A Framework to Evaluate the Energy Performance of School Buildings with a Real-Time Monitoring Plan

by

Yaqing Chen

A thesis submitted in partial fulfillment of the requirements for the degree of

Master of Science

in

Construction Engineering and Management

Department of Civil and Environmental Engineering
University of Alberta

Abstract

Building energy consumption contributes a significant portion of secondary energy use. Energy consumption in school buildings represents enormous annual cost for school boards nationwide. However, a large portion of the energy used in schools is wasted due to inefficient equipment and occupant behaviour. To reduce the operating budgets of schools in terms of energy costs, an effective energy management strategy must be developed and applied. This thesis presents a framework of an electrical management program to evaluate the energy performance of school buildings. The examination of building energy performance incorporates the analysis of historical electricity consumption data and the establishment of building energy benchmarks. A real-time monitoring plan is also proposed in order to continuously track the energy performance of school buildings and identify any energy saving opportunities. This research study is based on an ongoing project with Edmonton Catholic School District (ECSD) Facility Services. The methodology proposed in this research can be used as a reference by school districts to categorize school buildings based on energy performance and identify electricity-saving opportunities.

Acknowledgements

I would like to express my deepest gratitude to my supervisors, Dr. Mustafa Gül and Dr. Mohamed Al-Hussein, for their guidance and continuous support throughout my research.

This research is designed within in the scope of an energy-saving project for Edmonton Catholic Schools in Edmonton, Alberta, Canada. I would like to thank the project sponsor, ECSD Facility Services, for making this project possible, and for their assistance in providing the required data and the sensor installation. I also would like to acknowledge the help from Dr. Xinming Li, Dr. Ioanis Nikolaidis, Dr. Omid Ardakanian, and Regina Celi Dias Ferreira, who provided their expert advice at different stages of this project. Finally, I wish to give my deepest gratitude to my parents, husband, and friends for their continuous support and encouragement throughout my master's studies.

Table of Contents

List of Figures

List of Tables

CHAPTER 1 INTRODUCTION

1.1 Research Motivation

Energy consumption has been increasing worldwide due to growing economies, populations and other factors (U.S. Energy Information Administration, 2017). Experts expect that this trend of growing energy demand and consumption will continue (Pérez-Lombard et al., 2008). A study conducted by the United States Energy Information Administration (EIA), for instance, predicts that the world total energy consumption will increase by 28% from 168,515 TWh in 2015 to 215,700 TWh by 2040 (U.S. EIA, 2017). According to EIA's prediction, 77% of the global energy consumption in 2040 will still be generated using fossil fuels (U.S. EIA, 2017). Fossil fuels are a non-renewable energy source that will become increasingly scarce with increasing demand. Moreover, the carbon footprint caused by burning of fossil fuels must also be considered due to its environmental impact.

Because of the growing global population, increasing personal income in many countries, and more time spent inside buildings, buildings have become a more significant contributor to world total energy consumption (Pérez-Lombard et al., 2008). In developed countries, the energy consumed by buildings accounts for 20-40% of total final energy consumption, exceeding the energy consumption of some major economic sectors such as industry and transportation (Pérez-Lombard, Ortiz and Pout, 2008). In 2007, buildings in the United States accounted for 9% of global $\mathrm{CO_2}$ emissions, 72% of national electricity consumption, and 36% of national natural gas consumption (U.S. Department of Energy, 2010). In 2010, buildings in Canada were responsible for one-third of national total energy consumption

(Mohareb, 2014). In order to lower the energy consumption of buildings, the energy efficiency of buildings should be improved in the design phase and operational phase.

Statistics show that office buildings have become Alberta's largest final energy consumer as of 2015 and account for 35.3% of the final energy consumption in the commercial and institutional sectors (Natural Resources Canada, 2018c). Among the diverse types of buildings in the commercial and institutional sectors, a substantial number of research studies have been conducted assessing the energy consumption of commercial office buildings while relatively few research studies are available in the literature which focus on the energy consumption of school buildings (Ouf and Issa, 2017).

In the United States, around 8 billion dollars are spent yearly on energy consumption of schools nationwide (Harrigan, 2014). With the utility bills for electricity and natural gas usage accounting for a significant portion of the operational expense of schools, meanwhile, it is also estimated that at least 25% of energy used in schools is wasted (U.S. Department of Energy, 2018). However, the occupants of schools are not typically aware of the amount of energy and money wasted due to inefficient occupant usage patterns. According to the data collected from the PowerSave Schools program, by simply changing the behaviour of occupants in schools, 5 to 15% of energy consumption can be saved (Harrigan, 2014). In addition, with the upgrading of lighting and HVAC systems, energy use can be reduced by as much as 40% (Burlig et al., 2017). At present, however, there are relatively few studies available that focus on school building energy consumption in Canada (Ouf and Issa, 2017). Due to the above reasons, a closer look should be taken at the energy consumption situation in school buildings.

