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Generating low-cost national energy benchmarks: A case study in commercial buildings in Cape Town, South Africa

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ABSTRACT

National benchmarks are a valuable tool for assessing and monitoring energy consumption in existing building stocks worldwide, but can be time consuming and expensive to generate. I explore a low-cost alternative by coordinating building related data collected by municipalities in South Africa for billing and rates purposes, to create energy use intensities (EUI) for the existing building stock. For a sample of commercial buildings in Cape Town, I link electricity data supplied by the municipality billing department with gross floor area data from the municipality valuation (rates) department, to establish EUIs. From these I calculate benchmarks that represent typical annual electricity usage for retail and office buildings in Cape Town. In addition I identify a number of improvements to data quality and access that would enable South Africa to realise the current opportunities that exist in the structure of its building data collection. In doing so South Africa can potentially leapfrog many other countries in the development of performance-based benchmarks and rating tools for a range of building activities, positioning it at the forefront of building energy-data collection.

1. Introduction

Energy consumed within existing buildings accounts for up to 40% of the annual world energy consumption [1]. Although the greatest savings in energy use per building can often be achieved in new buildings, the largest overall energy savings are often achieved by retrofitting existing buildings [2]. Improving the understanding of the energy consumed in existing buildings is therefore a high priority for those seeking to reduce energy consumption and hence carbon emissions in the national building stock [3].

A critical element for implementing any building energy-efficiency strategy in existing building stock, is measuring and monitoring energy use and setting and meeting targets for improvement. Benchmarks can provide a mechanism for this by defining a value that represents typical energy use, against which any building can be compared. Energy benchmarks are a key part of the process of generating energy ratings, an important tool for comparing and ranking the energy performance of buildings.

South Africa has set ambitious targets for improvements in energy-efficiency, aiming for a 15% improvement by 2015 [4]. Generating energy use benchmarks for existing buildings is an important part of realising this target. The most common approach to generating energy benchmarks for existing building stock involves collecting energy use data from a sample of individual buildings considered to be representative of the national building stock (e.g. [5,6]). This is often achieved by collecting data through surveys, such as the USA Commercial Buildings Energy Consumption Survey (CBECS) [8], which asks building managers for specific data on energy consumption and building characteristics. A study undertaken in Cape Town in 2008 used the survey approach on a small scale to generate good practice benchmarks from a sample of 20 commercial buildings [9]. Although this study produced useful data, it was too small a sample to be applicable to a national scale. In 2012 the Green Building Council of South Africa (GBCSA) commissioned a larger survey to develop a benchmark methodology for integrating into the South African Greenstar environmental certificate for existing office buildings [10]. This study included undertaking a basic survey of 155 office buildings and a detailed survey of 87 office buildings throughout South Africa and presents the development and details of performance based benchmarks for South African office buildings based on the survey results. However surveys collecting energy performance data on other building activities such as retail, hotels and schools have not been undertaken in South Africa. This is largely because such surveys are expensive and time consuming to undertake, factors that have limited the development of national benchmarks in many countries to date [11].

With survey data lacking, alternative energy rating systems have been developed for South African commercial buildings relying on alternative benchmarks. The EnerKey performance

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certificate [12] and the Energy Barometer [13] both generate energy ratings for a selection of different commercial building activities. The EnerKey performance certificates use the design targets for regulated energy usage for new buildings, developed for the South African national building regulations [14], as the comparison benchmark. This approach allows building operators to track their progress each year against the national design targets and allows buildings to be compared against each other between years. However, as the design targets were developed using computer simulated archetypes, many existing buildings vary significantly in operating hours and levels of comfort for the tenant operated items (such as lighting, small power, heating and cooling), from the standard operating profiles and values used to generate the design targets. This often results in operational energy consumption values being much greater than the design target values. The Energy Barometer energy labelling scheme, compares the building under consideration against benchmarks developed from buildings assessed using the scheme in the previous year. This approach allows participants to track their progress each year with regard to the industry average. However, it does not allow buildings to be compared against each other between years, and the buildings used to generate the benchmarks will not necessarily provide a representational sample of national building stock.

