Energy and Buildings 111 (2016) 351–368

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

A high level method to disaggregate electricity for cluster-metered buildings

Nicholas So, Russell Richman*

Ryerson University, 350 Victoria Street, Toronto, ON M5B 2K3, Canada

ARTICLE INFO

Article history:
Received 21 July 2015
Received in revised form 5 November 2015
Accepted 6 November 2015
Available online 22 November 2015

Keywords:
Disaggregating electricity
Cluster-metered buildings
Multiple linear regression
Academic buildings
Electricity prediction

ABSTRACT

Many large institutions do not have a means to gauge electricity consumption for their campus building portfolios. The installation of utility meters is typically outside of the institution's budget. A multiple linear regression approach to estimating consumption for academic buildings is an ideal tool that balances performance and utility. Using 80 buildings from Ryerson University (Toronto) and the University of Toronto, significant building characteristics were identified that showed a strong linear relationship with electricity consumption. Four equations were created to represent the diversity in size of academic buildings on both campuses. Tested using cross-validation, the coefficient of variation of the RMSE for all models was 33%, with a range of error between 20% and 43%. The models were highly successful at predicting high-level electricity consumption at Ryerson University with an average error of 14.8% for five building clusters. Using metered data from each cluster, raw estimates for individual buildings were adjusted to improve accuracy.

1. Introduction

Between 1990 and 2010, overall electricity consumption for commercial and institutional buildings has increased by 32.5% across Ontario [1]. Commercial buildings account for 37% of the Greater Toronto Area's (GTA) total electricity consumption, and one third of the greenhouse gases (GHGs) emitted [2,3]. There is a need to focus on the reduction of energy consumption in these buildings in order to reduce overall energy demand.

Today, the majority of buildings in Ontario are constructed with smart meters in place, measuring and reporting consumption data that still needs to be manually read in many existing buildings. This evolution of metering technology has substantially increased the data available, and subsequently, the understanding of usage patterns for electricity and other utilities within buildings – short and long term benefits of which are explored by the Energy Efficiency Office [4] and Briones et al. [5]. Compared internationally, Ontario appears to be a leader having successfully installed smart meters for measuring electricity usage in most of its residential homes and small businesses [6].

Benchmarking buildings is a tool for assessing electricity consumption within a city. The benefits of benchmarking utility consumption are twofold: (1) buildings of a certain type within a city can be compared to one another to determine relative performance, and (2) buildings of a certain type and/or the entire stock of existing buildings can be compared across cities to measure the potential for savings. Benchmarking buildings is an important if not mandatory first step to addressing electricity consumption in the existing building stock. Unfortunately, before institutions can participate in such programs, an accurate measure for campus building utilities must exist for individual buildings. This missing link is not unique to academic institutions or even to properties in Ontario. The U.S. Energy Information Administration has reported that approximately half of sampled building respondents (approximately 1800) could not provide the required energy usage data for the completion of the Commercial Buildings Energy Consumption Survey [7]. Many institutions state the installation of new utility meters and energy management systems place a heavy financial burden on budgets; with limited financial resources, many properties forgo this necessary service.

Ryerson University (Toronto, Canada) currently does not have insight into the electricity consumption of its buildings on an individual basis. Of the 32 buildings on the campus, 14 share a meter with two or more buildings or spaces (i.e. energy consumption for these buildings is unknown on an individual level). This impedes building energy reduction management through both large capital projects and operating strategies. This problem is not uncommon for academic institutions. The University of Massachusetts Amherst also has less utility meters than the number of buildings on campus.

* Corresponding author.
E-mail addresses: nicholas.so@ryerson.ca (N. So), richman@ryerson.ca (R. Richman).

http://dx.doi.org/10.1016/j.enbuild.2015.11.019
0378-7788/

However, McCusker [8] was able to benchmark 84% of the total built area using available data in order to gauge energy performance for campus buildings.

For many institutions, the installation of individual building energy meters carry high upfront costs (e.g. over 2 million dollars for Ryerson University) and is outside forecasted budgets. The other option of creating traditional building energy models is time consuming and costly for complex academic buildings; this also is an unlikely solution for academic campuses. However, a method of disaggregating energy consumption based off of characteristic building variables that is low cost with second order accuracy is a viable option to gauge energy performance for institutional building portfolios and guide short and long term energy reduction management strategies. This paper establishes a methodology for creating a series of equations used to estimate electricity consumption in academic buildings, based on variables relating to space usage and built form. These equations will address the main prohibitive characteristic of other existing options to disaggregate electricity – high cost.

2. Relative literature

Research involving academic buildings, particularly post-secondary institutions, and their utility consumption patterns is limited due to: (i) being a small portion of newly constructed and existing buildings and (ii) their complexity in space usage, occupant density, and plug loads [9]. This shortage of peer-reviewed work is a driver for the creation of a number of regional and national initiatives targeting issues of sustainability, including energy use and efficiency (e.g. HEEPI, EcoCampus, CUSP, AASHE).