This thesis proposes an energy management framework to evaluate the energy performance of schools in terms of electricity use. In the developed methodology, a good understanding of energy performance of schools is achieved by analyzing the historical electricity consumption data and establishing building energy benchmarks. An in-depth investigation of electricity cost and electricity-specific Greenhouse Gas (GHG) emissions is also conducted, providing a means of systematically measuring the influence of electricity consumption. To identify issues which reduce the energy efficiency of buildings, a real-time monitoring plan is also proposed and is applied to a selected school based on the energy benchmarking result.

The developed methodology is implemented in an ongoing project with ECSD. From ECSD's utility bills and on-site meter data, the patterns of school energy performance are obtained. To categorize the school buildings, a simple descriptive statistics and multiple regression model are respectively developed to build energy benchmarks for schools. A 2-year submetering plan is proposed with the eGauge system to monitor the real-time electricity consumption with all electrical panels in a junior high school (School 14). Electricity costs and GHG emissions, which are the two major outcomes of electricity consumption, can also be quantified using equations developed in this thesis.

1.2 Research Objectives

The framework presented in this research helps school facility operators to conduct better building energy management. This research is based on the following hypothesis:

Understanding electricity consumption patterns of school buildings and conducting real-time monitoring based on energy benchmarking results can help school operators to better manage the electricity consumption of school buildings.

The objectives of this research are summarized below:

1) Evaluate historical electricity consumption of schools and identify energy consumption patterns accordingly;

2) Categorize schools based on energy benchmarking results, and select pilot schools;

3) Systematically measure the influence of electricity consumption on electricity cost and GHG emissions; and

4) Propose a real-time monitoring system.

1.3 Thesis Organization

Chapter 2 (Literature Review) begins with a general discussion of energy consumption in which different energy sources and secondary energy use in various economic sectors are discussed. A subsequent review of the relevant literature on school building energy management and energy factors which affect building energy efficiency is presented. Finally, existing energy benchmarking and real-time monitoring methods are described in detail.

Chapter 3 (Methodology) describes the methodology applied in this research. Pilot schools are selected based on the result of two methods of energy benchmarking for buildings. A real-time energy monitoring plan is proposed with the designed survey questionnaire. The proposed framework can be applied to identify problems in school energy operation and help school facility operators to improve their building energy management practice.

Chapter 4 (Implementation) discusses the implementation of the developed methodology in an ongoing project with ECSD Facility Services.

Chapter 5 (Conclusion) summarizes the research, states its contributions, limitations, and gives recommendations for future research.

CHAPTER 2 LITERATURE REVIEW

2.1 Situation of Energy Consumption

In this section, trends in world energy consumption are reviewed. Different energy sources and final energy consumption in various sectors of the economy are discussed in detail.

2.1.1 World Energy Consumption

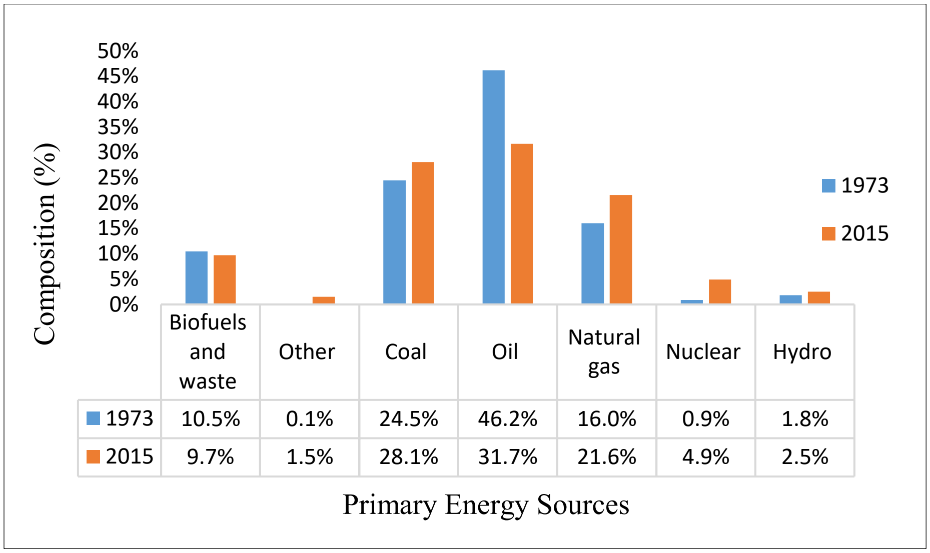
Population growth and urbanization have led to rapid growth in world energy demand (International Energy Agency, 2017). From 1970 to 2015, world primary energy consumption increased by 133% (Ritchie and Roser, 2018). Furthermore, economic growth compounds this growth of energy demand and consumption. The rapid economic growth in non-OECD countries with an annual 3.8% of increase in Gross Domestic Progress (GDP), for instance, is leading to unprecedented increases in energy consumption in these regions (U.S. EIA, 2017), and accounts for more than half of the increase in total energy consumption worldwide from 2015 to 2040 (U.S. EIA, 2017).

