heating, cooling and ventilation.

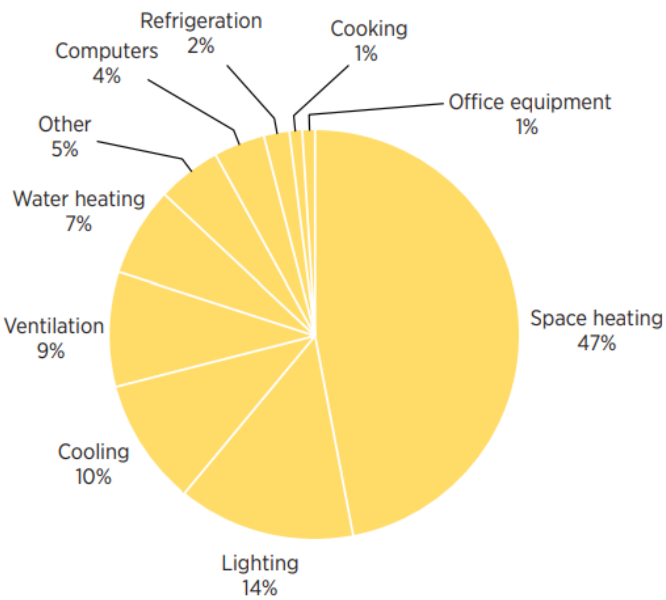


Figure 2-2 US schools: energy breakdown by end use reproduced from [8].

In a review on energy use in schools worldwide, it was found that European schools energy use intensity (EUI) ranged from 33 kWh/m^2 in the warm central region of Portugal to 217 kWh/m^2 in the maritime and continental climate of Finland (a summary of the energy intensity by country is depicted in Figure 3). The highest EUI from the studied countries was a heating dominated climate (Canada) with an energy intensity as high as 360 kWh/m^2 [9]. The EUI of Australian schools was approximately 50 kWh/m^2 and it was among the lowest from the dataset based on data collected from 2001 to 2011. It should be noted that a disclaimer on the completeness of the records for Australian schools was made in the pitt& sherry report [10], as Australian schools were reported to present the lowest average EUI of all Australian commercial buildings studied in that report. The low energy consumption is attributed to the missing data for the coldest states (Tasmania and Victoria) and the largest sample size for schools in milder climates (NSW) compared to colder climates (ACT), as the sample size for NSW included all schools in the State.

The variability of EUI among Australian states can be seen in Figure 4. There is a substantial difference in energy use between each state due to the different climates and practices. The more extreme climates (Northern Territory with a tropical climate and the Australian Capital Territory with a continental climate) present approximately 2.5 times higher energy intensity compared to the reported Australian average energy intensity.

The EUI variability is also present across all countries, as the EUI is highly dependent on the location of the study, the sample size in each location and the type of school. For example, a study undertaken by Issa et al. [11] with 35 schools in Toronto showed the EUI of 275 kWh/m^2/year, which corresponds to 71% less than the EUI reported by the average teaching facility for the whole Canada ([9]) or to more than double than the median EUI for the Canadian K-12 schools (127 kWh/m^2/year) in [12]. Therefore, it is important to report the boundary conditions (heating degree days, floor area, occupants, etc.) for benchmark analysis and the use of KPIs.

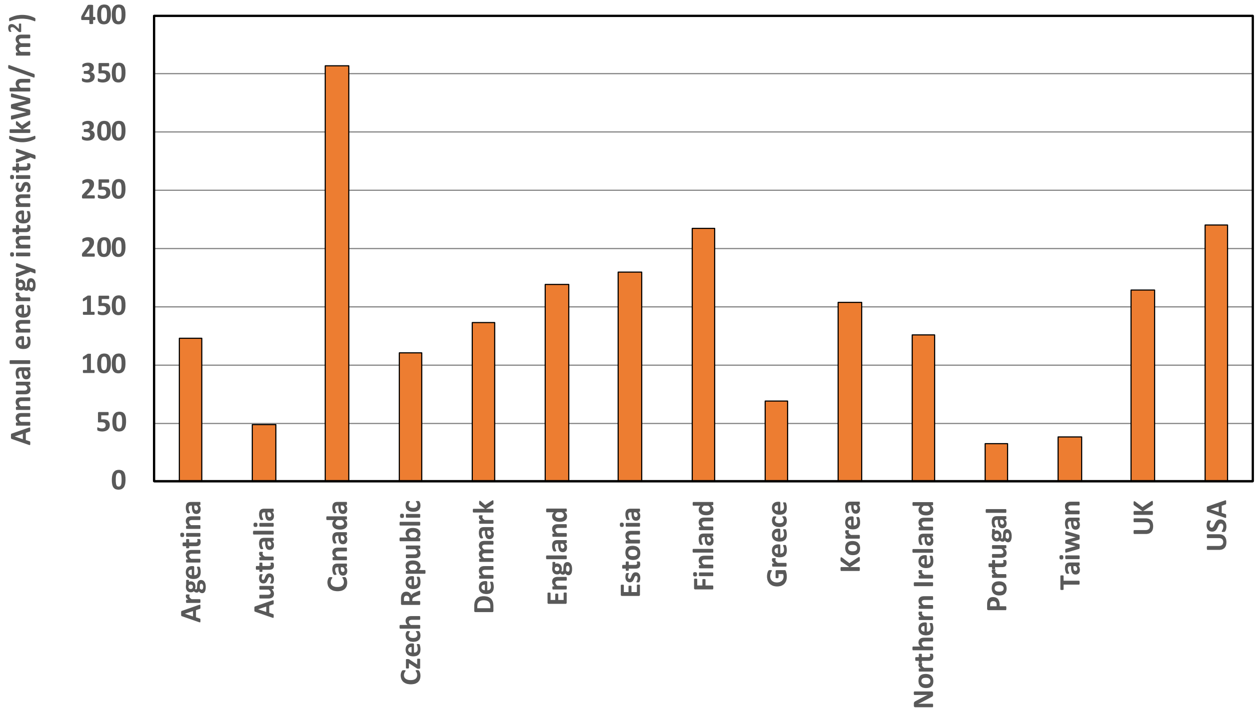


Figure 2-3 Annual average energy intensity for school buildings consolidated from [5,9,10,13].

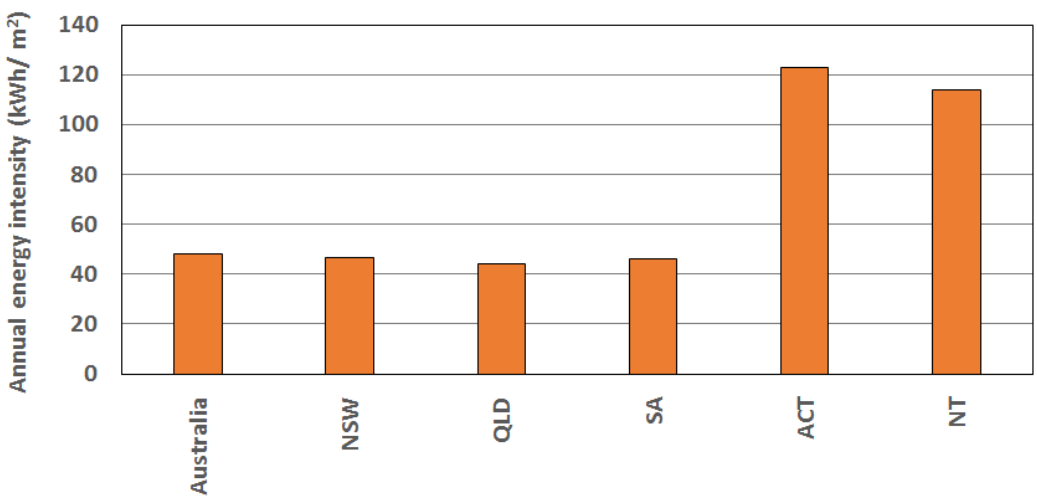


Figure 2-4 Annual average energy intensity for Australian schools consolidated from [10].

The electricity and thermal EUI benchmarks for schools that were published over the past two decades in England are shown in Table 1. The minor differences in the thermal EUI between primary and secondary schools suggests that, in this case, a shared benchmark for both schools could be possible.

Table 2-1 Energy consumption benchmark in terms of electrical energy use intensity (EUI) and weather adjusted thermal EUI of primary and secondary schools in England as consolidated from [14].

Existing Benchmark	Electrical EUI (kW·h/m²)		Thermal EUI (kW·h/m²)	
	25th %	Median	25th %	Median
CIBSE TM46 (2008)	-	40		150
CIBSE Guide F (2012): — primary	22	32	113	164
— secondary	25	33	108	144
ECG073 (1996): — primary	20	28	126	173
— secondary	24	30	136	174

It is crucial to select appropriate KPIs to express the energy performance of schools. For example, Desideri and Proietti [15] assessed the energy performance in Italian schools over a three-year period. Their results showed that normalising the energy consumption by student yielded to older schools performing better than newer schools. On the contrary, the new schools had a lower energy consumption than the older schools when normalised by unit volume. Another study [16] showed the large variability of EUI in middle schools in the same city in Korea, ranging from 67–240 kWh/m^2/yr. However, normalising the energy consumption per student led to similar results across these Korean schools.

In Portugal, two studies explored different normalisation methods of the energy consumption for six [17] and eight [18] secondary schools.

In [17], the normalisation was undertaken by adjusting for the floor area (gross floor area and total useful floor area), number of students and Heating Degree Days (HDD). Three KPIs (kWh/GFA, kWh/TUFA and kWh/student) are shown in Figure 5 together with the median (typical practice value) and 25% percentile value of the sample (good practice). It can be seen that the relative performance of each school changes depending on the KPI employed. Only the best performance school remains on top regardless of which of these KPIs are used. In the aim of adjusting climate differences, the energy intensity was also normalised by the heating degree days (HDD) in Figure 6. This metric provides a different picture once again (the relative ranking of each school has changed). For example, the worst performing school is now labelled as “BJA” while with the EUI KPI (kWh/m^2) it was identified as the 3rd worst performing. The study further investigated the normalisation using HDD by assessing the relation between HDD and the EUI. Results in Figure 7 show that, in this case, the two variables do not have a strong correlation. However, it should be noted that other studies employing this normalisation recommend separating electrical and thermal energy when normalising by the HDD (see for example [12,19]) which was not undertaken in the study shown in Figure 7 [17] .

