# Light-years apart:
# Energy usage by schools across the South African affluence divide

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**Abstract**

South Africa's source of energy in buildings is electricity from a struggling state utility running mainly on coal. But despite the constraints and the high cost, energy usage remains mostly unchecked and poorly managed in schools, whose attention is focused on reducing inequality in educational outcomes. School energy usages have been well studied in many countries but remain largely unexplored in South Africa. We use smart electricity meters to analyse the energy requirements of 16 schools across the country's polarised affluence spectrum. Comparing their usage with that of schools from other countries, we find that the affluent South African schools have energy densities of 13% as much as those in North America, compared to the poor schools with a mere 5%. We observe a large difference between the daily usage profiles of poor and affluent schools: poor schools used only 40% of the energy used by affluent schools. We ascribe this disparity to constrained infrastructure investment at the poor schools. We identified lighting as a major contributor to energy usage by schools, accounting for as much as 32% of the daily in-term usage by affluent schools and 21 to 65% by poor schools, compared to 14 to 25% in developed countries. Since most schools still use fluorescent lights, substantial savings can be achieved by replacing them with efficient LED lights.

*Keywords:* School electricity; School budget; Energy usage; Smart meter; School performance; School energy profiles

## 1. Introduction

Over the past decade, South Africans have suffered power blackouts and rapidly rising utility costs because of electricity system changes and crises of supply. Electricity tariffs rose by 446% from 2008 to 2019 [1], a more than four-fold increase, outstripping inflation of 98% over the period. This has resulted in attempts by various actors to keep demand and costs down and improve energy efficiency [2, 3]. It has also put financial pressure on the education system and made schools anxious to reduce costs and minimise waste [4]. Failure to do so means that funding earmarked to improve the quality and equity of South Africa's education is channelled into paying electricity bills.

Although South Africa spends more than 20% of government budget on education, spending on basic education is under pressure. The schools' budget per pupil decreased by 8% between 2010 and 2017, while electricity rates increased [5]. Schools use large numbers of state buildings and thus account for a large portion of the state's electricity bill. An estimated aggregated yearly energy usage of 2.2 GWh means that the cost impact of tariff increases is substantial and diverts funding away from essential maintenance and infrastructure development.

Apartheid has left South African schools a legacy of unequal distribution of facilities and resourcing. The quality of basic infrastructure varies widely and many schools fail to match up to national minimum standards [6, 7]. In 2020, 4,000 schools still had pit latrines. In 2018, of the 23,471 public schools, 20,071 had no laboratory (including a computer laboratory), 18,019 no library, 16,897 no internet and 9,956 no sports facilities. However, only 269 schools were without electricity, so it appears the electrification of schools has been done quite successfully [6]. This electrification rate is very high compared with the 80% of schools without electricity in sub-Saharan Africa. However, despite this high rate, pupils do not enjoy the benefits of light, heating and modern teaching tools [8]. The unequal distribution of facilities described above means that these benefits remain unrealised in many South African schools.

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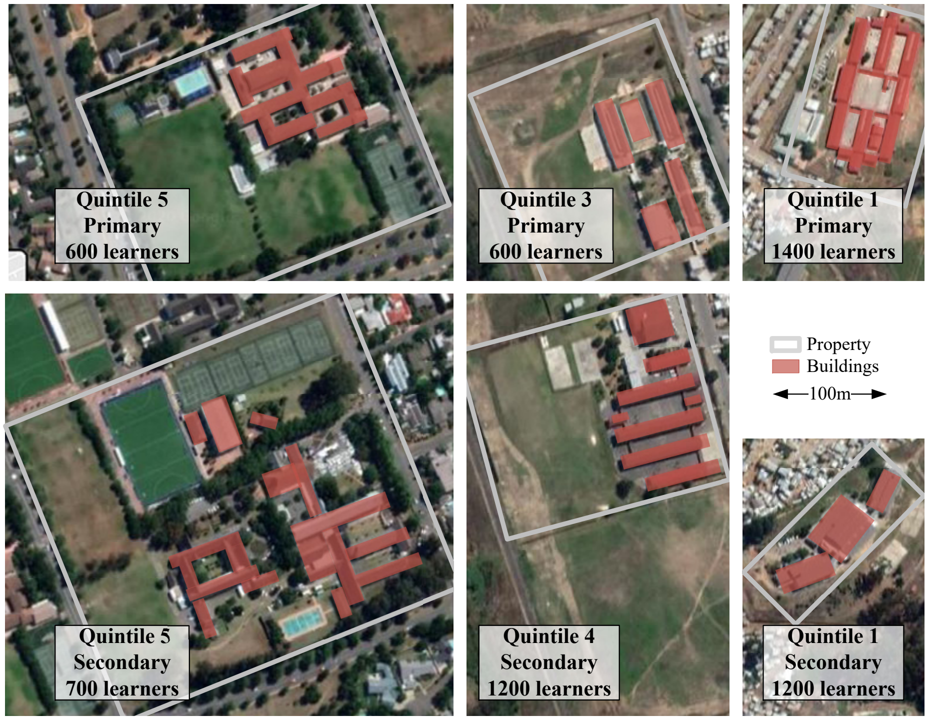



Figure 1: Satellite images of six of the schools in our study at the same zoom factor from Google Maps. The three top schools are primary, and the bottom three secondary. The schools are all public (i.e. government-owned) schools, and within a 2 km radius. Quintiles 5 to 1 represent decreasing quintiles of affluence.