As a continuation of this trend in energy use, the U.S. EIA is projecting 28% growth in world total energy consumption from 2015 (168,515 TWh) to 2040 (215,700 TWh) (U.S. EIA, 2017). Even though renewable energy is the fastest-growing energy source, increasing at a rate of 2.3% per year, this growth in renewable energy does not necessarily mean that renewables will dominate energy use in the near future (U.S. EIA, 2017). In fact, fossil fuels are still expected to account for 77% of global energy consumption in 2040 (U.S. EIA, 2017).

2.1.2 Different Energy Sources

Different energy sources are used by different end-users. In general, there are two forms of energy: primary energy and secondary energy. Primary energy can be defined as the energy that directly exists in nature without any transformation (International Energy Agency, 2005). According to the International Energy Agency (IEA), primary energy comprises coal, oil, natural gas, nuclear, hydro, biofuels, and renewables (IEA, 2017). Figure 1 shows the composition changes in world total primary energy supply (TPES) from 1973 to 2015 (IEA, 2017). As can be seen in the figure, crude oil sees the biggest drop at 14.5%, while natural gas see the biggest increase at 5.6% (IEA, 2017).

However, primary energy cannot be used directly by consumers, so it must first be transformed into secondary energy (U.S. Department of International Economic and Social Affairs, 1982). Two examples of secondary energy are hydrogen and electricity. According to 2015 statistics, the electricity sector accounts for 11% of total GHG emissions in Canada (Environment and Climate Change Canada, 2017). There are various ways to produce electricity and each method has a different GHG emission intensity, which can be defined as the amount of GHG emitted to produce one unit of electricity (Environment and Climate Change Canada, 2017). Among them, the electricity produced from coal-combustion has the highest GHG emission intensity (Environment and Climate Change Canada, 2017).



	Biofuels and waste	Other	Coal	Oil	Natural gas	Nuclear	Hydro
🟦 1973	10.5%	0.1%	24.5%	46.2%	16.0%	0.9%	1.8%
🟧 2015	9.7%	1.5%	28.1%	31.7%	21.6%	4.9%	2.5%

Figure 1. Fuel shares of world total primary energy supply in 1973 and 2015 (IEA, 2017)

2.1.3 Final Energy Consumption

Correspondingly, there are two types of energy use: primary and secondary. Primary energy use encompasses all possible energy needs from all possible users (Natural Resources Canada, 2016). It covers the final energy consumption by end-users, the energy required for the energy transformation, the energy loss during energy distribution, and the energy used as feedstock for industrial production (Natural Resources Canada, 2016). In 2013, Canadian total primary energy consumption was calculated to be 12,681 PJ (3,522 TWh), around 2.4% of world primary energy consumption (Natural Resources Canada, 2016). Secondary energy use, which is also known as final energy consumption, is part of primary energy use (Natural Resources Canada, 2016). As opposed to primary energy use, which covers all areas of energy requirements, secondary energy consumption only takes into account the energy consumed by different end-users in various sectors of the economy (Natural Resources Canada, 2018a). Figure 2 demonstrates different energy end-users and clarifies the relationship between primary and secondary energy use in Canada.

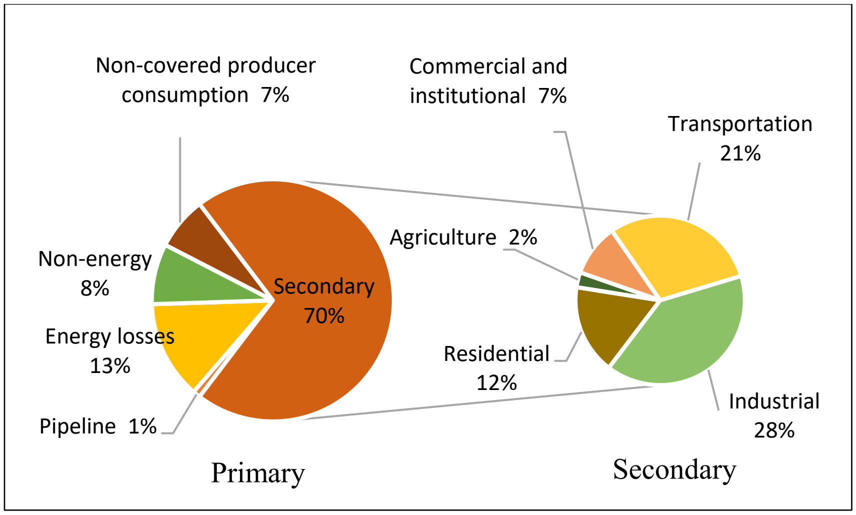


Figure 2. Canadian primary and secondary energy use by different sectors in 2013 (Natural Resources Canada, 2018a)

As can be seen in Figure 2, the final energy consumption is categorized based on five economic sectors. Industry is the largest energy-consuming sector at 28%, followed by transportation at 21%. The commercial and institutional sector is the lowest energy consumer, even lower than the residential sector. Building energy consumption cannot be clearly ascertained just based on this figure, though, since buildings themselves do not represent an independent sector in the economy. Pérez-Lombard et al. (2007) point out the necessity to define an independent sector for buildings, given that buildings represent 20-40% of total final energy consumption in developed countries. In Canada, for instance, buildings were responsible for one-third of the total final energy consumption in 2010 (Mohareb, 2014).