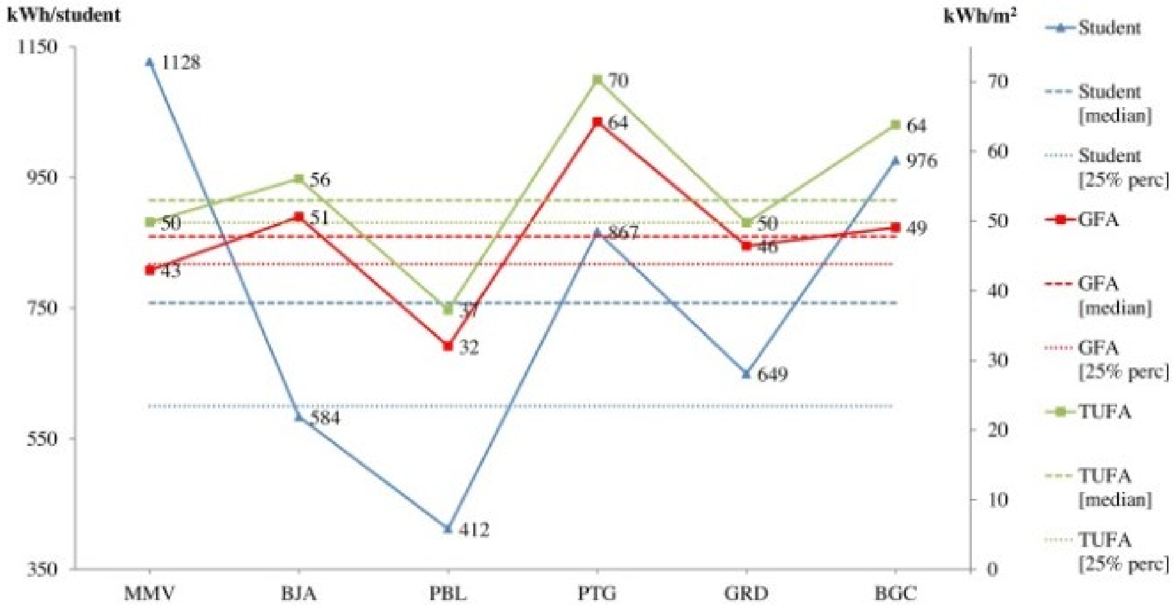


Figure 2-5 KPIs for 6 Portuguese schools relating the energy consumption to GFA and TUFA, expressed in kWh/m^2, as well as energy consumption related to number of students, expressed in kWh/student from [17].

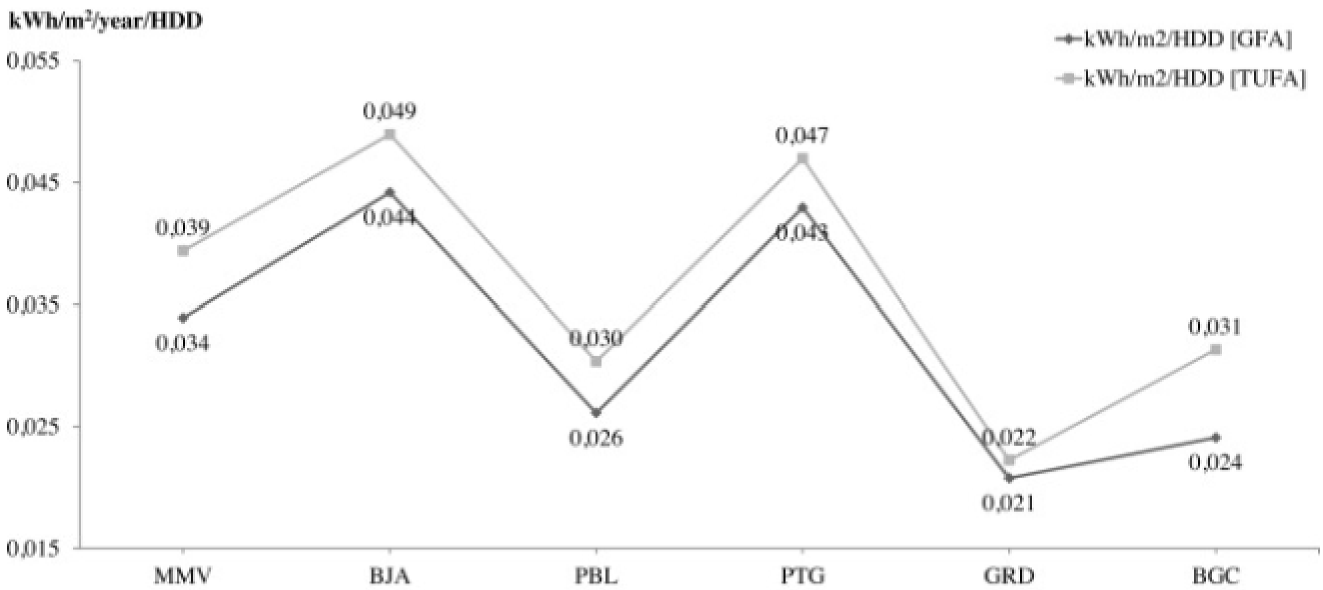


Figure 2-6 Energy intensity normalised by HDD for 6 Portuguese schools from [17].

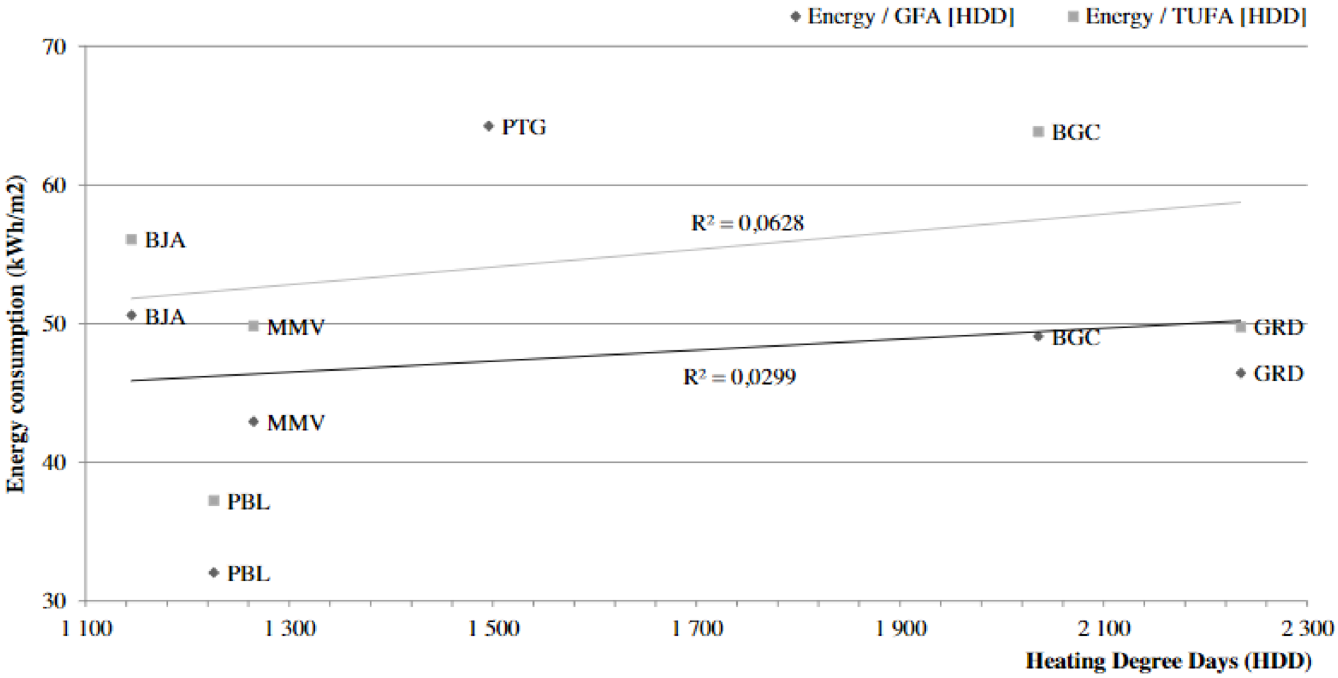


Figure 2-7 Energy consumption (kWh/m^2) against heating degree-days (HDD) from [17].

The study on 8 Portuguese secondary schools in [18] presented the energy consumption normalised by area, student and both area and student as illustrated in Figure 8. In this case, the school energy performance rankings also change according to the KPI used and only the best performance school remained constant (i.e. top position relative to the other studied schools) irrespectively of the KPI used.

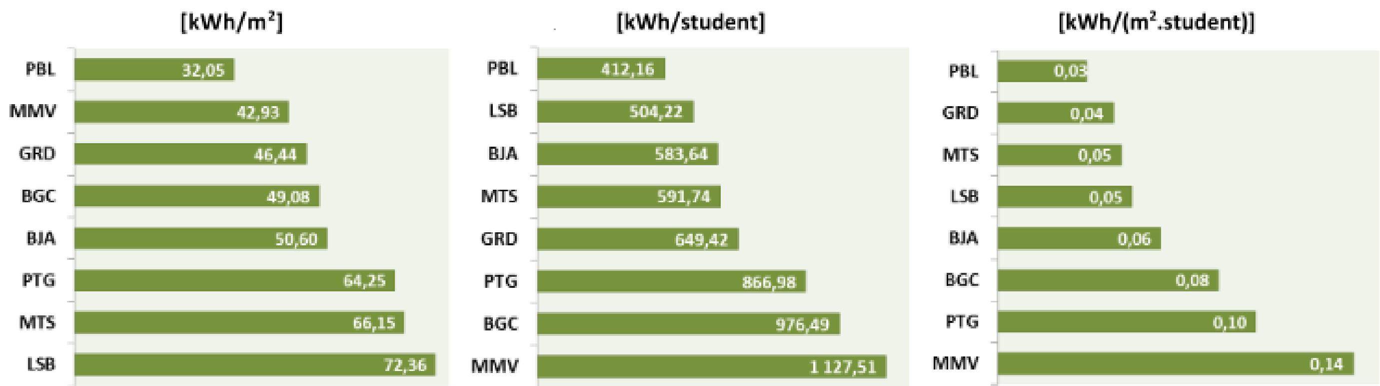


Figure 2-8 Schools energy performance ranked by kWh/m^2, kWh/student and kWh/m^2/student from [18].

2.2 Energy profiles

The climate zone has a strong impact on the monthly or seasonal energy demand. For example, a study in the USA reported that in cold and humid climates, heating accounts for as much as 40% of total energy consumption, whereas a school with a temperate and humid climate consumes

14% for heating (as shown in Table 2). To be able to compare the energy intensity against different climates, some studies suggest to normalise the heating consumption with heating degree days (e.g. [12,19]). The different climates also drive the mix of fuels used in the schools; for example in cooling dominates climates the use of electricity is larger while the use of natural gas and other fuels used for heating is reduced compared to heating dominated climates. These differences, in turn, alter the building's energy profiles, requiring different management of on-site renewable and integrated energy technologies.

Table 2-2 National US average school end use of energy ratios by climate from [8].

Climate	Heating (%)	Cooling (%)	Lighting (%)	Hot water (%)	Miscellaneous (%)
rCold and humid	40	12	30	11	7
Cool and humid	23	30	30	10	7
Cool and dry	32	21	30	10	7
Temperate and humid	14	41	30	8	7
Temperate and mixed	30	23	30	10	7
Hot and humid	18	35	30	10	7
Hot and dry	16	38	29	10	7

In Canada, a modelling study investigated the energy profiles of five different building types, i.e. 16 residential buildings, 1 restaurant, 1 supermarket, 1 small office and 1 primary school. The buildings were designed to be five energy hubs, where the on-site generated energy could be shared by the interconnection of the thermal and electricity grid to meet the demand loads of each of the buildings. The results of the building performance simulation in terms of the weekly average thermal and electrical profiles for each season are presented in Figure 9.