The Amended National Norms and Standards for School Funding, South African Schools Act No 84 of 1996, aimed to help reduce the historical inequities in the South African education system. For the purpose of government funding, schools are classified into five quintiles according to their socioeconomic status, measured as average income, unemployment rate and general literacy in the school's geographical area [9]. Quintile 1 schools, still mostly serving black pupils, are the poorest, and Quintile 5 schools, many of them formerly white schools, are the most affluent. Quintiles 1 to 3, which are non-fee-paying, receive the highest allocation per pupil and Quintile 5 schools the lowest, on the assumption that the parents can afford fees. Studies have shown that despite this attempt to distribute the funding to the benefit of poorer schools, inequalities persist in terms of access to good education [5, 10, 11].

In this article we investigate electricity usage patterns in a sample of 16 South African schools in the Stellenbosch area, in South Africa's Western Cape province. Our sample includes all five quintiles as defined by the 1996 Act. The research forms part of a larger project that aims to support improved school management and policy making and help reduce the drain on the national electricity grid and damage to the environment. Within this context, the aim with this paper is to better understand how energy usage of the schools in our sample compare with schools in other countries, and to quantitatively explore to what extent there is a difference between the affluent and poor schools' usage.

As an example, figure 1 captures some of the spatial differences between six schools that formed part of this study, all within a 2 km radius. Inequalities in schools are not limited to infrastructure. Classrooms in poor schools are overcrowded [6]. Vandalism and theft, especially of computer equipment (in those schools lucky enough to have it), burden schools with replacement expenditure. Inadequate safety and security arrangements put pupils and staff at risk in crime-ridden areas. Some schools suffer from bad financial management and some have been found to be in municipal arrears [12, 13, 14]. These problems exacerbate poor learning conditions and outcomes in South Africa's basic education system.

## 2. Energy efficiency studies

We first review studies of energy efficiency interventions and then those with a specific focus on school energy usage.

Table 1: Literature review map

| Geography and sample | Core focus and contribution | $kWh/m^2$ | GDP per capita | Energy management | Occupancy and Operational requirements | Technologies and assemblies considered/mentioned in analysis | | | Reference |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Mechanical | Lighting | Envelope | |
| Developing countries | | | | | | | | | |
| Slovenia (24 schools) | Energy audit; role of insulation, energy saving lights and boiler | 219 | 26,124 | No | No | Yes | Yes | Yes | [15] |
| Argentina (15 schools) | Energy benchmarking for schools | 121 | 11,684 | Yes | Yes | Yes | Yes | Yes | [16] |
| Tehran (2 schools) | Energy modelling and retrofit implementation | 220 | 5,628 | No | Yes | Yes | Yes | Yes | [17] |
| United Arab Emirates (1 school) | Energy management modelling | 438 | 43,005 | Yes | Yes | Yes | Yes | Yes | [18] |
| Pretoria, South Africa (1 school) | Infrastructural and operational data used to model electricity consumption in schools | 27 | 6,374 | No | Yes | Yes | Yes | No | [4] |
| Jordan (1 school) | Retrofit strategies to improve building envelope and increase energy savings | 46* | 4,242 | No | Yes | Yes | No | Yes | [19] |
| China (17 schools) | Found electricity to be the second highest energy source and cost | 122 | 9,771 | Yes | No | No | Yes | Yes | [20] |
| Taiwan (231 schools) | Three regression models for total energy consumption, energy use intensity and energy use per pupil in school building - showed that air-conditioning and lighting are heavy contributors to energy usage | 33 | 50,500 | No | No | Yes | Yes | Yes | [21] |
| Developed countries | | | | | | | | | |
| USA | Advanced energy retrofit guide | N/M* | 62,795 | Yes | Yes | Yes | Yes | Yes | [22] |
| USA | Energy usage in K-12 schools | 360 | 62,795 | Yes | Yes | Yes | No | No | [23] |
| Treviso, Italy (60 schools) | Energy consumption of air heating and hot water | N/M* | 34,483 | No | Yes | Yes | No | Yes | [24] |
| Canada (3 schools) | Energy consumption analysis | 251 | 51,358 | Yes | Yes | Yes | No | Yes | [25] |
| Spain (2 schools) | Investigated the reduction of emissions in schools in hot climate conditions; suggested lighting substitutions | 57 | 30,371 | No | Yes | Yes | Yes | Yes | [26] |
| Spain (2 schools) | Energy assessment method for low-carbon energy schools | 17 | 30,371 | Yes | Yes | Yes | Yes | Yes | [27] |
| Belgium (30 schools) | Developed benchmarks models of zero energy schools | 49 | 47,519 | Yes | Yes | Yes | Yes | Yes | [28] |
| Sweden (7 schools) | Benchmark energy model for (nearly zero grid energy) schools | 62* | 54,608 | No | Yes | Yes | Yes | Yes | [29] |

*1.N/M: This information was not mentioned in the article.*
*2.*: These values do not represent the total school usage. however the school usage considered in the paper is mentioned.*
*3. Average values are used for energy intensity (kWh/m2).*

### *2.1. Energy efficiency interventions*

As buildings use about 40% of energy worldwide and are responsible for one third of greenhouse gasses, a large body of research has investigated ways to improve their energy efficiency. The main ways of doing this are technological, organisational and behavioural [30, 31].