Since commercial buildings typically use more than one type of energy, it is necessary to define a standard unit that can be used to express consumption of any energy type. For commercial buildings, the source of energy is suggested by the U.S. Environmental Protection Agency (EPA) to be used when assessing building energy performance. This can be interpreted as the corresponding raw fuel needed for primary and secondary energy consumed on-site (ENERGY STAR, 2018). To be distinguished from site energy, which only considers the amount of all types of energy directly consumed by end-users and hence appears on the utility bill, source energy also considers the energy loss inherent in the storage, transport, and delivery of primary energy and in the production, transmission, and delivery of secondary energy (ENERGY STAR, 2018). To simplify the calculation of source energy, a national source-site ratio is given by the EPA.

In Canada, electricity and natural gas are the two major energy sources for buildings in the commercial and institutional sector. As illustrated in Figure 3, natural gas occupies the largest share of energy use at 46.8%, followed by electricity at 45.6% (Natural Resources Canada, 2013).

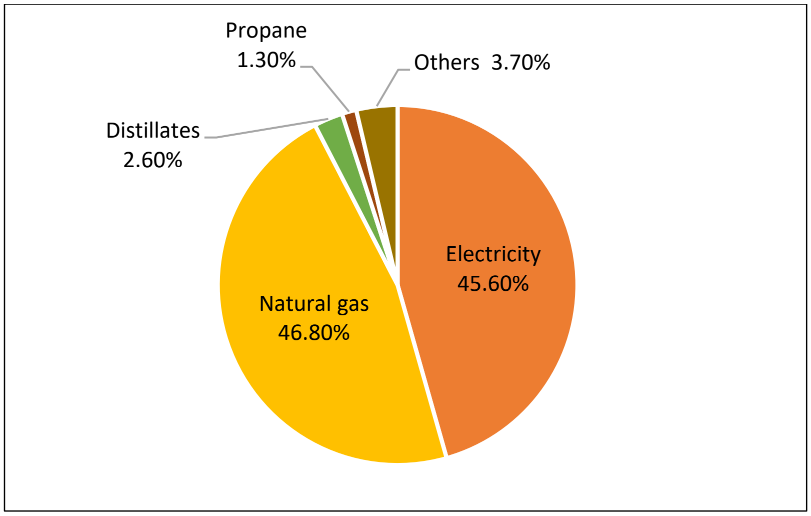


Figure 3. Fuel types used in commercial and institutional buildings in Canada (Natural Resources Canada, 2013)

According to the 2009 Survey of Commercial and Institutional Energy Use (SCIEU), there are significant differences in the energy use of commercial and institutional buildings across Canada (Natural Resources Canada, 2013). Despite the nearly equal consumption of electricity and natural gas in the Pacific Coast and Great Lakes regions, more electricity than natural gas is consumed in Atlantic Canada and Québec (Natural Resources Canada, 2013). As electricity is the main source of energy for heating, a share of 54.4% of the energy used in Atlantic Canada and Québec is electricity (Natural Resources Canada, 2012b). However, due to the abundance of natural gas in the Prairies and British Columbia, natural gas is used as the major heating source in those regions and has a share of 57.2% (Natural Resources Canada, 2013). Distillates account for only a small portion of energy use across Canada, with the exception of Atlantic Canada, where they account for 30.2% of energy use (Natural Resources Canada, 2013).

2.2 Building Energy Management

The energy performance of buildings refers to the relationship between the building energy consumption in the operational phase and the variables which influence the energy consumption (Natural Resources Canada, 2015). To improve the energy performance of buildings and make them more energy-efficient, a proper energy management strategy is needed. In this regard, this section covers the following three topics: (1) energy management systems; (2) energy use and management for school buildings; (3) factors affecting building energy use.

2.2.1 Energy Management System

Natural Resources Canada (NRCan)'s Office of Energy Efficiency commissioned the Energy Management Best Practice Guide in 2015. As part of the guide, energy management information system (EMIS) is suggested to be installed to monitor energy consumption activities (NRCan, 2015). As defined by the Vancouver School Board in its

Strategic Energy Management Plan, EMIS refers to the equipment installed to monitor the real-time energy consumption situation (Vancouver School Board, 2017). EMIS is a vital part of energy management, providing real data to inform decision making about energy management (Hooke et al., 2004).

2.2.2 Energy Use and Management in School Buildings

In Canada, among the various economic sectors, the commercial sector accounts for 20.9% of electricity consumption and 19.3% of natural gas consumption (NRCan, 2018c). Based on 2015 statistics, Figure 4 shows the final energy consumption breakdown in Alberta's commercial and institutional sector with respect to different activity types (NRCan, 2018c). As can be seen, the education service sector, with a 12.8% share of secondary energy use, is the third-largest final energy consumer among all types of activities in the commercial and institutional sector.