2.1. Normalization of electricity consumption within academic buildings

When measuring and benchmarking electricity consumption between buildings, the units that are most insightful are those attached to a key determinant of energy use. The most common EUI metric that is used for buildings in general is floor area (kWh/m^2) due to its simplicity and effectiveness in allowing comparisons to be made [10]. This is especially true when considering other forms of fuel, such as natural gas, due to its positive correlation with conditioned area; some studies have taken this further and have incorporated interior volume as the reporting metric [11]. Other metrics have been used consistently in existing literature; a common theme is focusing on the particular services offered by the building or space. For instance, occupants, such as students or staff, have been related to energy consumption in academic buildings, and the number of dishes prepared, used for kitchen spaces [12]. Ward et al. [13] studied 103 universities and 91 colleges to determine correlations with total energy consumption and certain indices (e.g. number of full time students, net internal area, age of buildings, etc.). It was found that the factors with the strongest correlations with energy consumption were gross interior floor area ($r^2 = 0.86$), net interior floor area ($r^2 = 0.83$), and number of full time research students ($r^2 = 0.83$).

It is important to note that the terms “energy” and “electricity” are used interchangeably throughout this paper. As this work is dealing exclusively with electricity, it should be assumed that references made to energy are synonymous to electricity – unless otherwise stated. This treatment of terms also extends to ratios where energy and electricity use intensities are used to refer to the same metric – the amount of normalized electricity consumed.

Table A1 represents a summary of literature on EUIs for education-related spaces. Buildings in North America use more electricity per unit area than those in Europe. A non-weighted average of the EUIs for academic-related spaces is approximately 210 kWh/m^2/annum for North America and 120 kWh/m^2/annum for Europe. The stark differences may be heavily attributed to the prevalence of air conditioning in buildings and a more temperate heating season. Baker and Steemers [14] point out that air conditioning can potentially account for 44% of energy demand in office buildings in the UK; a similar trend is reported for Asia [15]. Table A1 shows the variability that exists in the measurements for electricity use in academic buildings. Studies on buildings within the same continent vary considerably as well as within similar space classifications. Consequently, transferability of small sampled results is difficult between institutions.

Benchmarking energy consumption for buildings is a powerful tool that not only gives an indication of current performance, but also informs researchers of historic and future trends in the sector. Due to the resources required to track the number of buildings that exist, many databases are created and maintained by government. These databases were first created for high impact building types such as industrial or residential buildings; these types of buildings have a proportionately large energy footprint in the building sector either due to their sheer numbers, in the case of residential, or their energy requirements for operation, in the case of industrial [15,17]. Currently, the Energy Use Data Handbook [1] is updated annually by the Government of Canada and provides consumption information on major energy consuming sectors in Canada. While these types of reports give insight on overall trends in terms of supply and demand of energy across the country, they lack the detail provided by [7,18], documenting building characteristics and usage patterns alongside their energy demands. These programs are active but are less frequently updated and survey a sample of the entire building stock of that country.

There are few papers that are especially relevant to understanding and estimating electricity consumption in academic buildings. The objectives of Bonnet et al. [12] are very similar to those of this paper in which they: (1) attempted to establish a methodology for auditing energy consumption in academic buildings, (2) tested the methodology on real buildings at an academic campus (University of Bordeaux), (3) gathered data about energy consumption to compile a database specifically tuned to academic buildings, and (4) increased their understanding of the patterns and fluctuations specific to academic buildings. Electricity use intensities for area and occupancy were calculated for campus buildings and were categorized by primary activity such as research, catering, and lecturing spaces. They found that libraries showed the smallest EUI of all spaces (25 kWh/m^2/annum), while (high tech) laboratories showed the greatest (123.25 kWh/m^2/annum). Subcategories were created for catering and research areas due to large variations in consumption among those spaces making generalization difficult. Unfortunately, even with the subgroups created, large variations persisted in labs and correlation with area was not strong; the reported mean EUI of 117.25 kWh/m^2/annum for research areas was not statistically significant. The EUIs for all activity types were aggregated for all buildings and applied to the space usage breakdown for the University to determine what types of areas consumed the most and least electricity.

Another example of linking electricity consumption with a particular space type is outlined in [19] where estimation is based on average electricity benchmarks from United Kingdom academic institutions. The breakdown of space types for the higher education is comparable to those found in [12]. The guide was incomplete and no published EUI’s existed nor were there any performance metrics for the assessment. However, the method of relating consumption with specific activity spaces is very similar to the ones employed in this paper and other published work.

The challenges of generalizing electricity consumption for academic buildings are made evident by Elliott and Guggemos’ [20]