In this study I develop an alternative to the above techniques, which has the potential to access energy data for 60% of the electricity customers in South Africa. As electricity dominates energy consumption in commercial buildings in South Africa [15], it was considered that electricity benchmarks would provide a useful indicator of energy performance. This allows for the data collection process to be simplified considerably compared to countries where multiple fuels are used. The process can be further simplified in South Africa as around 60% of the electricity customer base is supplied by local municipalities [16]. This contrasts dramatically with other countries, which often have a proliferation of independent energy suppliers (e.g. the UK has over 70 suppliers of electricity and gas [17]). As municipalities also collect building related data for purposes such as rates calculations, this provides the opportunity to develop a comprehensive building stock database from data that is already collected. I explore this opportunity by linking electricity sales data obtained from the City of Cape Town municipality electricity billing department [18] with gross floor area data obtained from the City of Cape Town municipality on-line valuations database [19], to create energy use intensities (EUIs). Further these data are used to generate energy benchmarks for office and retail buildings in the City of Cape Town.

2. Methodology

Following methods typically used for generating energy benchmarks for existing buildings (e.g. [5–8]), I calculated energy use intensities (EUIs) for a sample of commercial buildings in Cape Town. In the context of this study the EUI is defined as annual energy consumption per square metre (kWh/m^2). I defined the annual energy as the whole building annual electricity consumption in kWh and the building area as the gross lettable floor area of the whole building in m^2. Although many rating schemes consider source energy (also described as final or primary energy) or carbon emissions, baseline benchmarks are usually presented in the form of site energy and converted to source energy or carbon emissions using national average conversion factors during the comparison process [20]. This allows for the conversion factors to change annually with differing national energy generation strategies without impacting the initial benchmark database. I collected site energy data from monthly electricity sales data collected for billing purposes by the Cape Town municipality [18]. Following the recommendations given by UNEP for a common carbon metric [21], I selected gross lettable area (m^2) of the building as the EUI indicator.

Monthly electricity billing data was provided for a sample of electricity consumers on the large power user (LPU) tariff for a twelve month period from October 2006 to September 2007. The sample contained electricity-consumption data for 1200 customers in the City of Cape Town. The data contained the top 75% of consumers on the municipality LPU tariffs. To convert the electricity billing data into useful EUIs I applied the following four filters to the dataset:

Building sector – The building sectors represented in the initial sample were commercial, agricultural, residential, public sector, industrial and unknown. I excluded all buildings not in the commercial sector. I defined the commercial sector as all non-residential buildings except public-sector buildings, industrial, agricultural, and unidentified buildings. After the building sector filter had been applied to the sample there were 422 commercial electricity customers remaining.

Building activity – Due to the diverse nature of activities undertaken in commercial buildings I grouped similar building activities to allow more specific benchmarks. I divided the customers into nine building activity categories (retail, catering, accommodation, office, warehouse, education, healthcare, mixed use, and other). Any buildings that could not be classified into these categories were discounted. I developed the categories from reviewing existing building performance databases [5], [8], and reviewing standard classification systems used internationally that define economic activity [22]. The final selection of building activities followed those used in the Greenhouse Gas Inventory for South Africa [23], with the addition of mixed use buildings as recommended by the United Nations Environment Programme (UNEP) [21]. I assigned building sector and activity using the customer names provided with the electricity billing data.

Energy use intensity (EUI) indicator – To obtain floor area data for each building in the electricity sample, I used the ERF number for each building to access the relevant information in the municipality's on-line valuation database. The ERF number is the existing national system intended to be a unique identifier for each building plot. Any building for which floor area could not be determined due to lack of necessary data was excluded from the sample. After the EUI indicator filter had been applied to the sample there were 158 commercial electricity customers remaining.

Analytical – To test whether the selected EUI indicator of floor area was legitimate for the Cape Town sample, I fitted a linear model to the data using least square regression. Examination of the residuals revealed that buildings with very low (less than 100 kWh/m^2) and very high (greater than 500 kWh/m^2) annual energy intensities, invalidated the assumptions of a linear model. In the case of retail the low energy intensities were generally associated with warehouse style retail premises. The high energy intensities, were associated with large retail businesses, where the extent of the premises included in the billing data was not clear, hence it was likely that floor area was underestimated. For the office sample the reason for the very high and very low energy intensities was less clear, but is also likely to be due to anomalies between the buildings that were included in the billing data and those included in the associated floor area calculations or due to low or unoccupied premises. Based on the linear relationship indicated by the statistical analysis, the floor area was considered to be a suitable EUI indicator only for buildings with EUI's greater than 100 kWh/m^2 and less than 500 kWh/m^2 and any buildings falling outside this range were excluded from the sample. After this analytical filter had been applied there remained 101 commercial electricity customers.