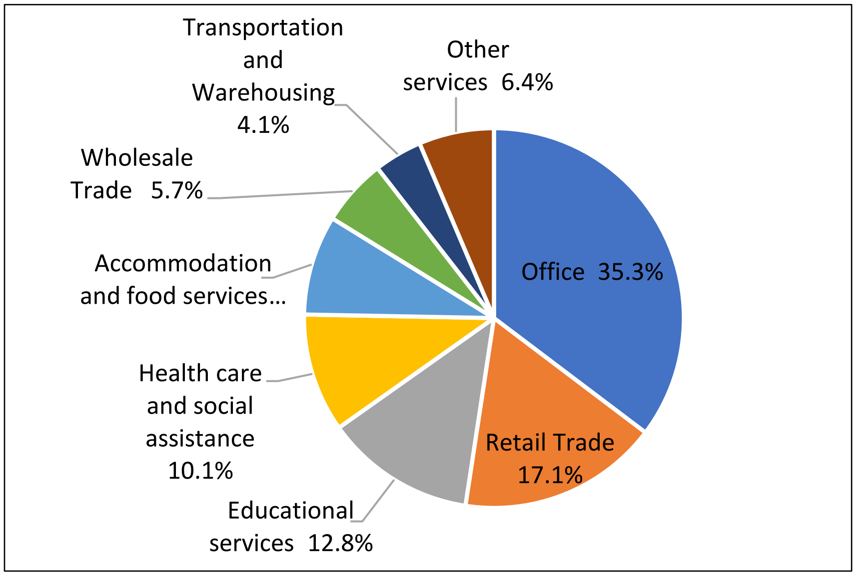


Figure 4. Breakdown of secondary energy use by activity type in Alberta's commercial and institutional sectors (NRCan, 2018c)

Few studies to date have focused on the energy performance of schools (Ouf and Issa, 2017). Instead, researchers prefer to analyze the energy performance of commercial office buildings due to the large share of consumption by the commercial sector they represent (Ouf and Issa, 2017). As mentioned by the director of the U.S. Department Of Energy (DOE)'s Building Technologies Office, among all types of operational expenses in schools, the cost of energy consumption is the second-highest, exceeded only by expenditure on salaries (U.S. Department of Energy, 2018). Newly energy-retrofitted schools, meanwhile, are found to have less natural gas consumption but increasing electricity consumption (Issa et al., 2010; Ouf et al., 2016; Sharp, 1998), hence the potential energy efficiency of these school buildings is not fully realized. Due to the above reasons, among others, a close investigation of the energy performance of schools is warranted. Within the scope of the present research, it should be noted, only the electrical performance of school buildings will be analyzed.

Some studies which focus on analyzing school building energy performance are listed as follows. Sharp (1998) analyzes the electrical energy use of schools with the application of a similar method to what the one he had applied to commercial office buildings in an earlier study (Sharp, 1996). The regression analysis in his research can further be utilized by school boards to identify the top energy-consuming schools within their jurisdiction (Sharp, 1998). Issa et al. (2010) select 10 conventional and 20 energy-retrofitted schools among 550 schools in the Toronto District School Board (TDSB) to investigate electricity, water, and gas consumption trends. Building on this research, Issa et al. (2011) add three more LEED green Toronto schools to the previous list of 30 schools. The amount of energy consumption and the life cycle cost of green buildings are investigated to determine whether green buildings are more economical in the long run. Hong et al. (2014) apply artificial neural network (ANN) in order to analyze the intrinsic features of buildings in 464 UK schools. In their study, more features are taken into account for school energy benchmarking, thereby increasing the level of comparability (Hong et al., 2014). Ouf (2017) investigates the energy performance of school buildings in Manitoba as well as the effect of occupant behaviour on electricity consumption.

The Canadian government and various school boards across Canada also actively pursue school energy savings measures. With the aim of properly directing school facility operators and helping them to conduct effective energy management, NRCan published two guides in 2001, “Best Practices Guide for School Facility Managers” and “Benchmarking Guide for School Facility Managers”. The first guide identifies various energy-saving opportunities that fall into different cost levels and payback periods (NRCan, 2001b). The second guide provides detailed steps for energy benchmarking for school buildings (NRCan, 2001a). As part of Ontario’s sustainable school program, the most energy-efficient Ontario school board is recognized in the Top Energy Performing School Boards Report published by Toronto and Region Conservation Authority (TRCA) (TRCA, 2016). In the report, the methodology used to analyze school energy consumption is also demonstrated in detail. Vancouver School Board has engaged in many programs related to school energy use and GHG reduction. The 2015-2016 Strategic Energy Management Plan (SEMP) outlines all activities to be implemented in the period 2013-2017 for the purpose of reducing school energy use and GHG emissions (NRCan, 2018d).

2.2.3 Factors Affecting Building Energy Use

Factors which influence a building's energy efficiency need to be taken into account when conducting building energy benchmarking (Chung, 2011). These energy-use drivers can be considered the principal variables influencing the energy efficiency of buildings (Sharp, 1998). As suggested by Chung (2010), when energy benchmarking is conducted on select buildings, these factors need to be normalized (Chung, 2011).