Technological interventions involve changing mechanical components, the lighting system and the building envelope (the outer shell that helps to regulate the indoor environment), and micro-generation (off-grid sources of energy generation such as integrated photovoltaic thermal systems). Heating, ventilation and air conditioning use the highest proportion of energy in a building [32]. Interventions include converting or upgrading the existing system, or using natural ventilation for cooling and heating and moisture recovery, for example with enthalpy exchangers (energy recovery ventilators) in the building's ventilation system. Lighting systems account for approximately 15% of building energy demand [32].

Interventions include installing state-of-the-art lighting components, such as LED, and installing sensors or automated lighting controls. Interventions involving the building envelope include using thermal mass elements (materials with the ability to store or absorb heat such as wall insulation and concrete), changing the building's window design, upgrading the façade in various ways, for example with a ventilated double skin, and using micro-generation systems [33].

Organisational interventions involve using real-time energy monitoring to identify unexpected levels of usage and benchmark typical energy use, so as to set a baseline for comparisons and standardisation [34, 35].

Behavioural interventions involve establishing an energy efficiency culture in an organisation. Here various factors like occupancy behaviour, organisational culture and technology adoption play a role [36].

### *2.2. Energy efficiency and school lighting*

Table 1 summarises the studies reviewed for this paper, grouped according to country and mapped against the main energy efficiency interventions discussed in section 2.1. Studies in both developing and developed countries have shown the benefit of compiling data sets and improving the visibility of school energy usage.

Energy efficiency interventions are complicated by schools' individual electricity arrangements, such as their power sources, equipment and usage profiles; by the seasons and the weather, which makes seasonal, monthly, weekly and daily analysis necessary [37]. Furthermore, literature has shown that the socio-economic status of schools also plays a role [10].

Lighting has consistently been found to account for a large percentage of schools' energy usage, for example 14% in the USA [22], and in Spain 21% [26] and 25% [27]. The percentage was 46% in a single Quintile 5 school in Gauteng, South Africa [4]. In a European life cycle assessment to investigate ways to reduce emissions in schools in hot climate conditions, Gamarra et al. [26] recommend energy efficiency improvements in lighting and air-conditioning. In an analysis of school building energy usage in 17 schools in Tianjin, China, Ma et al. [20] found that schools' total energy consumption was large, despite they schools' relatively small energy use intensity compared to other public buildings. They found that the second highest energy source was electricity, which was also the second highest expense. Investigating the final energy usage (monthly billed energy usage) of 231 schools in Taiwan, Wang [21] found that air-conditioning and lighting were heavy contributors. In Belgium, Attia et al. [28] developed benchmark models of near zero energy schools (these are schools with energy demand equal to or less than grid-supplied energy). Their analysis of four years' worth of monthly energy data found that two thirds was electricity usage.

## 3. Method

Table 2 summarises the characteristics of the 16 schools in our sample. Although all within close range of each other, they differ substantially. The Quintile 5 schools tend to have more extensive buildings overall and a lower pupil to building size ratio, and all had hostels on the premises.

We used smart meters to capture the schools' electricity usage. These were of two types: municipal smart meters and retro-fit third-party smart meters. The measurements used were energy (kWh) and demand (kW and kVA), monitored at 10 to 30 minute intervals. These data were then downloaded from the cloud databases for analysis.

To compare the schools' energy demand we measured energy usage intensity, usage per pupil, baseload usage and average usage. Since energy intensity is widely used to quantify and compare efficiencies of buildings, it provides a useful yardstick with which to compare and contextualise South African schools' energy usage. We compared the schools' annual energy intensity with the figures reported in the literature, using annual energy usage per building size, given as $kWh/m^2/year$.

Table 2: Summary of the 16 schools in our data set. All except one are within a 4 km radius of the centre of the town of Stellenbosch.

| Primary/Secondary | Quintile | No of pupils | Size of building [$m^2$] | Hostel (Y/N) |
|---|---|---|---|---|
| Primary | 1 | 1600 | 5160 | N |
| Primary | 2 | 600 | 3874 | N |
| Primary | 3 | 300 | 3133 | N |
| Primary | 3 | 700 | 4344 | N |
| Primary | 4 | 600 | 2263 | N |
| Primary | 4 | 900 | 4850 | N |
| Primary | 4 | 1000 | 2504 | N |
| Primary | 5 | 600 | 5744 | N |
| Primary | 5 | 850 | 5582 | N |
| Primary | 5 | 900 | 8800 | N |
| Secondary | 1 | 800 | 2348 | N |
| Secondary | 2 | 150 | 628 | N |
| Secondary | 4 | 1150 | 4917 | N |
| Secondary | 5 | 550 | 7652 | Y |
| Secondary | 5 | 700 | 8826 | Y |
| Secondary | 5 | 1200 | 12703 | Y |