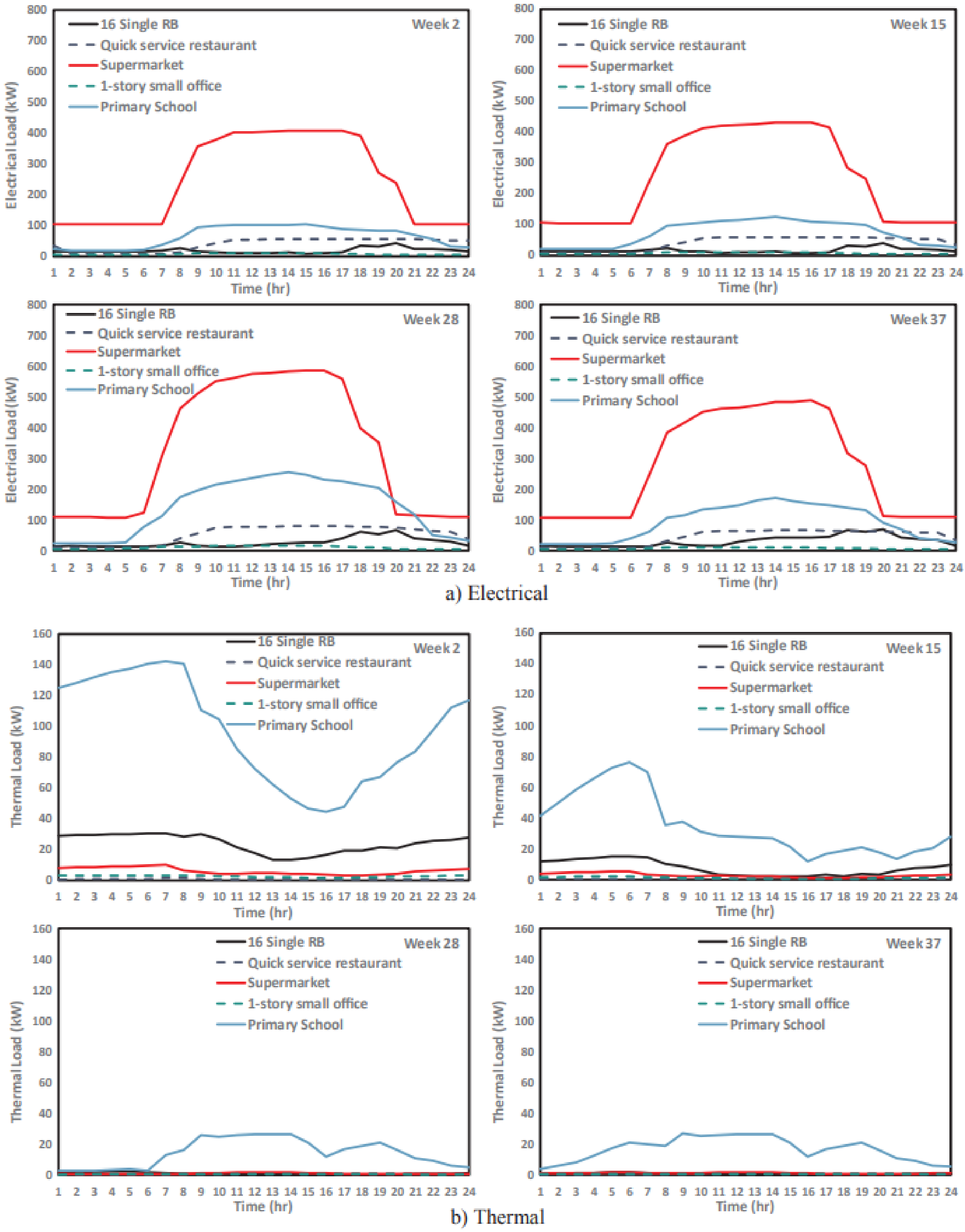


Figure 2-9 Hourly electrical and thermal load profiles for each hub at different weeks (a) electrical, and (b) thermal buildings, consolidated from [20].

The primary school has the second highest electrical demand (Figure 9a) and the highest thermal load (Figure 9b). The higher thermal load compared to the other buildings was explained by the building dimensions and construction, as the school had several floors and large window-to-wall ratios, which increases the heat transfer towards the outdoors. In this Canadian study, electrical grid, conventional and renewable technologies were employed to provide electrical and thermal energies to meet the demand loads.

The same study in Canada also assessed the effect of electrical storage capacity with four battery sizes as a percentage of the average electrical load of the primary school to estimate the optimum battery size. Figure 10 shows the hourly electrical load profile for the primary school on week 15, including the charging and discharging electrical energy during off-peak and on-peak hours, respectively with battery sized 60% of the average electrical load. It can be seen that during the off peak hours (before 7am and after 22pm) the battery is used to store energy while during the day (particularly from 8am to 10am), part of the demand is covered by the electrical energy discharged from the battery.

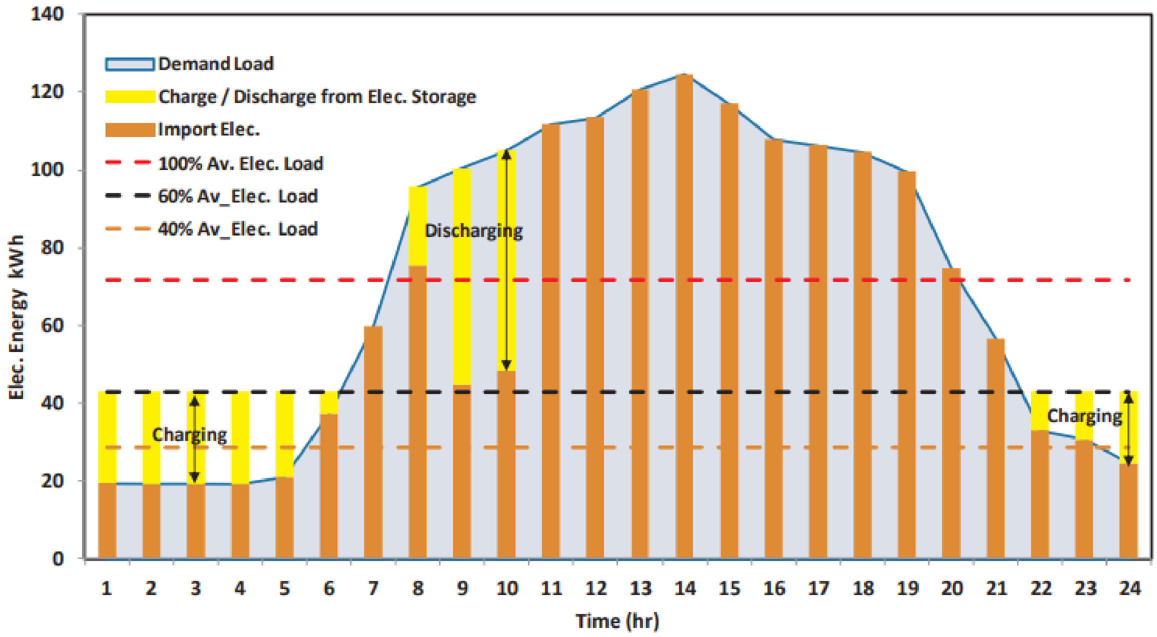


Figure 2-10 Primary school electrical profile including charging and discharging electrical energy on week 15 for 60% of the average electrical load from [20].

Another important factor for the rise of energy consumption and the dynamically varying energy profiles in schools is the provision of adequate indoor environmental quality. Evidence showed that indoor environmental quality (IEQ) including indoor air quality (IAQ), thermal, acoustic and visual comfort significantly affects not only the building energy performance but the pupils' health, academic performance and well-being [21–27].

2.2.1 Indoor Environmental Quality

Classroom IEQ conditions, and related impacts on students and teachers, are some of the 'value propositions' that could be quantified when evaluating renewable energy technologies. However, based on [28], the majority of the 3.9 million school students in Australia spent their day in inefficient schools with poor indoor IEQ [28].

A crucial parameter for maintaining Indoor Air Quality (IAQ) is ventilation. This importance is demonstrated for example in [29]; this study assessed five mechanically ventilated classrooms to understand how poor IAQ affect the performance of schoolwork. Their results showed that doubling the ventilation rate would lead to an improved performance of schoolwork by 8%. Adequate ventilation employs approximately 30% or more of space conditioning energy demand [30]. As a result, there is conflicting interests between minimising ventilation rate to reduce energy demand and maximising ventilation for optimum indoor air quality (IAQ) and occupants' well-being. Therefore, the use of a ventilation strategy that balances good IAQ while reducing ventilation heat losses in winter and reduces the risk of overheating during summer is key. These ventilation strategies can range from natural, mechanical or mixed-mode.

Thermal comfort is another critical requirement that is needed fora good learning environment. Multiple studies have established the role of thermal comfort and student's learning outcomes and health. Acceptable thermal comfort conditions are defined through guidelines (e.g. CIBSE Guide A [31]) and standards (ASHRAE 55 [32], ISO 7730 [33]), however these indoor conditions are not always met. For instance, an investigation undertaken on five Hellenic schools by Dascalaki et al. [27] monitoring classroom indoor conditions, specifically CO_2, temperature and humidity, showed that 60% of the recorded indoor temperature and 1/3 of the relative humidity were inconsistent with these standards.

The best source of illumination is natural daylight, and there is evidence suggesting that it improves academic performance [14]. Hence, maximising natural light during occupied periods should be a design objective. However, due to potential excess of heat gain in summer or heat loss in winter occurring from large glazing areas (Figure 11) a balance of day light with artificial lighting is typically required. Guidelines on lighting power density for classrooms can be found, for example, in ASHRAE 90.1-2010 [34]. An appropriate lighting control strategy will reduce the school's energy consumption and automatic dimming and switching off the electric lighting should be implemented to avoid relaying on the occupants.

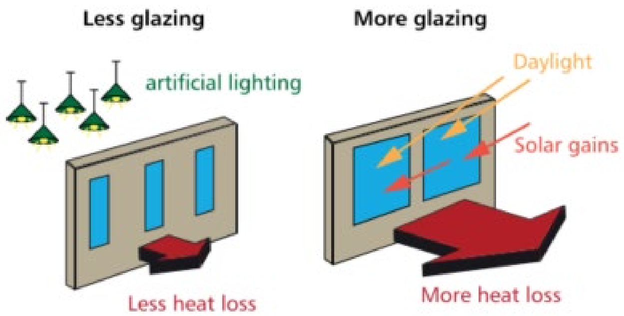


Figure 2-11 Daylight interaction between solar gains and electric lighting from [14].

Another parameter that have a detrimental effect upon the cognitive development of primary school children is noise; there is existing research linking good acoustics to successful academic performance [21]. The existing international guidelines for acoustics of teaching spaces typically recommend values for reverberation time and background noise levels (e.g. The World Health Organisation noise guidelines [35]).