Differences between the mean and median Energy Use Intensities (EUIs) are identified by Sharp (1996) in most census divisions of U.S. office buildings. Arguing that the mean value of sample EUIs is not an ideal benchmark because of some extremely high EUIs skewing the distribution, Sharp (1996) uses a linear regression method to develop benchmarks for office buildings. By applying screening criteria to clean the dataset to 1,358 buildings and conducting stepwise regression analysis, Sharp identifies six building characteristics that strongly affect EUIs: the logarithm of the number of workers per square foot, number of personal computers, operating hours, whether or not the owner is an occupant of the building, usage of an economizer, and usage of a chiller (Sharp, 1996). Piper (1999), meanwhile, identifies seven categories of building energy-use drivers: people factors, building type factors, occupancy factors, climate factors, age factors, construction factors, and energy end-use system factors. In addition, six major categories of variables are summarized by the IEA in Energy in Buildings and Communities (EBC) Annex 53: climate, building envelope, building services and energy systems, building operation and maintenance, occupant activities and behaviour, and indoor environmental quality (Yoshino et al., 2017).

2.3 Building Energy Benchmarking

Building energy benchmarking is a process to build the baseline of a building energy performance (NRCan, 2018e). It is a component of building energy management (Hong et al., 2013), which can be utilized to improve the energy efficiency of buildings. Building operators can compare a building's energy performance with this baseline in order to determine whether the building is performing better or worse than this the established standard. It is crucial to see the benefits of energy benchmarking before using it. Some of the benefits of benchmarking identified by NRCan are summarized below (NRCan, 2018e):

- Objectives on building energy use will be established
- Building energy management plan will be more complete and advanced
- Awareness of the importance of building energy efficiency can be increased among occupants, which will lead to some beneficial behaviour changes
- Poor-performing buildings will be identified, and energy practices from best-performing buildings can be applied to improve the poor-performing ones
- Energy cost will be reduced

EUI is used as an exemplary unit to examine the situation of a building's performance (Eto et al., 1990). As an energy efficiency indicator (Chung, 2011), EUI is usually calculated by normalizing the sum of buildings' annual electricity and fossil thermal energy use based on floor area (Hong et al., 2013). Energy benchmarks are normally interpreted in in terms of EUI (Hong et al., 2013), such that the energy performance of different buildings can be directly compared. The reason energy is normalized by floor area is because building floor area is commonly recognized as a primary energy-use driver (Sharp, 1996).

In a study by Ouf and Issa (2017), three energy benchmarking types are mentioned. The first benchmark is the energy consumption of similar-type buildings, the second benchmark is the national or regional average, and the third is a simulation-based result. The first two energy benchmarks are existing benchmarks that can be directly used and compared. For instance, in their study, the first objective is to compare the energy performance of 30 schools in Manitoba with existing Canadian benchmarks (Ouf and Issa, 2017). The most recent national benchmarks for commercial buildings in Canada are from the 2009 SCIEU (NRCan, 2012b). For the United States, the 2012 Commercial Building Energy Consumption Survey (CBECS) has the most updated national benchmarks. The third energy benchmark identified by Ouf and Issa (2017) is not obtained directly and needs to be determined using the output of an energy simulation model. For example, Federspiel et al. (2002) use an energy simulation model to develop an energy benchmarking system for laboratory buildings.

In order to compare with existing benchmarks or even to have a general idea of which building within the organization uses energy more efficiently, a benchmarking process needs to be developed (Chung, 2011). There are no rules defining how a benchmark should be established, so a range of different methods have been carried out in previous studies. Chung (2010) summarizes six general mathematical methods to develop the benchmarking system and categorizes the benchmarking system into two criteria, public benchmarking and internal benchmarking. Public benchmarking can be applied generically and it includes three mathematical methods: Ordinary Least Square (OLS), Stochastic Frontier Analysis (SFA) and simple descriptive (Chung, 2011). On the other hand, internal benchmarking system is specific to a particular organization and is not intended for public use due to the difficulty of retrieving the model built in the benchmarking process. The mathematical methods included in internal benchmarking are Data Envelopment Analysis (DEA), energy simulation, and ANN (Chung, 2011).

Hong et al. (2014) define the top-down and bottom-up approaches for energy benchmarking, where top-down energy benchmarking only uses the building-level information as a reference, hence the building's energy benchmark in EUI is derived without knowing any information regarding the specific sub-systems (Hong et al., 2013). Top-down energy benchmarking methods include simple descriptive, OLS, ANN, and DEA. Bottom-up energy benchmarking, meanwhile, as a detailed energy simulation approach, entails collecting all detailed information pertaining to the energy performance of each sub-system, then aggregating it into a representative benchmark EUI (Burman et al., 2014).