We used the five quintile rankings to organise our sample into an affluent group (Q5) and a poor group (Q1–4). We compared the two groups' daily usage profiles, expressed as energy used per time period (e.g. per hour) per pupil. We compared all the schools using this metric, but since the Quintile 5 secondary schools all had hostels, we also compared the primary schools separately. The profiles were created for the 24 hours of the day and normalised to the pupil number of the schools (Wh/pupil). We used the temporal profile to identify significant usage characteristics at specific times of day and reported them in kWh, kW and per pupil equivalents.

Finally, we used average energy usage, reported in kWh, for in-term and out-of-term times, to compare distributions in our two groups of schools. For each period the weekday and weekend energy usage were recorded. This energy information over these periods was useful to identify usage and extra activity for the different schools. The term period was 1 October to 6 December 2019 and the out-of-term period was 7 December 2019 to 15 January 2020.

## 4. Results

Figure 2 shows school energy intensities reported in the literature for different regions and countries in annual kWh/$m^2$, compared with the results from our two South African groups. The results unequivocally demonstrate that the energy intensity of both our groups is substantially less than that of other regions.

Two notable exceptions were one school each from two Mediterranean countries, Italy and Spain. The surface area was derived by summing the surface areas of all the buildings from Google Maps' satellite imagery, which does not take into account the second and third levels of buildings. However, since energy intensity decreases with increased surface area, the box plots representing the South African schools will only go lower when those levels are also considered. Moreover, the international studies did not say whether they included the multiple levels or not. The figure also highlights the stark difference between affluent and poor schools in South Africa. The median affluent school's energy intensity is approximately an eighth of the energy intensity of schools in the USA and Canada; conversely, the median poor school's is a twentieth. Table 2 and Figure 1 show that this energy intensity difference is not the result of poor schools having more extensive buildings.

Figure 3 shows the hourly energy usage profiles for the two groups, with the shaded bands indicating the schools in each group with lowest and highest average aggregated usage per day. Figure 3(a) shows the distribution for all the schools in our set with hostels included, while Figure 3(b) excludes the secondary schools, and therefore includes no hostels.

The affluent schools use substantially more energy than the poorer schools. In fact, the affluent school with the lowest usage uses substantially more than the poor school with the highest usage. For the full data set, the median affluent school has an average in-term daily use of 643 Wh/pupil, while the median poor school uses only 28% as much, at 178 Wh/pupil. For the primary schools, the median poor school uses 40 % as much as the median affluent school. The variation in the group of affluent schools is wider than that of the poor schools, which can be explained by the fact that the three heaviest consuming schools have hostels. If we consider only the primary schools in Figure 3(b), the variation bands are substantially narrower, but the inequality gap is still gaping, especially during school hours and extra-mural hours of 8am to 5pm.