An effective strategy to maintain a school at the ideal indoor conditions for learning in a lean and efficient manner could be achieved through optimal operation of the building systems. This optimal operation of the building systems is also crucial to be able to manage the peaks on the electricity demand. The use of AC is placing a strain on the national electricity system, particularly during heat waves as the electricity demand peaks [36]. Nevertheless, the increase of the grid capacity to meet these peaks might not seem a cost effective solution, as the AC-driven peak loads are occasional. That is why strategies to manage the peak demand are important. A smart ventilation system, for example, would enable the modulation of ventilation airflows in response to several factors, including outdoor conditions, utility peak loads, occupancy, and operation of other air systems utility peak loads. This strategy could be integrated in the building control system, which is capable of driving the operation of natural and mechanical ventilation with adequate window opening for ventilation, thermal comfort and acoustics.

2.3 Energy use in Australian schools

There is limited information currently available regarding energy consumption in Australian schools, and no benchmarking data at the level of individual schools. The latest large, publicly available dataset on energy consumption across Australian schools was published in the Baseline Energy Consumption and Greenhouse Gas Emissions In Commercial Buildings in Australia report [10]. This report included an average annual energy intensity from 2001 to 2011, shown in Figure 12. The trend line shows that average energy intensity increased from approximately 168 MJ/m^2/year in 2001 to 190 MJ/m^2/year in 2009, then a decrease from 2009 onwards. However, the report did not include data for many states (i.e. there was no energy data for Victoria, Western Australia, South Australia or Tasmania).

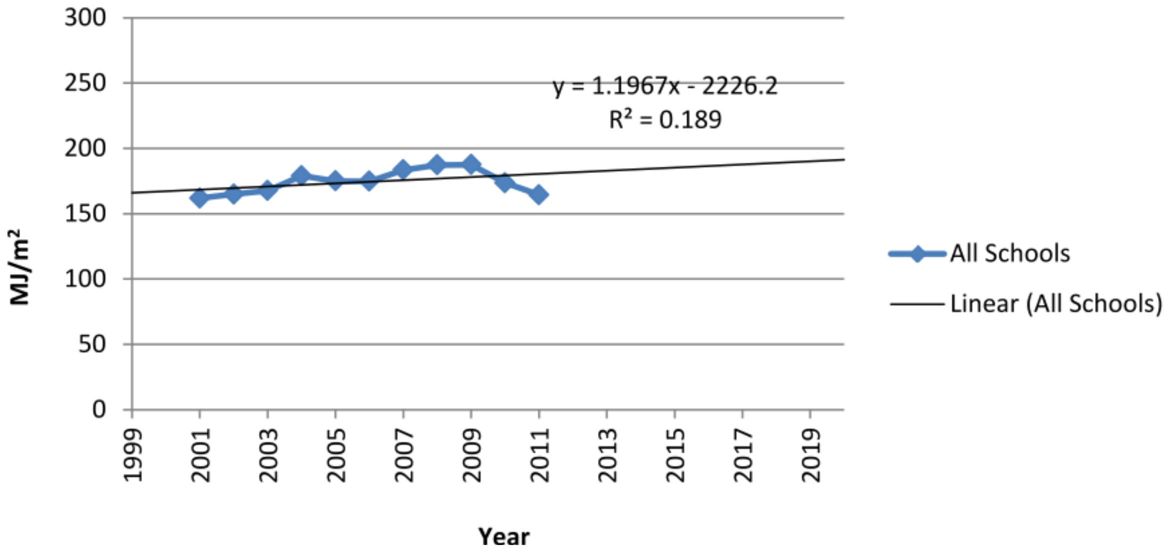


Figure 2-12 Average energy intensity of 1641 schools in Australia for 2001 - 2011 from [10].

For the current iHub project, substantial effort has gone into accessing new data regarding school energy consumption. Discussions and/or data requests were made to all Australian state and territory education departments, and a substantial new data resource has been compiled:

- ACT. Smart meter interval data has been obtained for all ACT primary schools, for the period 2015 -2020 and on an ongoing basis for the duration of the iHub project. An analysis of this data is included in the current report.
- Victoria. Smart meter interval data has been obtained for 1,083 state primary schools in Victoria for 2019. In many cases, these schools will have net-metered solar installations, which are not separately metered. Data was received too close to this milestone to be processed and included, however it will be analysed and shared in future publications.
- Queensland. Annual energy consumption figures were obtained for 1271 Queensland state primary schools for FY 2014-2015 to 2019-2020. There are some concerns regarding data quality, as data was manually entered, and additional information regarding schools, e.g. gross floor area, was not able to be obtained. Data was received too close to this milestone to be processed and included, however it will be analysed and shared in future publications.
- Tasmania. Annual energy consumption figures were obtained for 161 Tasmanian state primary schools for FY 2014-2015 to 2019-2020. Data was received too close to this

milestone to be processed and included, however it will be analysed and shared in future publications
- NSW. Substantial discussion have occurred with the NSW education department, and it appears likely that monthly utility data will be able to be obtained for NSW state primary schools. This is an ongoing process, if the data is received it will processed and shared in future publications.
- Western Australia. Discussion with the Western Australian Education Department determined that energy consumption data was not held centrally:

  WA public schools have a one-line budget which provides them with flexibility to meet their operational costs including utilities, and develop educational programs and staffing profiles that best suit the needs of the school communities. WA public schools have their own bank accounts and pay their own utility bills. Where a schools has or installs a solar system, the school is able to utilise the savings elsewhere to meet the needs of their students. While the Department monitors the cost of utilities, we do not hold the requested information centrally.

  Unfortunately, the Department of Education is unable to assist you in your request. Sorry we could not be of more assistance in this matter, and thank you for your patience.[1]

- South Australia. South Australia does not hold existing data on the energy consumption of their schools in a centralised repository. It is possible that energy data may be able to be compiled from disparate sources, and further enquiries will explore this possibility.
- Northern Territory. The NT department of education hold financial records of utility expenditure in a central repository, however they do not hold consumption or generation data. The NT Power and Water Corporation do hold consumption data for individual accounts, but we're unwilling to share the data due to privacy concerns. To access this data individual requests to the utility company would likely be required, and this was beyond the scope of this benchmarking.

In summary, a substantial new data resource has been created as part of this project, including annual consumption data for school serving half of Australia's population, and interval data for schools serving one quarter of the population. If ongoing discussion with NSW are successful this coverage will increase to over 80% of the population. Unfortunately, this substantial data resource, the result of extended discussions, was unable to be meaningfully analysed in time for the current report. Analysis has been completed for the ACT schools data, and the additional schools data will be presented in a future publication.

[1] Western Australia Department of Education, (personal communication: Case# CS4716540), 18 January 2021.

2.3.1 Australian Capital Territory Schools energy use benchmarking

A dataset with the annual energy consumption in terms of electricity, gas and gross floor area of all schools in the Australian Capital Territory was obtained from the senior director of infrastructure and capital works for the education department in the ACT Government. The ACT schools energy dataset contained information on electricity and gas usage from 2013 to 2018 for 137 facilities in 2013 to 138 facilities in 2018. The type of school buildings in the dataset is shown in Table 3. Most of the buildings are primary schools (38%) and preschools (34%) as seen in Figure 13. Not all the facilities had gas bills, with the majority of preschools (42) and one primary school not having information for gas consumption. This is because some of them have combined gas meters with adjacent primary schools and others only use electricity.

Table 2-3 Dataset with the ACT schools' level (2018 data).

School Level	Number
Preschool	47
Primary School	53
High School	14
P-10 School	6
Special school	3
College	9
Early Childhood School	6

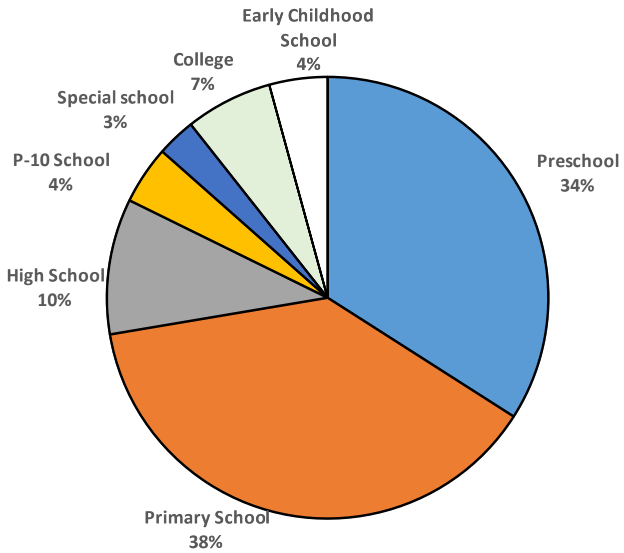
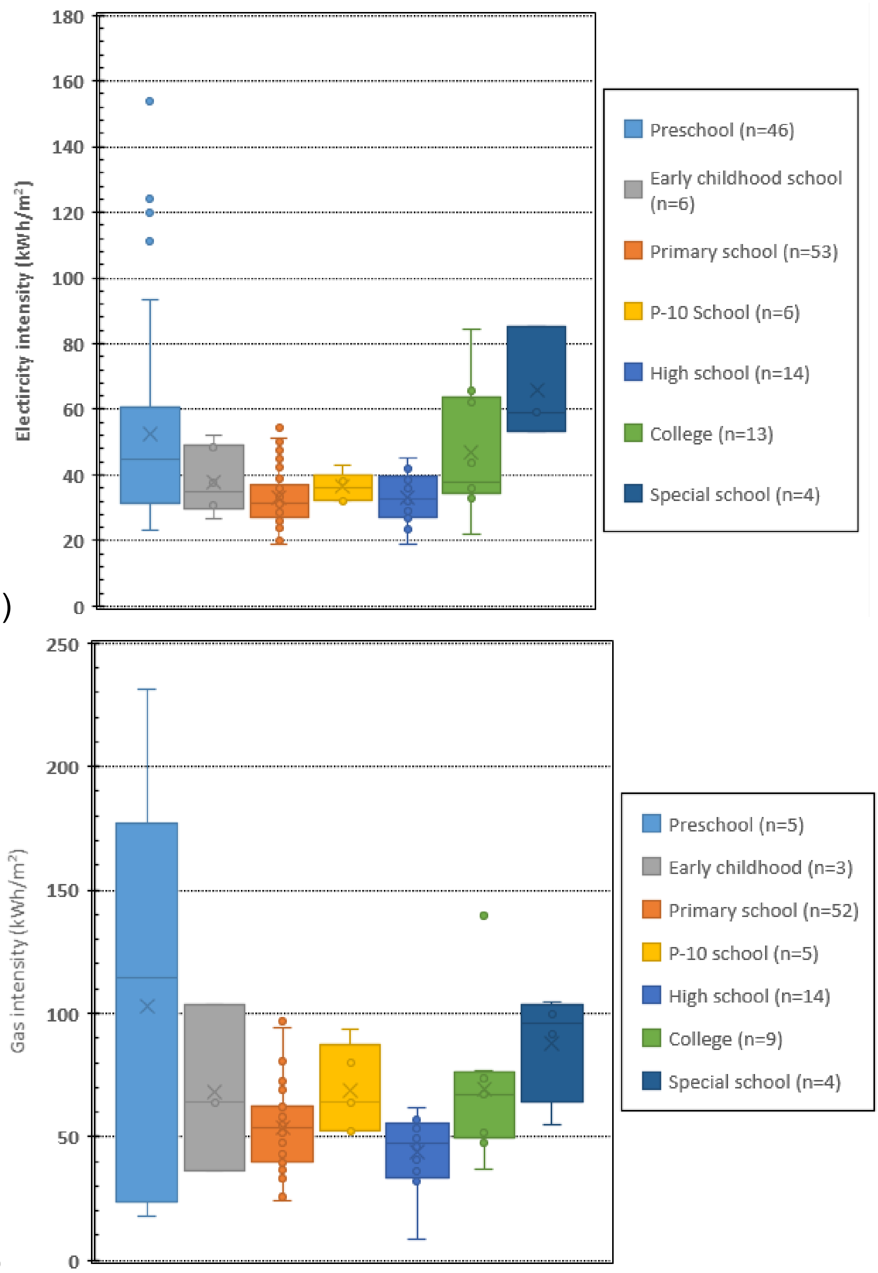


Figure 2-13 ACT school level breakdown (2018 data).