It should be noted that, in the tracking section of the Energy Management Best Practice Guide, NRCan recommends the benchmarking tool "Portfolio Manager" for assessing the energy performance of commercial buildings. This energy benchmarking tool is a product of ENERGY STAR derived from the U.S. EPA's model based on the 2012 CBECS database (ENERGY STAR, 2016). It launched in Canada in 2013 with Canadian energy consumption data from the 2009 SCIEU (NRCan, 2018f). In 2017, the City of Edmonton published a document to instruct building owners and operators on the use of ENERGY STAR Portfolio Manager (City of Edmonton, 2018), thereby encouraging participation in Edmonton's Building Energy Benchmarking Pilot Program. Portfolio Manager is a free cloud-based energy benchmarking tool that satisfies the standards of LEED and BOMA BEST, which are Canada's two leading building rating programs (NRCan, 2012a).

ENERGY STAR Portfolio Manager scores building on a scale from 1 to 100, ranking the position of a specific building's performance among all similar buildings nationwide (NRCan, 2012a). However, the entered energy data must include all types of energy consumed by the building. In the present case, with only the electricity consumption under consideration, the ENERGY STAR score is not calculated.

2.4 Real-Time Energy Monitoring

As an integral component of energy management, energy monitoring can obtain specific consumption statistics which are valuable for further energy optimization (Hooke et al., 2004; Zoha et al., 2012). Abubakar et al. (2017) summarize two types of monitoring methods for home energy management, intrusive load monitoring (ILM) and non-intrusive load monitoring (NILM). ILM is a distributive sensing monitoring method that in turn has three subdivisions: sub-metering system, smart plug and smart appliance (Ridi et al., 2014). In this method, sensor instrumentation must be installed for every load of interest, from circuit-level monitoring of a zone of appliances to monitoring of a single appliance (Ridi et al., 2014). In contrast to ILM, NILM involves no intrusion to the individual appliance, as it measures the overall energy use at the point of utility service entry (Zoha et al., 2012). However, because of the method of measurement in NILM, load disaggregation is required based on each appliance's signature (Zoha et al., 2012). In this research, due to the complexity of appliances in schools, ILM is used to monitor the space-level electricity consumption

CHAPTER 3 METHODOLOGY

This chapter summarizes the methodology applied in this research. As illustrated in Figure 5, the methodological approach consists of four major components: inputs, methodology, criteria, and outputs. Based on the input parameters and criteria, the outputs are obtained by implementing the processes in the methodology.