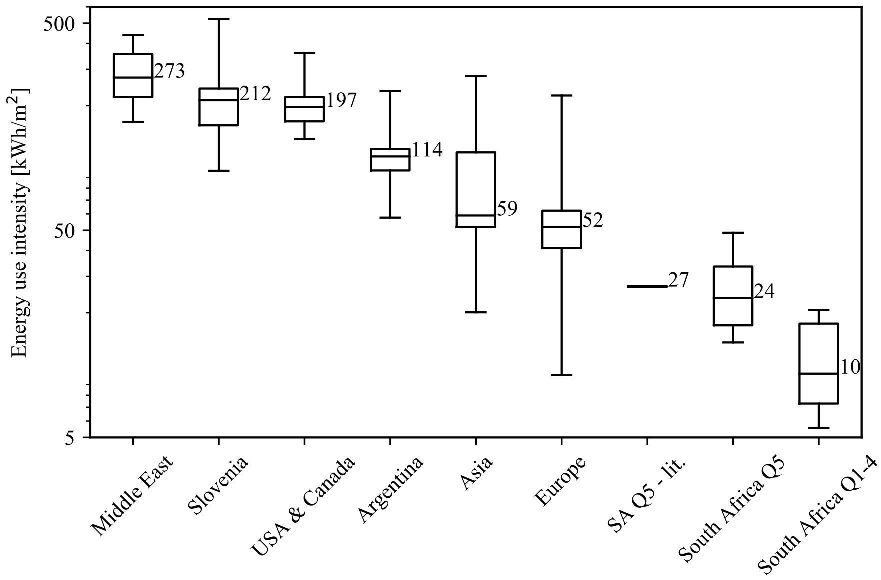
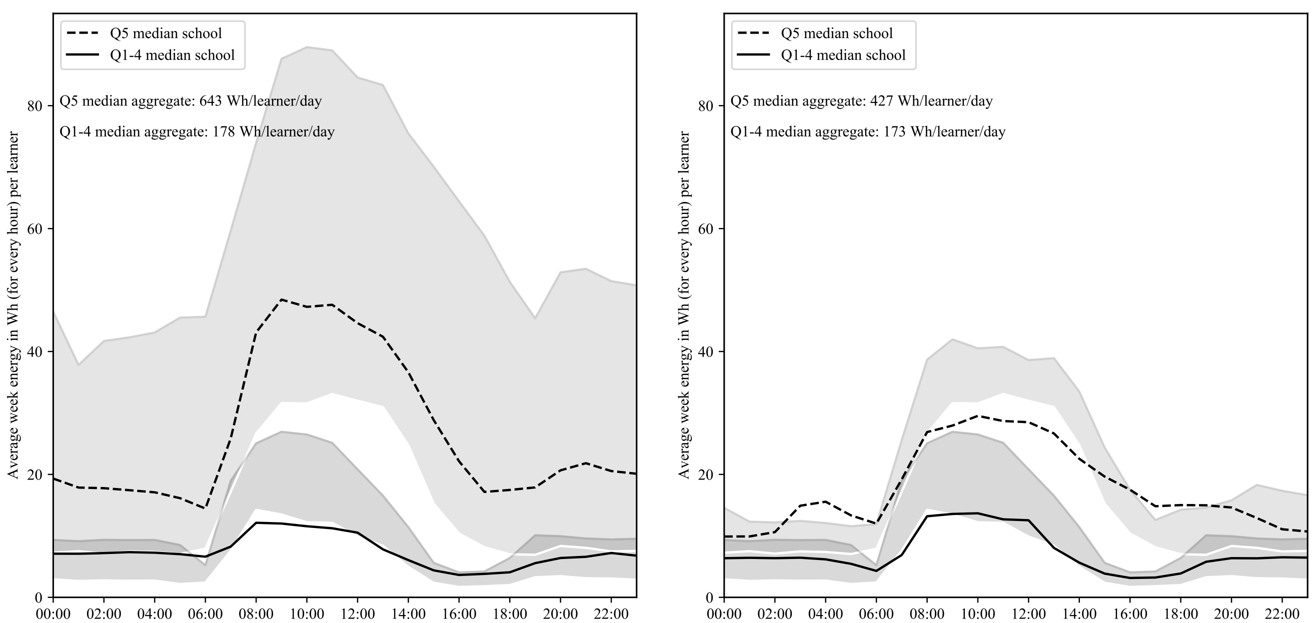



Figure 2: Energy use intensities per year (kWh/m$^2$/y) reported in the literature for schools in various countries and regions compared with the two school groups in our data set. *Notes:*
*1. The vertical axis is logarithmic.*
*2. Grouping by region, where applied, is our own.*
*3. The South Africa sample from the literature (SA Q5 - lit.) is a single quintile 5 school in Gauteng, South Africa [4].*




(a) All schools

(b) Only primary schools

Figure 3: Time-of-usage profiles of average energy usage on in-term weekdays (term 4: 1 Oct to 6 Dec 2019) for affluent schools (Q5) and poor schools (Q1–4). (a) captures all schools that include hostels, and (b) only primary schools. The shaded bands show the schools with the maximum and minimum usage for each type.

We found substantial differences between the schools' energy usage in the early morning and night times. In the hours from midnight to 6am, the median affluent school in Figure 3(a) has an average load of 10 kW (17 W/pupil). In comparison, the median poor school has an average load of 2 kW (7 W/pupil). The most obvious feature behind this difference is the hostel, which contributes to the secondary schools' load. Although the difference is diminished in Figure 3(b), as the primary schools have no hostels, it still persists: 11 kW (12 W/pupil) versus 4 kW (6 W/pupil). One explanation for this is the larger property sizes that require more lighting for night-time security. Another less obvious explanation is the presence of boreholes (for irrigation) and swimming pools, both of which require long hours of pump activity. The affluent schools typically schedule these to run in the evenings to avoid peak time-of-usage tariffs. In extreme cases, affluent schools even have swimming pools that are heated with electricity. On the other hand, the poor schools have a low and flat load profile all the way through from midnight to the time when school starts. In the early evening, the profiles are also markedly different for the two groups. The affluent schools have more variation until 9pm, probably because of evening sport, that uses flood lights, and cultural activities. The poor schools again have a mostly flat profile in the evenings, primarily due to security flood lights. All the schools show a slight increase from 7pm to 9pm, as security lights are turned on.

The load profiles during school hours (Figure 3(a)) clearly show how the inequality gap between the haves and have-nots widens, with the midday peak of the median affluent school at 28 kW (48 W/pupil) and that of the poor school at a mere 5 kW (11 W/pupil). For the primary schools only (Figure 3(b)), the gap is less pronounced: 24 kW (28 W/pupil) versus 7 kW (11 W/pupil). The reason for the gap between the affluent and poor schools can partially be explained by the energy spent per pupil on lighting energy: there are more pupils per classroom in poor schools than in affluent schools, so the energy spent on lighting per pupil will therefore be less. Moreover, our preliminary assessments have shown that lighting accounts 32% (approximately 500 lights per school) of a poor school's total energy usage, and also 32% (approximately 600 lights per school) of an affluent school's total energy usage. This is in the same range as the 46% reported by the one existing South African study [4], but substantially different from the 21% reported by Gamarra et al. [26] and the 25% reported by Lizana et al. [27], both from Spain, a developed country.