The average electricity and gas intensity per year for the different school levels in the dataset for 2018 is depicted in Figure 14. The highest electricity and gas consumers are preschool facilities. On average, the electricity intensity of early childhood schools, primary schools, P-10 schools and high schools are similar with averages within 10% difference (Figure 14a). Preschools and colleges have higher average electricity intensity than the other schools except for the special school category, which has the largest electricity intensity of all the school levels. In terms of individual facilities, preschools have the highest electricity intensity buildings of the whole dataset. Preschools also present the highest gas intensity average usage (Figure 14b), which doubles the high school gas intensity. Further investigation on the reasons why the preschools have the largest energy intensities should be undertaken. A potential reason for this could be that the set-points of the internal environment in preschools are different than the other schools, particularly in winter.



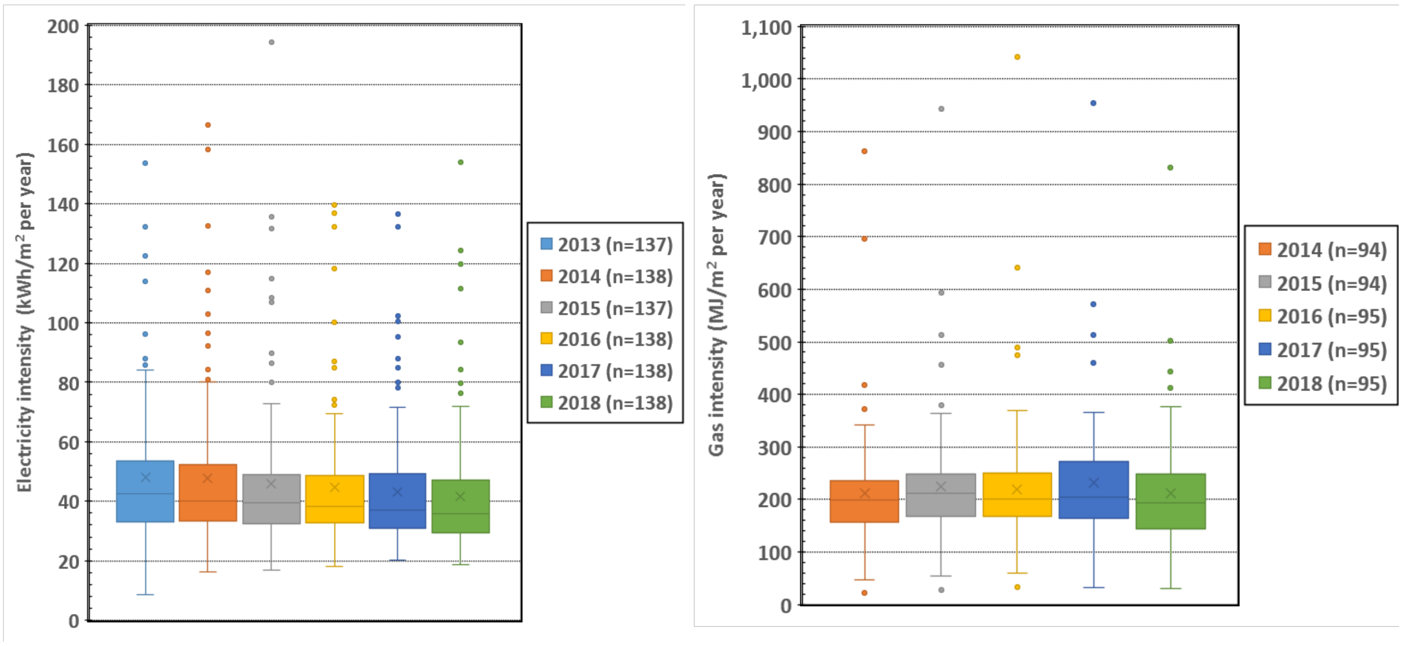
(a)

(b)

Figure 2-14 Different school levels average annual (a) electricity intensity and (b) gas intensity for 138 ACT schools in 2018.

Looking at the energy intensity across years, the electricity intensity (Figure 15a) present a descending trend from 2013 to 2018. In contrast, the gas intensity (Figure 15b) shows a relatively similar average consumption across years with slightly lower average gas consumption on 2018.

A possible explanation on the descending trend in the electricity could be that the electricity used is mostly driven by lighting, which could have become more efficient across years through replacements of older fluorescents. In contrast, the gas consumption is mostly due to heating and consequently is largely dependent on the weather with small variations over the last years.



(a) (b)

Figure 2-15 Historical average annual (a) electricity intensity and (b) gas intensity for ACT schools.

To provide an overview of the spread of the energy intensity including gas and electricity together for a year, Figure 16 displays the average energy intensity of each ACT schools during 2018 colour coded by school level. It should be noted that the sample size is n=137, as one of the P-10 schools junior and senior has been added together due to the gas for both facilities being metered in one meter. The top three energy consumers corresponds to a college, special school and a preschool with more than two times the average energy consumption of the dataset. The less energy intensity facilities are also preschools, which evidences the large differences in school energy practices and the need to investigate the potential reasons for the disparity in energy usage and the high-energy intensity.

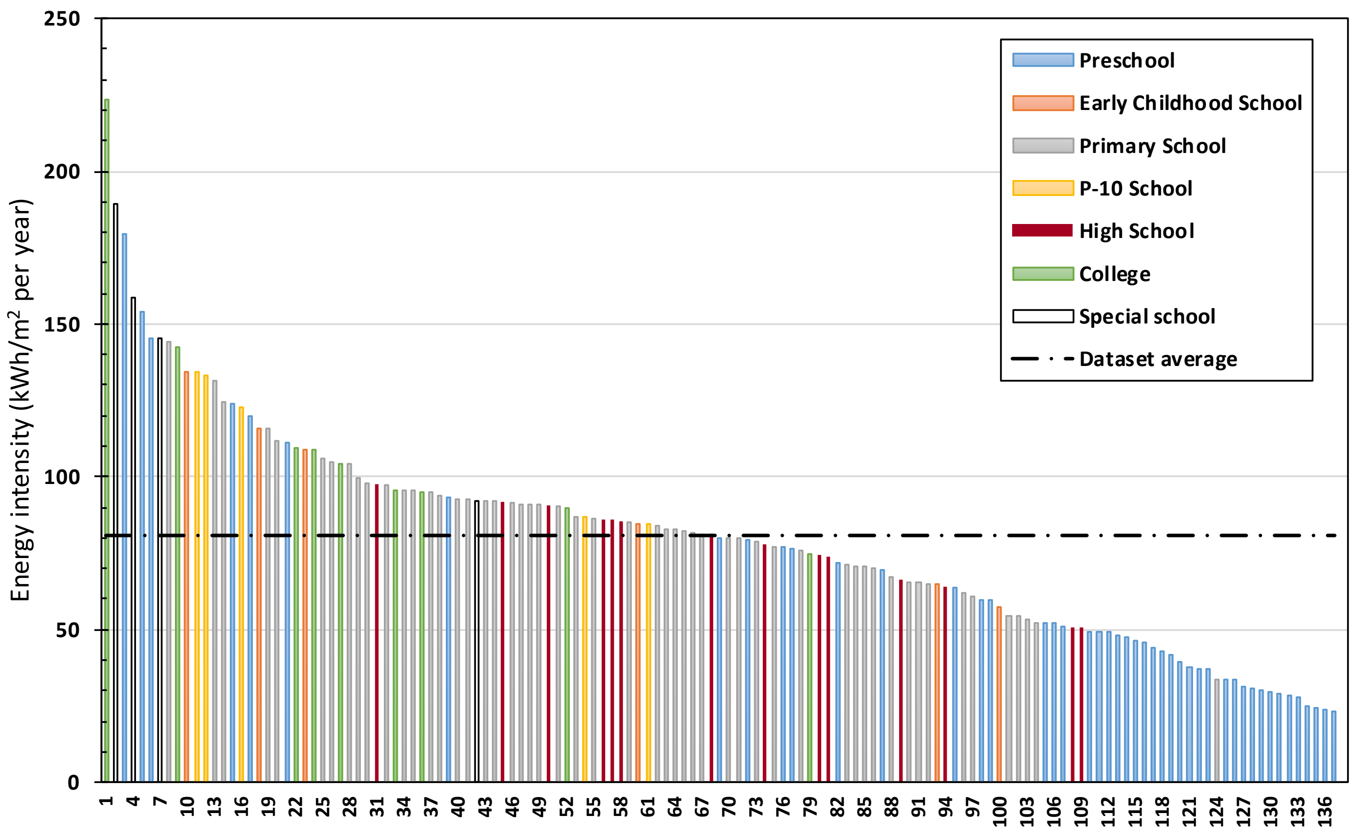


Figure 2-16 Energy intensity 2018 for ACT schools.

It is important to recognise the other primary sources because future policy changes or technology advances may mean:

- Electricity will **replace** non-electrical loads
- Electricity will **be replaced by** non-electrical sources

Examples of this are heat pumps replacing gas hot water. A fuel source replacement may not change overall energy consumption; however, it is noteworthy due to potential impact on building design when considering demand response integration with renewable energy, storage technologies and electricity tariffs.

2.3.2 ACT Schools REETSEF benchmarking

A Renewable Energy and Enabling Technology and Service Evaluation Framework (REETSEF) has been developed for the current project to provide a method of evaluating the impact of a range of upgrades on the value of renewables in the schools sector. This section presents a baseline summary of the REETSEF KPIs for ACT schools. The following baseline data is drawn from 15 minute interval smart meter utility billing data collected from the ACT government account management tool. Electricity interval data was available for 49 primary schools in the ACT, and data is presented for the 2019 base year. It should be noted that many of the REETSEF KPI's cannot be calculated with the available benchmarking data, and therefore are not reported.

REETSEF KPI 1: Avoided GHG emission (tCO_2-e and $).

CO2-e is the sum of GHG emission for all fuel sources in use at the site, and was calculated as per the National Greenhouse Accounts Factor method for fuel combustion (gas) or scope 2 emissions electricity. Most schools use both gas and electricity: scope 2 emissions from electricity were calculated using the emissions factor of 0.81 kg CO2-e/kWh; combustion emissions from gas were calculated using the emissions factor of 51.53 kg CO_2-e/GJ.

Baseline CO_2-e emissions have been calculated using historic billing data, available for full years 2016, 2017, 208 and 2019.

Table 2-4. KPI 1 – ACT schools baseline GHG emission.