Table 1
Electricity benchmarks based on the median energy intensity value for Retail & Office buildings in the City of Cape Town. Annual kWh (electricity)/m^2 (gross floor area).

Building activity	n	Median (typical) (kWh/m^2 yr)	Upper quartile (good) (kWh/m^2 yr)	Lower quartile (poor) (kWh/m^2 yr)
Retail	40	242	163	358
Office	41	176	140	213

In this remaining sample there were two core groups of buildings with sample sizes large enough to be further analysed; retail (n = 40) and office (n = 41).

For these two groups, I used statistical indicators to identify typical (median), good practice (upper quartile) and poor practice (lower quartile) benchmarks. Defining the benchmarks in this manner enables buildings to be rated relative to the proportion of the sample they perform better (or worse) than. To allow meaningful comparison with benchmarks from other studies, I calculated further descriptive statistics including the mean and associated standard deviation and standard error for both the office and retail datasets.

For the benchmarks to be useful for a wide range of buildings within each defined activity, the sample needs to represent a range of building quality and sizes. Although South African buildings have historically not been subjected to minimum environmental performance standards, I assumed that as architectural preferences and engineering capabilities vary in different decades, quality can be related to building age. Based on this assumption, in addition to floor area data, I obtained the year of construction of each building in the sample from the municipality valuation database and analysed these data to determine whether there was a sampling bias towards buildings of a certain building quality and size within the sample.

3. Results

The range of EUIs for the retail sample and the office sample are presented in Figs. 1a and 2a. The benchmarks generated from these data are presented in Table 1. Further descriptive statistics including the mean and associated standard deviation and standard error are presented for both the office and retail datasets in Table 2.

The age distribution of the buildings used for generating benchmarks for retail and office are presented in Figs. 1b and 2b respectively. For retail buildings, the sample is biased towards post 1980s buildings (Fig. 1b). For offices there is a peak in buildings constructed in the 1970s and 1990s (Fig. 2b). These may lead to the benchmarks being unrepresentative for buildings built in the last decade or for historic buildings. The distribution of floor areas in the samples for retail and office are presented in Figs. 1c and 2c respectively. Floor areas from 0 to 20,000 m^2 are well represented (Figs. 1c and 2c). However there is a gap for buildings between 30,000 and 70,000 m^2 indicating that benchmarks may be unrepresentative for properties greater than 30,000 m^2.

Table 2
Sample summary statistics for Retail & Office buildings in the City of Cape Town. Annual kWh (electricity)/m^2 (gross floor area).

Building activity	n	Mean (kWh/m^2 yr)	Standard deviation (kWh/m^2 yr)	Standard error (±kWh/m^2 yr)
Retail	40	259	112	18
Office	41	188	70	11