However, the stark differences are caused by more than the lights. Affluent schools have well-equipped staff rooms and tea rooms, larger school halls, air conditioners, audio-visual training aids, wireless communications and improved access to computers.

The absolute temporal distributions are shown in Figure 4(a–d) for different periods, making it possible to compare the energy used by the schools (a) per weekday in term time, (b) per weekday during the holidays, (c) per weekend during the term, and (d) per weekend during the holidays.

For all the periods reported, the median of the affluent school is more than double that of the median of the poor schools. In fact, for the term-time weekdays, the poor school with the highest usage uses only 221 kWh while the affluent school with the lowest usage uses 302 kWh. The median for poor schools for this period is 140 kWh, and the median for affluent schools is 393 kWh – almost triple. This stark difference is also observable for weekends in term time, with respective medians of 38 kWh and 112 kWh, which are explained by the wealthy schools' sport activities. Note the tennis courts, rugby fields, astro turf, swimming pools, and other facilities at Q5 schools in Figure 1.

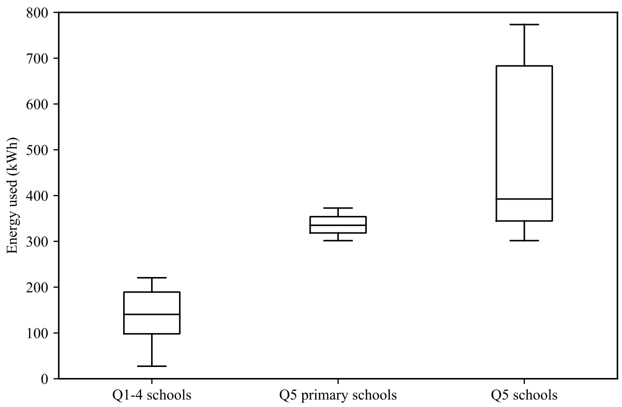
Energy used per day out of term times is also substantially different for the two groups. This means that even during the holidays, when no classes are being held at the school, the median affluent school uses 74 % more than the median poor school (median Q1–4 = 68 kWh; median Q5 = 258 kWh).

## 5. Conclusion

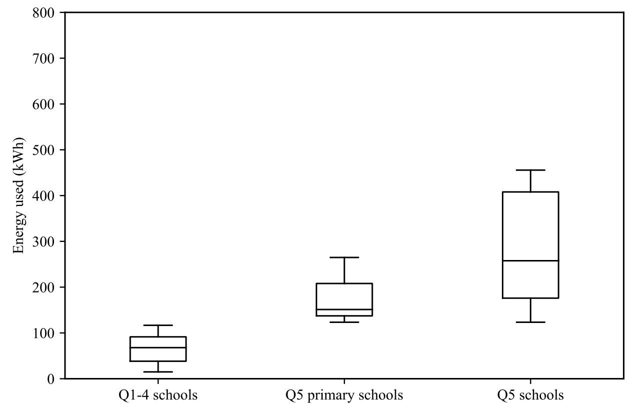
With South Africa's education system and energy generator both severely constrained, we set out to determine the extent to which South African schools use energy, which comes down to using electricity.

We analysed the literature on energy usage at schools, comparing developed and developing countries separately (Table 1). From this literature search, we created a review map that compared the energy usage, energy management, occupancy and technologies representative of the schools. Our data set of 16 schools covers a spectrum of affluence in the town of Stellenbosch, South Africa. The differences in usage that we found largely reflect the segregation line enforced during apartheid, and demonstrate that this distinction is still evident through an energy lens: affluent schools (Quintile 5) are better resourced and thus better positioned to benefit from electrification than poorer schools (Quintiles 1–4).

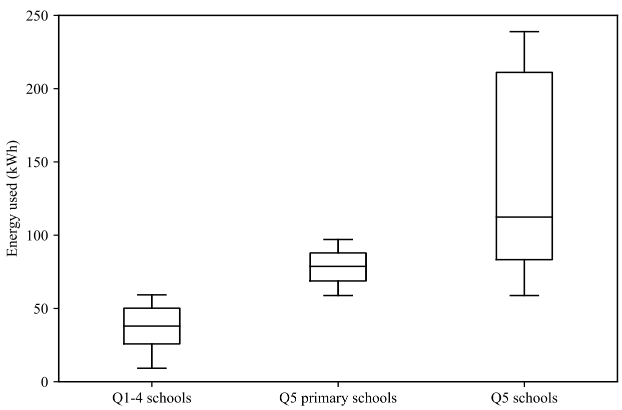
We used municipal and third-party smart meters to collect high resolution energy usage data. Comparing average usages per year to those reported in the global literature, we found that Stellenbosch's affluent schools use substantially less energy per surface area than schools around the world. The median affluent schools in our