	Max	Min	Mean	Std Dev
GHG emissions (t CO2-e)	837.49	95.39	180.14	104.11
GHG emissions intensity (kg CO_2-e/enrolment)	1302.37	199.80	431.73	185.79
GHG emissions intensity (kg CO2-e/m^2)	64.47	17.74	35.57	8.98
Social cost of GHG emissions[2]	$ 40,743.85	$ 4,640.55	$ 8,763.63	$ 5,065.16

REETSEF KPI 2: Avoided air pollution

The social benefit due to avoided air pollution puts a cost value to air pollution (PM_{10}, NO_x, and SO_2) impacting populations close to power station. The calculation applies a damage benefit to each MWh[3] of energy saved of $13.8/MWh for electricity, and $0.74/MWh for Gas[4].

Baseline cost of air pollution for this site is therefore:

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[2] Conversion from emission (tCO2-e) to societal benefit ($) uses an estimated social cost of carbon of AUD$48.60/tCO2 as a conversion factor from http://www.climateinstitute.org.au/verve/_resources/TCI_SocialCostOfCarbon_PolicyBrief_September2014.pdf. This is slightly higher than the current price of carbon with the EU ETS (AUD $41.8)

[3] https://apo.org.au/sites/default/files/resource-files/2009/03/apo-nid4196-1189331.pdf

[4] https://www.atse.org.au/wp-content/uploads/2019/01/the-hidden-costs-of-electricity.pdf

Table 2-5. KPI 2 - ACT schools avoided air pollution.

	Max	Min	Mean	Std Dev
Electricity consumption (GJ)	2670	313	585	330
Gas consumption (GJ)	4592	0	941	684
Cost of air pollution	$ 11,180.80	$ 1,319.56	$ 2,436.08	$ 1,378.65

REETSEF KPI 3: Peak 30 minute electricity demand.

Peak demand was calculated as the highest 30 min electricity demand. Peak demand is reported monthly, seasonally and annually (i.e. highest 30 min consumption per month, seasons, year), however, given the short monitoring period for the initial baseline report, only monthly peaks are shown. Figure 2-17 shows the daily profile of the peak 30-min demand for the day when maximum peak demand was recorded.

Table 2-6. KPI 3 - ACT schools peak 30 minute electricity demand.

	Max	Min	Mean	Std Dev
Half-hourly peak demand (kWh/30 min)	188.48	26.66	54.94	31.61
Half-hourly peak demand (Wh/EFTE)	452.9	53.0	133.4	71.9
Half-hourly peak demand (Wh/m^2)	26.1	4.4	11.0	4.4

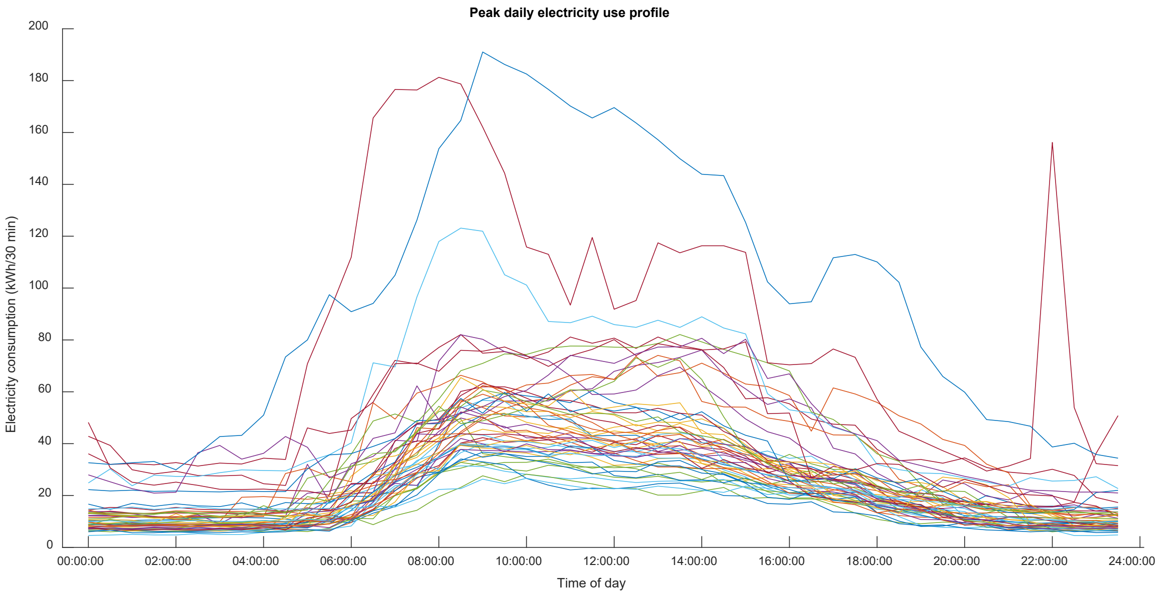


Figure 2-17 – Peak 30 minute demand profile, showing the max 30 min electricity demand for each half-hour period in the day for the historic interval data.

REETSEF KPI 4: Peak 30 minute electricity export.

As for PKI 3, peak export was calculated as the highest 30 min electricity export. Peak export is reported monthly, seasonally and annually (i.e. highest 30 min export per month, seasons, year).

Table 2-7. KPI 4 - ACT schools peak 30 minute electricity export.

	Max	Min	Mean	Std Dev
Half-hourly peak export (kWh/30 min)	4.89	0.00	2.38	1.06

REETSEF KPI 6: Total self-consumption rate (0-1).

The self-consumption rate of renewable generation (SC) is the proportion of on-site renewable generation that is consumed on-site by the facility.

Table 2-8. KPI6 - ACT schools total self-consumption rate

	Max	Min	Mean	Std Dev
Self-consumption rate	1.00	0.95	0.99	0.01

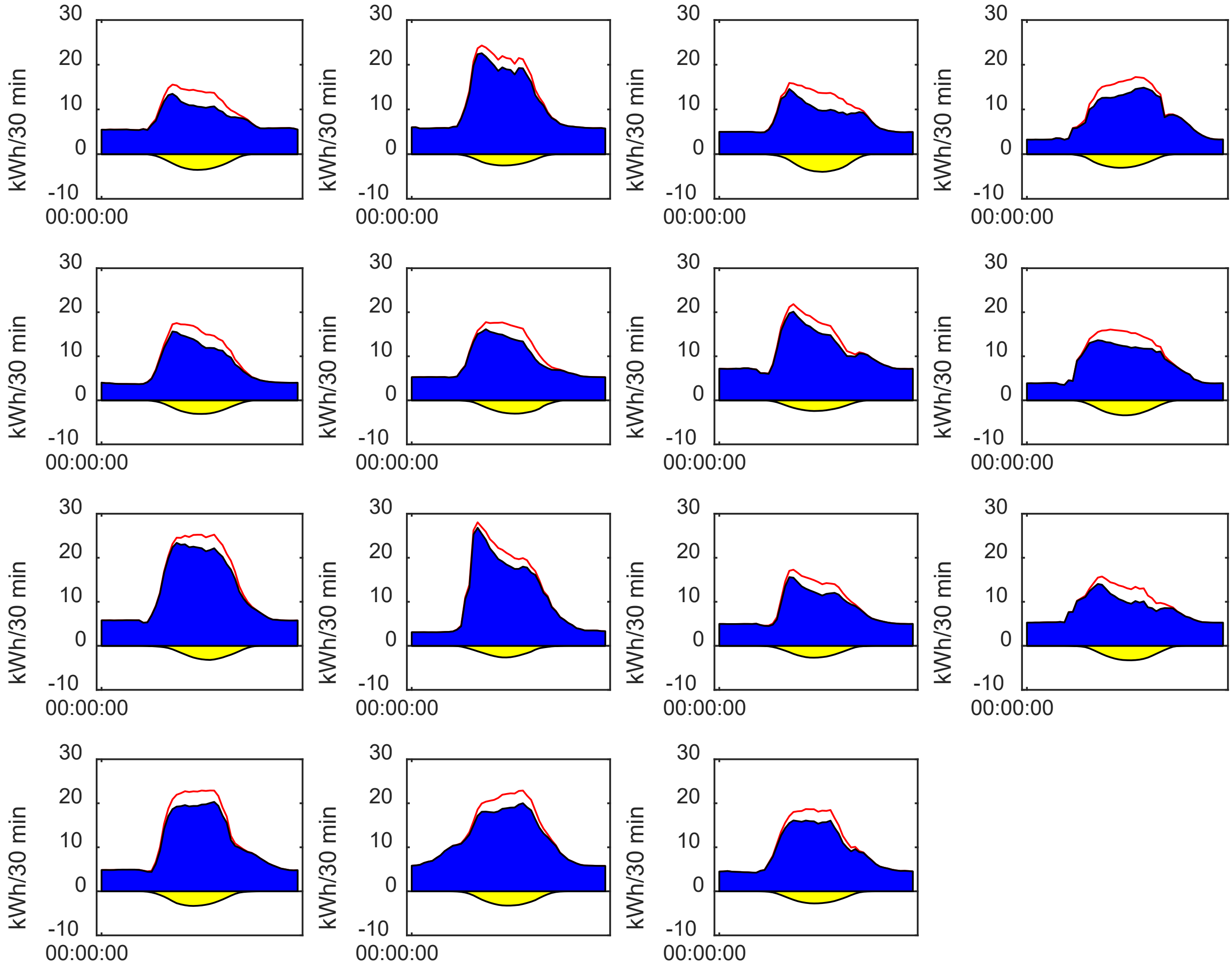


Figure 2-18. Average daily gross and net consumption, and generation for ACT schools with solar generation installed.

REETSEF KPI 8: Total renewable energy fraction

Renewable Energy Fraction (REF) is the proportion of energy use for a facility ($E_{elec,gross,i}$) that is generated by on-site renewable generation ($E_{PV,gross,i}$).

Table 2-9. KPI 8 – ACT schools renewable Energy Fraction

	Max	Min	Mean	Std Dev
Renewable energy fraction	21%	5%	12%	4%

REETSEF KPI 10: Net Facility Load Factor.

Net Facility Load Factor is the average electrical load divided by the peak load during a specified time period, and is a measure of how 'peaky' an energy use profile is.

Table 2-10. KPI 10 – ACT schools net facility load factor.

	Max	Min	Mean	Std Dev
Renewable energy fraction	0.28	0.08	0.18	0.04

REETSEF KPI 13: Energy Use Intensity / Productivity

Energy use intensity is a measure of how much energy is used in a facility normalised for comparison with relative benchmarks. Current school sector EUI KPIs are typically based on kWh/m^2 or kWh/enrolment.