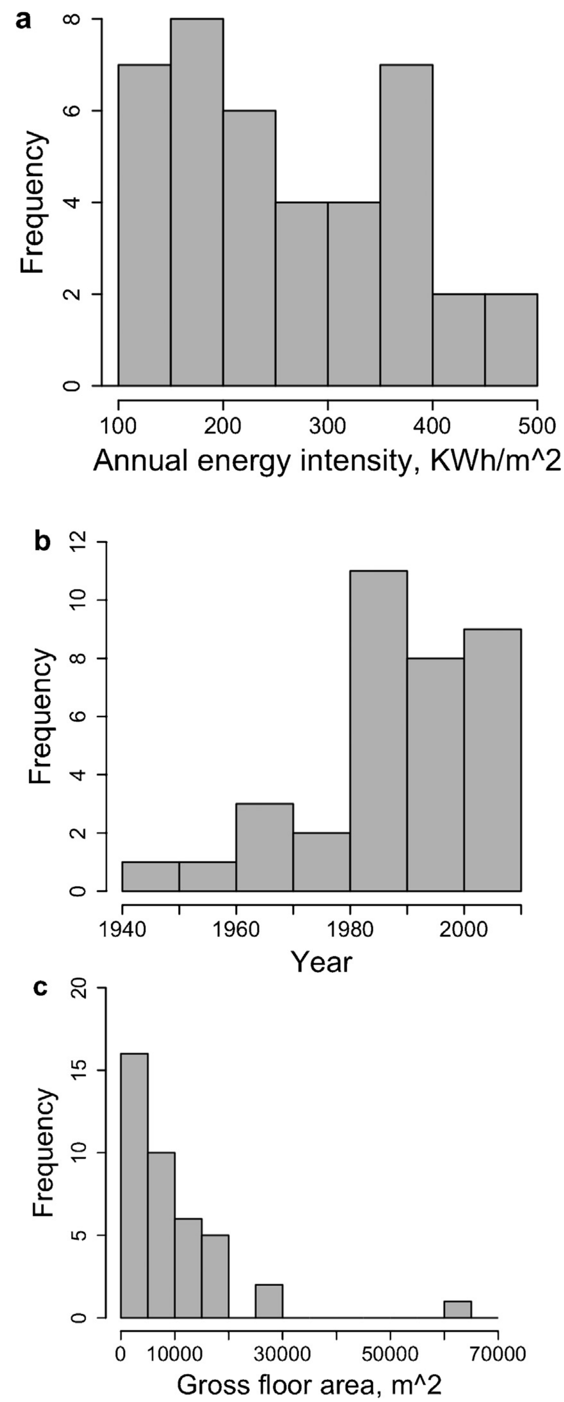

Fig. 1. Distribution of the retail building sample in Cape Town by (a) annual energy intensity (median = 241.76 kWh/m^2, mean = 259.29 kWh/m^2, Std. Dev = 111.6, n = 40). (b) year of construction (median = 1990, mean = 1989, n = 35). (c) gross floor area (median = 6566.5 m^2, mean 9472.6 m^2, n = 40).

4. Discussion

This study demonstrates that it is possible to extract the appropriate data from existing municipality databases to generate basic annual electrical EUI benchmarks, without having to undertake a large scale national energy survey of commercial buildings. However, improvements to the data collection process and an expansion of the data collected to include basic building characteristics would greatly increase the accuracy and scope of these benchmarks. Current limitations to this approach in five key areas, together with

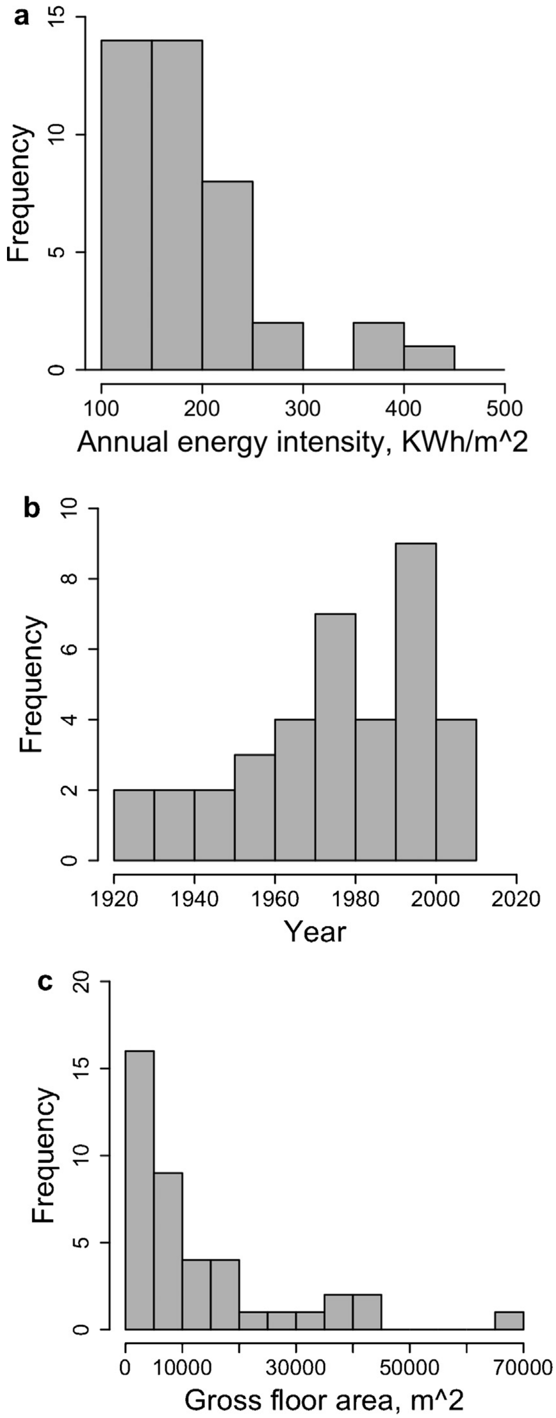

Fig. 2. Distribution of the office building sample in Cape Town by (a) annual energy intensity (median = 176.14 kWh/m^2, mean = 188.38 kWh/m^2, Std. Dev = 69.71, n = 41). (b) year of construction (median = 1980, mean 1976, n = 37). (c) gross floor area (median = 6198.00 m^2, mean = 12641.85 m^2, n = 41).

recommendations of ways in which they can be addressed are discussed below.