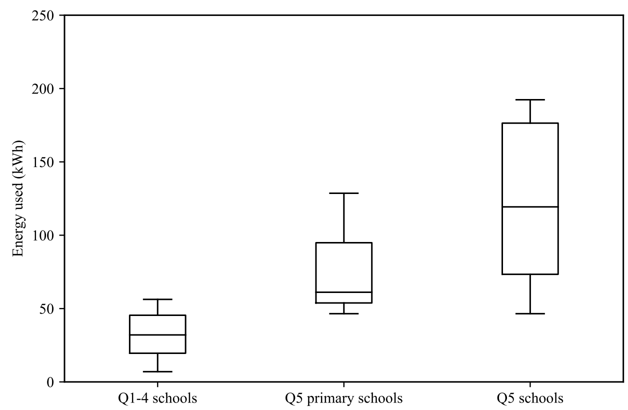

(a) Average energy used per day on a weekday, in term.




(b) Average energy used per weekday, out of term.




(c) Average energy used during a weekend day, in term.




(d) Average energy used per weekend day, out of term.

Figure 4: Energy usage of the schools at different times. The Q5 primary schools are also shown in isolation, to remove the impact of hostels. In term: 1 Oct to 6 Dec 2019. Out of term: 7 Dec 2019 to 15 Jan 2020.

study reported energy intensities at an eighth of the schools in North America; the poor schools reported at a twentieth. The energy intensity of our South African schools is evidently substantially less than those in other countries for both affluent and poor schools. This result holds for schools in warmer and colder climates. We therefore contend that this metric, which is typically used to measure building efficiency, in this case belie a relative lack of investment in infrastructure, rather than incredibly high efficiencies. Such lacking infrastructure include climate control (heating and/or cooling) to improve learning, but more importantly probably expose a shortfall in information technology equipment, mainly computers, especially in the poorer schools. Moreover, poor schools in our sample use substantially less than affluent schools. As with the lower energy intensities than those reported in international studies, this apparent lower usage by the poor schools is not due to energy efficiency, but the lack of equal access to energy-consuming resources, such as laboratories, computers and sporting facilities.

We compared the daily energy usage profiles of the two groups of schools in our data set for one term, expressed as energy per pupil per year. Time-of-usage profiles were generated that featured all the schools and only the primary schools, grouped according to their levels of affluence. The profiles revealed the inequality gap between schools, with the poorer quintiles using 28% less than the most affluent quintile in the all-schools comparison and 40% in the primary schools comparison. Moreover, the temporal profiles allowed for time-based investigation of two specific times. The average baseload of affluent schools was five times larger than that of the poorer schools. The reason for the affluence-energy gap during the day can be explained by sustained low investment in infrastructure at the poor schools. Infrastructure investment takes time, which was also the case for the affluent schools. The stark differences observed here has also taken a long time to accrue, and will accordingly take time to correct.

A large contributor to high usage during the day was identified as outdated fluorescent lights. Lighting was responsible for 32% of daily use at the affluent schools in our sample, and 21 to 65% at the poorer schools; substantially more than the 14% to 25% observed in other countries.

The energy usage for the two groups was also compared on a day-basis for the weekdays and weekends during the term and during the holiday. For all reported periods, comparison of median usage showed that the affluent schools' usage was more than double that of the poorer schools. This is further indication of the inequities in the two groups of schools to benefit from energy further putting South Africa's poor children at a disadvantage.

For future work, these energy-use inequalities could be further investigated; also how various energy efficiency interventions may result in savings for especially poor schools where lighting make up the highest percentage of electricity bills. We thus suggest a study where the lighting systems of South African schools be rolled over to energy efficient lights. We also acknowledge that monitoring and awareness are crucial in reducing energy usage of humans and thus suggest using organisational and behavioural interventions in combination with the above. An earlier pilot study was conducted using both these interventions and yielded 11 to 14% energy savings for affluent schools who took part.

**References**


[1] Eskom, Tariff History, 2020.

[2] M. Kohler, Differential electricity pricing and energy efficiency in South Africa, Energy 64 (2014) 524–532.

[3] S. Essex, J. de Groot, Understanding energy transitions: The changing versions of the modern infrastructure ideal and the 'energy underclass' in South Africa, 1860–2019, Energy Policy 133 (2019) 110937.

[4] J. Gibberd, Rapid identification and evaluation of interventions for improved energy performance at schools, in: Southern African Energy Efficiency Confederation, October.

[5] N. Spaull, Equity: A Price Too High to Pay?, in: South African Schooling: The Enigma of Inequality, volume 79, Springer International Publishing, Cham, 2019, pp. 1–24.

[6] Amnesty International, South Africa: Broken and unequal: The state of education in South Africa, 2020.

[7] M. J. Booysen, B. Wijesiri, C. Ripunda, A. Goonetilleke, Fees and governance: Towards sustainability in water resources management at schools in post-apartheid South Africa, Sustainable Cities and Society 51 (2019) 101694.

[8] B. K. Sovacool, S. E. Ryan, The geography of energy and education: Leaders, laggards, and lessons for achieving primary and secondary school electrification, Renewable and Sustainable Energy Reviews 58 (2016) 107–123.