Table 2-11. KPI 13 – ACT schools energy use intensity /productivity

	Max	Min	Mean	Std Dev
Electricity consumption (GJ)	2670	313	585	330
Gas consumption (GJ)	4592	0	941	684
Total Energy Consumption (GJ)	7263	424	1526	963
Electricity intensity (GJ/m^2)	0.19	0.06	0.12	0.03
Gas intensity (GJ/m^2)	0.39	0.08	0.18	0.07
Total energy intensity (GJ/m^2)	0.53	0.11	0.30	0.08
Electricity intensity (GJ/enrolment)	3.70	0.72	1.39	0.54
Gas intensity (GJ/enrolment)	5.44	0.82	2.20	1.00
Total energy intensity (GJ/enrolment)	7.62	0.89	3.55	1.26

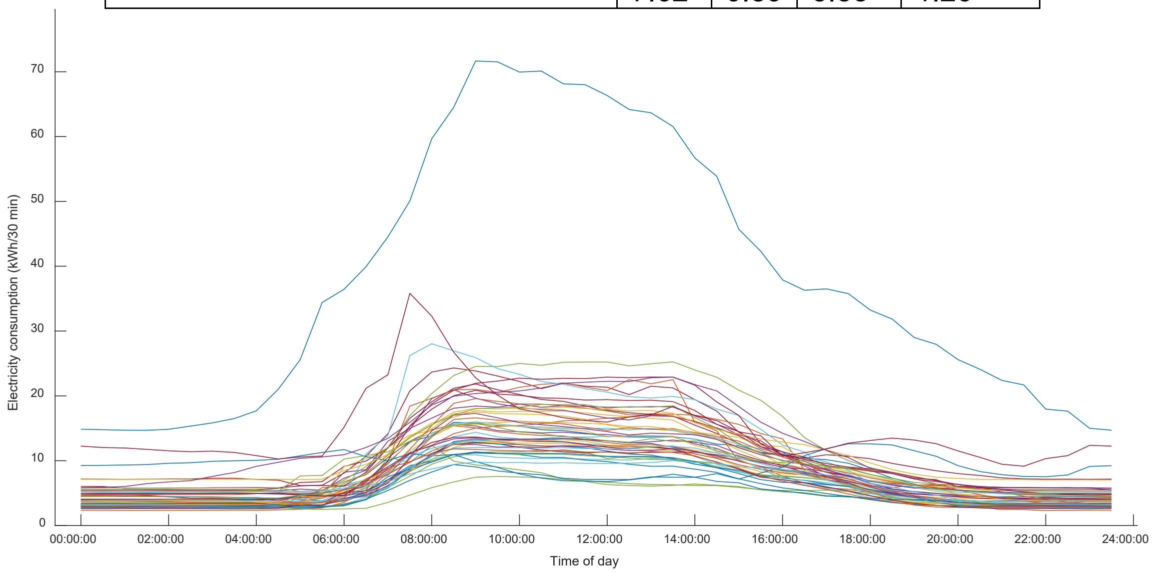


Figure 2-19 – Average daily electricity consumption profile for all ACT primary schools.

2.4 Impact of policy trends on energy

In Europe, there are broad range of policies and supportive measures that aids national EU governments to improve energy performance of buildings including schools (European Directive 2010/31/EU [37]). This directive is adhered at different levels of compliance by each member state of the European Union. An example on how some countries followed the directive is provided in Table 5, where Belgium, Slovakia, Denmark, Finland and Czech Republic have a yearly maximum space heating demand limit for new schools and major renovations.

Table 2-12 Energy performance of buildings directive implementation in different European countries from [5,38].

Location	Type of building	Indicators and units	Maximum limit
Belgium	New schools	Global energy performance level (calculated primary energy consumption divided by calculated primary energy consumption of a reference building) kWh/m^2 per year	100
Slovakia	Schools	Energy class global indicator: kWh/m^2 per year, primary energy (and also an energy class for heating energy)	205-272
Denmark	Education	Primary energy calculated consumption (heat, electricity, water): kWh/m^2 per year (primary energy conversion factors are being used in the calculation (primary/useful energy))	80
Finland	Schools	E-value requirements (overall maximum values for energy consumption): kWh/m^2 per year primary energy consumption (calculated with weight factor of energy source).	170
Czech Republic	Education	Energy class global indicator: kWh/m^2 per year, primary energy (and also an energy class for heating energy)	90-130

In Luxemburg, the school buildings constructed after new sustainability regulations became effective consumed 36% less energy compared to the schools constructed pre-regulations [39]. The inclusions of the new energy standards resulted into better airtightness and higher insulation levels in the schools buildings that translated into a lower heating demand in the new schools in Luxemburg (less than 15 years of age) compared with other older European schools (Figure 23).

In contrast, the comparison of the electricity consumption of the newly constructed school facilities in Luxemburg with other old and new European schools showed a higher mean electricity consumption than the other European schools. The increase in electricity consumption was attributed to the canteens kitchens, use of electronic equipment (i.e. personal computers and projectors) and the use of mechanical ventilation systems. These items compensate for the savings of the improved lighting in the newer schools.

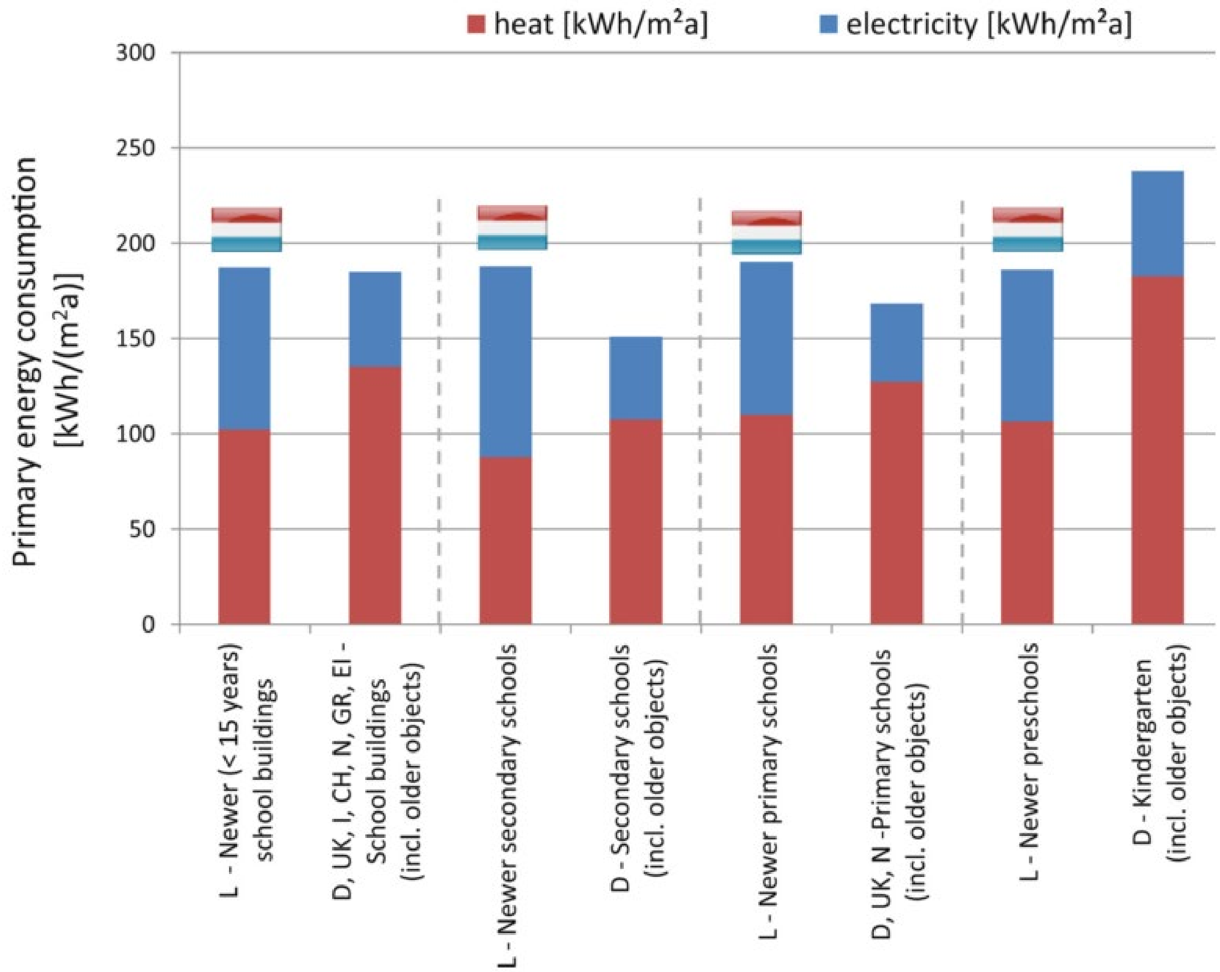


Figure 2-20 Comparison of primary energy consumptions of school buildings in Luxemburg against European schools (reproduced from [39]).

In Canada, a study analysing historical data on 126 Canadian schools revealed a decreased in gas consumption in newer constructed schools compared to old schools (Figure 24) [40]. This descending trend was attributed to the inclusion of more stringent building regulations on the Canadian building code in the 90s. However, the electricity consumption in the older schools was lower than the middle-aged and new schools. The more complex HVAC systems and occupant behaviour in the newer schools compared to the older ones was found to be the potential reason.

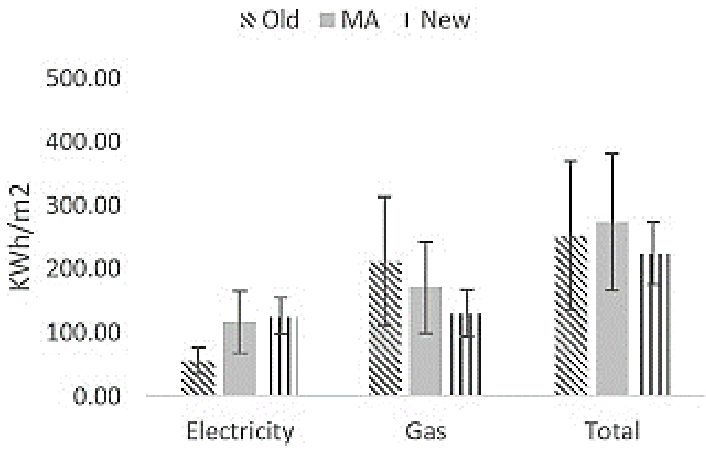


Figure 2-21 Average annual electricity, gas and total consumption in 136 Canadian schools [40].

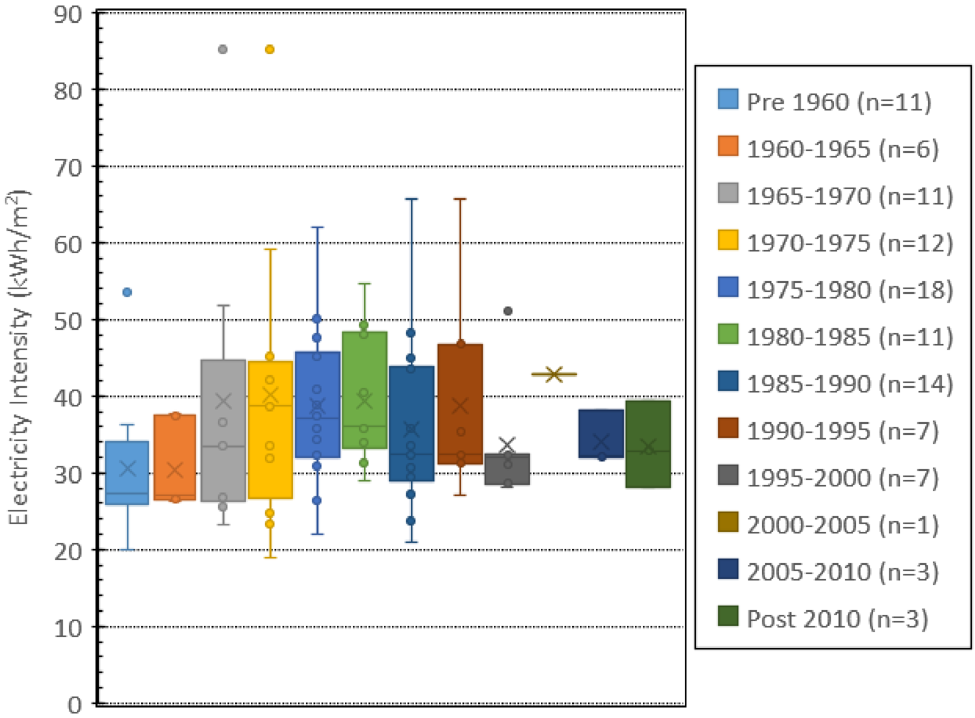
In Australia, conventional educational buildings have been usually designed to meet minimum standards in the building code resulting in the majority of the facilities not being necessarily comfortable, productive and healthy for students and staff. In addition, there is an increase prevalence of demountable buildings at schools, which despite being a temporary solution, have turn into a permanent school [41].