4.1. Building activity descriptors

The definition of the commercial sector and the building activities that make up this sector were found to be inconsistent between various bodies that collect building related data, both in South Africa and internationally. Standardising these definitions could greatly increase the sample size available to create energy benchmarks.

In this study the billing data had to be categorised manually by accessing the customer name in the municipality's billing database, this was then cross referenced with the building activity descriptors assigned to each building in the valuation database. If the billing department assigned the same building activity descriptors to each customer as the valuation department, this process could easily be automated.

The Cape Town municipality have a valuable opportunity to implement this as they are in the process of streamlining and updating their property database systems using an integrated spatial information system (project ISIS) [24]. This will link the SAP system (currently used by Cape Town municipality to collect billing data) with other property related information (including the valuation data) using GIS software. Including building activity descriptors in this system, would provide the ability to extract EUI data for each building activity using computer algorithms rather than having to classify each line of data manually. To maximise compatibility with other data sets, an internationally accepted definition of building activities, such as the North American Industry Classification System (NAICS) [21], should be adopted.

4.2. Standardising metrics

The standardisation of metrics is critical when comparing a building's EUI against a benchmark or comparing benchmarks from different studies. The EUI indicator (in this case floor area) has a significant impact on the final benchmark value and it is therefore important that the floor area metric is clearly defined and accurately measured. Guidelines developed by UNEP on measuring energy use and reporting greenhouse gas emissions from building operations for the Common Carbon Metric [23], suggest that the gross floor area should be the energy-indicator, defined as the floor area measured from the outside face of external walls. However, this definition has not been adopted by many building data gathering entities and consequently floor area is often inconsistent between data sets. For example, the definition of gross floor area used in UK benchmarks refers to internal measurements rather than external measurements [5]. Australia changed from gross floor area to net lettable area (NLA) for their energy rating scheme (then the ABGR) after a year of operation [25] on the grounds that NLA was the production variable in the industry and that using gross floor area rewarded buildings with large unconditioned, unoccupied areas. The Cape Town survey undertaken in 2008 [9] used net usable floor area defined by SAPOA [26] this excludes service areas, parking and common areas. SAPOA also define net rentable area, which is the net usable area including parking and common areas. The South African building regulations use net area but do not specify whether they refer to usable or rentable net area. The Cape Town municipality valuations department publishes gross floor area excluding parking [27]. The variations and lack of clarity in reporting floor areas between countries and internally within South Africa, highlight the need for standardisation in reporting of these data.

4.3. Consumer privacy issues

The 2003 South African White Paper on energy highlighted that "concerns about privacy and confidentiality usually put in place principally to protect owners from commercial harassment" was a limit to data coordination [28], little has changed in 10 years. This study relied on Cape Town municipality allowing access to customer energy records. These records revealed customer identities and had to be treated in the strictest confidentiality. In this dataset customer ID was crucial in categorising the properties into the various building activities. Eskom (South Africa's state owned public utility company) was also approached for data, however they could not provide data disaggregated by building activity and, due to their customer privacy policy, would not provide raw data with customer details from which this information might be ascertained. If building activity definitions could be agreed and coordinated across all data collection bodies (e.g. all municipality departments, Eskom, etc.) as discussed in Section 4.1 and each property were assigned to a building activity category by the collection body, customer privacy could be upheld and the quantity of useful building energy data available in South Africa would increase greatly.

4.4. Data quality

There were a number of issues with the quality of the data available, largely due to the data not being collected primarily for the purpose of generating energy benchmarks. In most instances these issues can be readily and inexpensively dealt with or were found to be already in the process of being dealt with by the municipality.

Firstly, the electricity collected by the municipality, primarily for billing purposes, did not distinguish between estimated and actual metre readings and consequently this could not be accounted for in this study. The simple inclusion of an indicator distinguishing actual and estimated readings would enable data to be filtered to exclude estimated readings and the existence of any systematic bias to be assessed.

Secondly, the system currently used by Cape Town municipality to collect the building related data relies on ERF numbers to identify individual properties. These have become confused over the years as plots have been subdivided and municipality boundaries changed, resulting in missing data and inaccurate information. For example, in this study, once the final datasets for offices and retail had been developed, ERF numbers were used to match energy billing data with valuations floor area data. However, only 38% of the commercial buildings in the billing sample could be found in the on-line valuation database, despite having ERF numbers for the entire billing sample. This reduced the number of buildings in the final samples considerably. This issue is being addressed by the municipality of Cape Town as part of the introduction of the ISIS system [24]. This system includes replacing the ERF numbers with newly generated 'LIS-KEY' numbers that will be recorded in a GIS system.