[9] U. I. Ogbonnaya, F. K. Awuah, Quintile ranking of schools in South Africa and learners' achievement in probability, Statistics Education Research Journal 18 (2019) 106–119.

[10] S. Van Der Berg, How effective are poor schools? Poverty and educational outcomes in South Africa, Studies in Educational Evaluation 34 (2008) 145–154.

[11] S. Van Der Berg, E. Moses, How better targeting of social spending affects social delivery in South Africa, Development Southern Africa 29 (2012) 127–139.

[12] N. Maistry, T. M. McKay, Promoting energy efficiency in a South African university, Journal of Energy in Southern Africa 27 (2016) 1–10.

[13] Ground Up, Water and electricity cut because school can't pay bills, teaching stops, 2019.

[14] News24, City pulls plug on school _ News24, 2019.

[15] V. Butala, P. Novak, Energy consumption and potential energy savings in old school buildings, Energy and Buildings 29 (1999) 241–246.

[16] C. Filippín, Benchmarking the energy efficiency and greenhouse gases emissions of school buildings in central Argentina, Building and Environment 35 (2000) 407–414.

[17] M. Tahsildoost, Z. S. Zomorodian, Energy retrofit techniques: An experimental study of two typical school buildings in Tehran, Energy and Buildings 104 (2015) 65–72.

[18] F. Al-Faris, A. Juaidi, F. Manzano-Agugliaro, Improvement of efficiency through an energy management program as a sustainable practice in schools, Journal of Cleaner Production 135 (2016) 794–805.

[19] H. Ali, R. Hashlamun, Envelope retrofitting strategies for public school buildings in Jordan, Journal of Building Engineering 25 (2019) 100819.

[20] H. Ma, J. Lai, C. Li, F. Yang, Z. Li, Analysis of school building energy consumption in Tianjin, China, Energy Procedia 158 (2019) 3476–3481.

[21] J. C. Wang, Energy consumption in elementary and high schools in Taiwan, Journal of Cleaner Production 227 (2019) 1107–1116.

[22] NREL, K − 12 Schools Advanced Energy Retrofit Guide: Practical Ways to Improve Energy Performance, 2011.

[23] Epa, DataTrends Energy Use in K-12 Schools Benchmarking by State, 2015.

[24] R. Arambula Lara, G. Pernigotto, F. Cappelletti, P. Romagnoni, A. Gasparella, Energy audit of schools by means of cluster analysis, Energy and Buildings 95 (2015).

[25] M. M. Ouf, M. H. Issa, Energy consumption analysis of school buildings in Manitoba , Canada, International Journal of Sustainable Built Environment 6 (2017) 359–371.

[26] A. R. Gamarra, I. R. Istrate, I. Herrera, C. Lago, J. Lizana, Y. Lechón, Energy and water consumption and carbon footprint of school buildings in hot climate conditions. Results from life cycle assessment, Journal of Cleaner Production 195 (2018) 1326–1337.

[27] J. Lizana, A. Serrano-Jimenez, C. Ortiz, J. A. Becerra, R. Chacartegui, Energy assessment method towards low-carbon energy schools, Energy 159 (2018) 310–326.

[28] S. Attia, N. Shadmanfar, F. Ricci, Developing two benchmark models for nearly zero energy schools, Applied Energy 263 (2020) 114614.

[29] B. Simanic, B. Nordquist, H. Bagge, D. Johansson, Predicted and measured user-related energy usage in newly built low-energy schools in Sweden, Journal of Building Engineering 29 (2020) 101142.

[30] R. Ruparathna, K. Hewage, R. Sadiq, Improving the energy efficiency of the existing building stock: A critical review of commercial and institutional buildings, Renewable and Sustainable Energy Reviews 53 (2016) 1032–1045.

[31] R. Dé, A. Pal, R. Sethi, S. K. Reddy, C. Chitre, ICT4D research: a call for a strong critical approach, Information Technology for Development 24 (2018) 63–94.

[32] L. Pérez-Lombard, J. Ortiz, C. Pout, A review on buildings energy consumption information, Energy and Buildings 40 (2008) 394–398.

[33] A. Ibrahim, A. Fudholi, K. Sopian, M. Y. Othman, M. H. Ruslan, Efficiencies and improvement potential of building integrated photovoltaic thermal (BIPVT) system, Energy Conversion and Management 77 (2014) 527–534.

[34] A. C. Cheng, C. J. Chen, C. Y. Chen, A fuzzy multiple criteria comparison of technology forecasting methods for predicting the new materials development, Technological Forecasting and Social Change 75 (2008) 131–141.

[35] C. Martin, Generating low-cost national energy benchmarks: A case study in commercial buildings in Cape Town, South Africa, Energy and Buildings 64 (2013) 26–31.

[36] K. B. Janda, Building communities and social potential: Between and beyond organizations and individuals in commercial properties, Energy Policy 67 (2014) 48–55.

[37] L. Dias Pereira, D. Raimondo, S. P. Corgnati, M. Gameiro Da Silva, Energy consumption in schools - A review paper, Renewable and Sustainable Energy Reviews 40 (2014) 911–922.