To assess if the introduction of the energy efficiency provisions in the Australian building code in 2005 affected the ACT schools energy performance, a categorisation of the energy consumption by facility opening year on the dataset of the ACT schools was undertaken. In this instance, the preschools were excluded due to data availability.

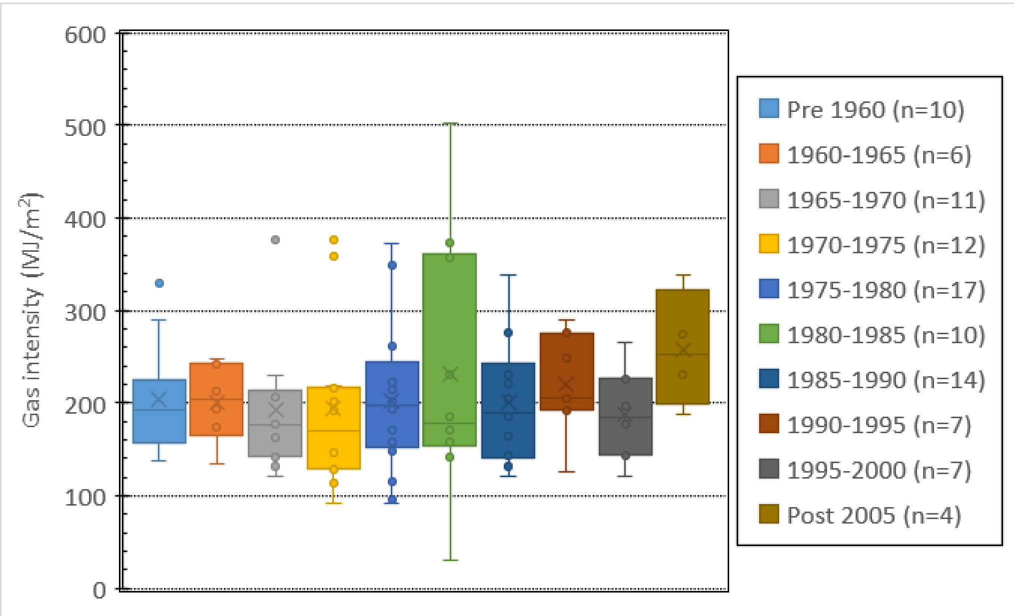
It is seen in Figure 25a that the electricity intensity across different years follows an inverted parabolic trend. That is schools opened before the 60s used the least electricity, then it increases until the early 80s to start decreasing until now, were the average electricity consumption is similar to the older schools in the dataset.

In contrast, the average gas intensity (Figure 25b) appears to be similar across different school ages except for the newer schools (facilities opened post 2005) whereby the average gas intensity is higher than the rest of years. Potentially this increase in the gas intensity could be due to extra facilities in the schools (e.g. heated pools and canteens with gas cooking onsite) compared to older schools.

The performance requirement for schools stated in the National Construction Code 2019 establishes for a conditioned space an hourly regulated energy consumption averaged over the annual hours of operation of no more than 43 $kJ/m^2/h$ [42].



(a)



(b)

Figure 2-22 ACT schools energy intensity grouped by school opening year (a) electricity intensity (n=90) and (b) gas intensity (n=85).

2.5 KPI effectiveness

Due to the inexistence of any standard procedure for the use of the data collected in energy surveys, there is an enormous variability in the normalisation procedures, in the units and indexes and in the variables considered for energy benchmarks. We have presented in this report the complexity of benchmarking, as the use of different metrics could result in different conclusions on the building energy performance and thereby it is crucial to select appropriate KPIs. The most widely employed KPIs are shown in Table 6. Each of those KPIs has benefits as well as a few limitations described in the table.

Table 2-13 Existing KPIs overview
(summarised from [5,12,13,19]).

KPIs	Evaluation
Heating : kWh per space volume per degree day per annum ($kWh/(m^3 x DD x year)$) ***Electricity:*** ***kWh per space floor area per degree day per annum (($kWh/(m^2 x DD x year)$)***	Benefits: • Demonstrated correlation to energy use. • Allows comparison to other climates. • Differentiate between fuel mixes (electricity and gas). Limitations: • Cooling degree-days normalisation is not well established for electricity normalisation. • The heating consumption cannot always be obtained separately from the total consumption.
kWh per floor area per annum ***kWh/m^2 per year***	Benefits: • Widely understood measure, suggested by guidelines. • Allows comparison to other sectors. • Data acquisition and analysis is not significantly difficult • Demonstrated correlation to electricity use Limitations: • Does not differentiate between: types of floor space, hours of use of each type of floor space, fuel mixes (e.g. electricity and gas). • Some studies found that variation in school size do not correlate with significant differences in CO_2. • Significant difference between buildings from different age groups.
kWh/student per year	Benefits: • Demonstrated correlation to electricity use • Data acquisition and analysis is not significantly difficult Limitations: • Significant difference between buildings from different age groups

kWh/m^2/student per year	Benefits: • No significant difference between buildings from different age groups. Limitations: • Not widely use
$/ m^2/student per year	Benefits: • No significant difference between buildings from different age groups • Data acquisition Limitations: • Not widely use

The most widely adopted KPI is the EUI in terms of kWh/m^2 per year. However, EUI is associated with climate, as typically harsh climatic conditions results in a higher EUI than in region with milder conditions. Therefore, some studies (e.g. [4,12,19]) recommended to always normalise the energy against the climatic conditions to be able compare the thermal energy uses across different facilities.

Age of the educational facility has also been shown to influence the EUI. Typically, newer buildings will follow a set of regulations with energy efficiency provisions, and thereby they are expected to have lower EUI than buildings constructed pre-regulations. Therefore, it is also important to report the age of the facility. Nevertheless, as shown in different studies [39,40] this is not always the case, as additional teaching, recreational facilities and equipment might lead to an increase on the EUI. In addition, determinant factors in the energy consumption of the schools that could vary with the age of the school, such as the use and management of the building systems are not usually taken into account in the regulations.

In terms of KPIs targeting to assess the value of renewable energy or enabling renewable energy technologies for schools, the Leadership in Energy and Environmental Design (LEED) scheme assesses the onsite renewable generation through their sustainability performance rating for schools (and other building typologies). The definition of the LEED onsite renewable KPI is the energy produced by renewable systems expressed as a percentage of the building's annual energy cost [43].

Another study in Spain [44] defined a KPI for renewable energy to suit a higher education institution goals of minimising both non-renewable energy consumption and greenhouse gas emissions (GHG). The KPI was defined as the ratio of renewable energy consumption over the total energy demand. The data sources to compute the KPI can be easily accessed through direct measurements and invoice details.

3 Education sector discussion and recommendations

Research has shown the large variability in the indexes considered for schools energy benchmarks, highlighting that the characteristics of the KPIs should ensure usability, comparability, and consistency [44]. For example the Chartered Institution of Building Services Engineers [45] or ASHRAE Standard 105- 2014 suggest using a particular KPI, by means of the delivered energy consumed per unit floor area (kWh/m^2/yr). Consequently, it is recommended to include this KPI to evaluate the change in value of renewable energies as a benefit to the school sector. Adjustments for weather and occupancy could also be considered.

In terms of KPIs targeting specifically renewable energy, one study was found to employ the total self-consumption rate in a university [44]. This KPI could be included to assess the value of renewables as a benefit to the network. Due to the limited available literature on KPIs for assessing value of renewables, purpose-oriented energy KPIs will also need to be generated. The guiding principles to create these purpose-oriented energy KPIs propose a set of criteria with the acronym **SMARTCS** (Table 7). The SMARTCS criteria are extended from the traditional SMART principle in management theory [46]. The two added components are C for comparable and S for systematic. Comparable is included because energy KPIs are often for comparison or evaluation purposes. Energy is not isolated from other social aspects, to create better learning environment for schools through a good indoor environmental quality, a systematic view (system thinking) is needed.

Table 3-1 SMARTCS Criteria to select purpose oriented KPIs.

Key criteria	Description
Specific	Be strategic and specific, detailed, and meaningful for desired purposes
Measurable	It can be measured, or calculated based on measurements/data
Attainable	Have tools or resources to attain
Relevant	KPIs need to be relevant to -the energy performance of the technologies under evaluation - health or safety of staff and occupants (adequate indoor environmental conditions)
Time based	In a period; reflect resolution, e.g. yearly, seasonal or monthly, weekly, daily
Comparable	The KPIs can be compared with - itself over time - other facilities KPIs
Systematic	System thinking in designing energy KPIs

4 Conclusion

A range of KPIs to assess the energy baseline of schools have been identified based on an extensive literature review. Despite there is no consensus on the use of a particular KPI across studies, the most commonly accepted KPIs to measure the energy performance of schools are:

- the energy use intensity, defined as the energy consumption normalised by floor area (kWh/m^2) or per student (kWh/student); and
- the energy use intensity adjusted by climate through the cooling and heating degree days separating the heating energy ($kWh/m^3/HDD$) and the electricity ($kWh/m^2/CDD$).

Research has shown that the utilisation of different KPIs can lead to different conclusions on the energy performance of the schools, and therefore it is important to report the boundary conditions such as heating and cooling degree-days, conditioned floor area, student numbers and the construction year of the school. For example, the results of comparing different KPIs for the living laboratories of this project, Amaroo and Fadden, have shown that Amaroo's energy intensity is 1.2 times higher than Fadden. However, the cost of energy per square meter and per student is 3.5 times larger in Fadden than Amaroo. The literature studies have also highlighted the need to preserve and include metrics about the indoor environmental conditions, particularly the indoor air temperature, in the classrooms.

To the best of the authors' knowledge, there is very limited literature on KPIs for renewable energy in education facilities (e.g. self-consumption rate) and no specific literature related to KPIs for evaluating the change in value of renewable energy as a result of a technology upgrade. Thereby, these purpose-oriented energy performance KPIs will need to be developed in the Renewable Energy and Enabling Technology and Services Evaluation Framework following the SMARTCS criteria.

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