Thirdly, the floor-area data used in this study was collected primarily for calculating government rates and was presented in an on-line database intended for individual building owners to review their building valuation. Consequently the structure and presentation of the valuation on-line database was not designed for extracting data for a large numbers of properties and resulted in the floor-area data being time-consuming to extract and open to misinterpretation and error. There were also some errors within the database, for example where floor areas had been repeatedly entered, and identifying and correcting these errors was time-consuming. Again the introduction of the ISIS system should resolve these issues. It is envisaged that the building data collected by all departments will be cleaned up and entered into the new ISIS system. However, the expertise to operate the ISIS system currently resides in Germany [24], and although most municipalities in South Africa already use GIS to some extent [29], extensive training would be required to realise this vision nationally. This system, if successfully implemented, would be the first of its kind [24,30] and would greatly improve building data quality and access.

4.5. Building characteristics

There are a number of building characteristics that can influence energy-consumption, but are outside the control of the operator, such as outside air temperature and annual hours of use. To assist in identifying systems and operation strategies that are less efficient than typical, these characteristics are often corrected for when comparing a building against a benchmark. For this process, data on key operational and physical building characteristics are required.

Although the municipality data includes information on location and size, it lacks detailed data on other building characteristics typically assumed to influence energy consumption, such as annual occupancy hours, occupancy density, and the density of computers and other energy consuming specialist equipment. Correcting for variations in outside air temperature between locations and years, requires detailed information about climate and the annual split of energy used for heating and cooling in the buildings. Although climate data in the form of degree days is available for most regions in South Africa [31], the split of energy used for heating and cooling is very difficult to ascertain, as electricity is often used for both heating and cooling systems and there is rarely sub-metering of these systems.

In a recent study on benchmarks for offices in South Africa, Bannister and Chen [10] use statistical regression analysis to understand how building characteristics influence energy consumption in offices in South Africa. They observe that there is no empirical support for a climate correction in their dataset. They also show a weak correlation between annual hours of occupancy and annual energy use, and suggest that in the absence of empirical data on annual occupancy, which can be unreliable, a theoretical correction based on building simulation outcomes should be used. Some international rating tools for offices correct for computer and occupancy density (e.g. [6,7]). Bannister and Chen suggest that as most office workers now work with one computer, computer density can be used as a proxy for occupancy density and only one factor needs to be assessed in the rating process, namely computer density as this is easier data to collect. These observations suggest that the building characteristic data currently collected by the Cape Town municipality is sufficient for use in a basic energy rating tool for offices, and the addition of computer densities should be considered to further improve the data.

For commercial buildings other than offices, detailed building characteristic data are still required to ascertain how they determine energy consumption. Using the same approach as Bannister and Chen [10], these data could be collected by undertaking detailed surveys of an unbiased, representative subset of the full sample for each building activity. Inferences based on analysis of these smaller sets of data can then be applied to the broader sample to identify any underlying trends in the relationship between the building EUI and building characteristic and identify the key building characteristics lacking from the municipality's existing database.

5. Conclusion

At a time when escalating energy consumption and the impact of carbon emissions continue to be one of the world's greatest challenges, providing cost effective methods of collecting data to improve awareness and understanding of building energy consumption has immediate relevance. This is particularly true in developing countries and those in transition, such as South Africa.

Using building and electricity sales data collected by the municipalities in South Africa provides an opportunity to collect substantial real world data on building energy consumption. A number of improvements to data quality and access would be required before this could be fully realised, such as co-ordination of building activity descriptors, standardisation of key metrics, ensuring that data access is not limited by consumer privacy issues and the introduction of transparent quality assurance. In addition, the collection of detailed building characteristics' data for a small subset of the sample would provide further insight into the drivers of energy consumption for a range of commercial building activities. If these limitations can be addressed, the introduction of the ISIS data collection process pioneered by the City of Cape Town municipality has the potential to provide one of the most comprehensive and accessible building data sets in the world. Using this source of basic building data could allow South Africa to leapfrog many other countries in the development of performance based benchmarks and rating tools for a range of building activities and position South Africa at the forefront of building energy-data collection.

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