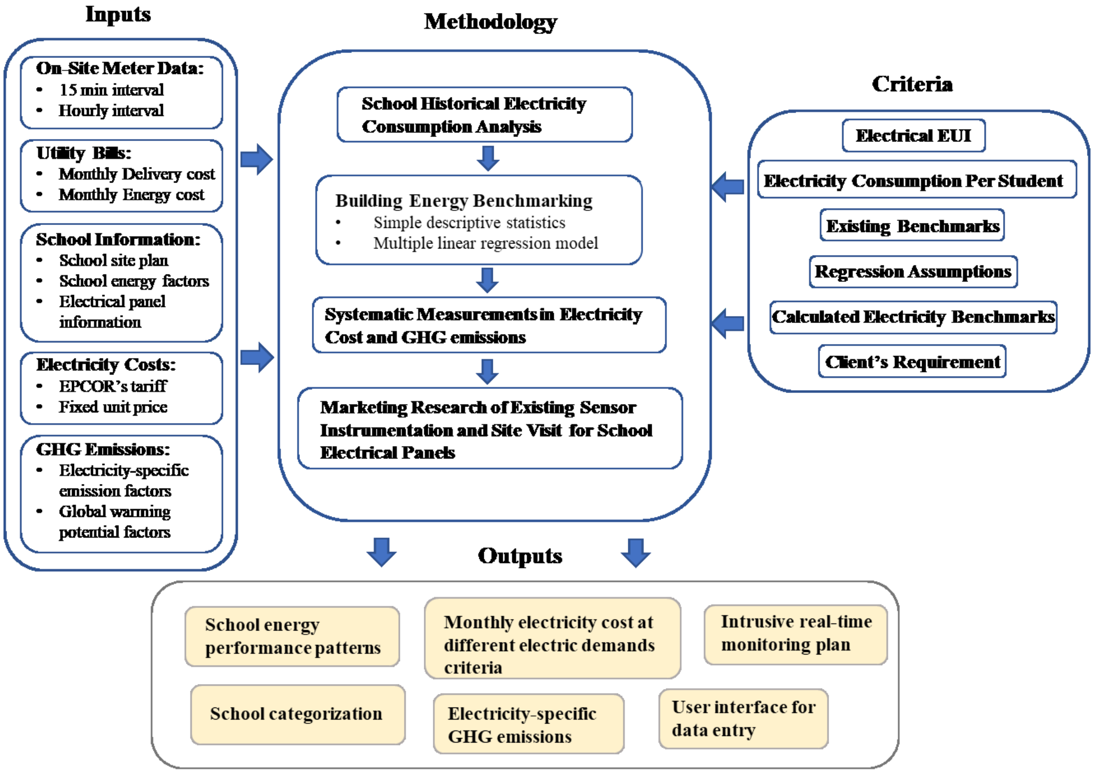


Figure 5. Overview of research approach

In order to help the collaborating partner, Edmonton Catholic School Division (ECSD), to achieve better energy performance by reducing electricity consumption for their schools, four successive processes need to be applied: (1) analyzing historical electricity consumption of the schools; (2) categorizing school building energy performance using energy benchmarking; (3) developing formulas regarding electricity costs and GHG emissions; and (4) creating a continuous monitoring plan for selected schools. The inputs are on-site meter data, utility bills, school basic information, electricity costs, and GHG emission parameters. The outputs resulting from the implementation of the methodology include school energy performance patterns, school categorization results, formulas for monthly electricity cost at different electricity demand and electricity-specific GHG emissions levels, a user interface, and a proposed real-time monitoring plan. The outputs are subject to the research criteria, which include metrics in EUI and electricity consumption per student for energy benchmarking, existing benchmarks, calculated energy benchmarks, regression assumptions, and owner-occupant requirements. By using the framework proposed in this research, school operators can conduct better energy management and make school buildings more energy-efficient.

3.1 School Historical Electricity Consumption Analysis

To gain better understanding of school building energy performance, historical electricity consumption for all 86 schools under consideration needs to be evaluated. This information is collected from ECSD utility bills and on-site meter data. The majority of schools have utility bills available from June, 2012, to May, 2017, the two exceptions being two newly constructed schools, which have invoice information available only from September, 2016, to May, 2017. From the utility bills, monthly electricity usage patterns and seasonal variations can be obtained. A more accurate weather-normalized annual electricity comparison in 2015 and 2016 is also conducted for ECSD. On-site meter data in 15-min and hourly intervals from June, 2016, to June, 2017 is available for 84 of the schools, though not for the two new schools. The on-site meter data can be used to verify the electricity consumption data from the utility bills, and can also be used to view usage patterns for shorter time interval. From the daily consumption patterns, the differences between weekdays, weekends, and statutory holidays can be observed. The hourly consumption patterns also demonstrate the rush hours of school operation. By summing up the on-site meter data to the monthly interval, the trends of electricity consumption in utility bills can be verified.

Four of the schools feature two meters on site which independently record electricity consumption data from portable rooms and the main school building. As required by ECSD and due to the presence of separate heating systems for the main school building and the portables, a comparison of the electricity consumption in the two respective areas is conducted through the analysis of on-site meter data for these four schools. EUI as an energy-efficiency indicator is calculated for the core area and portable rooms, respectively, using the Equations (1) to (4). It is assumed that each portable room evenly shares the linkage area in the "other area" of school, and that the portable EUIs calculated are the same for all portables in meter 1 and meter 2.

$$\text{Average portable room area (m}^2\text{)} = \frac{\text{Other area } (m^2)}{\text{Total number of portables}} \tag{1}$$

$$\textbf{Portable EUI (kWh/m}^{\mathbf{2}}\textbf{)} = \frac{\text{Annual electricity consumption in meter 1 (kWh)}}{\text{Average portable room area (m}^2\text{)} \times \text{Number of portables in meter 1}} \tag{2}$$

Core area annual electricity consumption (kWh) = Annual electricity consumption in meter 2 – Portable EUI × Average portable room area × (Total number of portables – Number of portables in meter 1) (3)

$$\textbf{Core area EUI (kWh/m}^{\mathbf{2}}\textbf{)} = \frac{\text{Core area annual electricity consumption (kWh)}}{\text{core area (m}^2\text{)}} \tag{4}$$

3.2 Methodology for Building Energy Benchmarking

Rather than looking at all the school buildings in ECSD's portfolio, it is important for school operators to focus on some pilot schools and make improvements in their energy performance. This section summarizes the methodology applied to categorize schools using simple descriptive statistics and multiple linear regression.

3.2.1 Simple Descriptive Statistics

After testing with the coefficient of determination, two metrics—EUI and electricity consumption per student—are respectively applied in simple descriptive statistics. The annual electricity consumption in 2015 and 2016 for each school is used to calculate the two metrics. The average EUI for each school is then obtained by taking the average of 2015 EUI and 2016 EUI. After fitting all schools' average EUIs into a distribution, the benchmark in EUI for ECSD is achieved by selecting the value between the mean and median. In this case, since the average EUIs follow a normal distribution, mean and median values are the same. EUI residuals are calculated by subtracting the school board's EUI benchmark from each school's average EUI. To categorize the schools, the EUI residuals are fitted into a distribution with the top and bottom 15%. For the metric of electricity consumption per student, the same procedure is used as for EUI. The only difference is that the fitted distribution is a right-skewed log-logistic distribution curve, hence the median value is taken as the benchmark. In simple descriptive statistics, schools with different performance values are selected based on the results of the intersection among the top and bottom 15% from both metrics.

3.2.2 Multiple Linear Regression Model

With average EUI set to be the response, and selected energy factors serving as the predictors, a multiple linear regression model is built and computed in the software application Minitab (Ryan et al., 1972). The multiple linear regression model is expressed as follows (Chung, 2011; Montgomery et al., 2013; Sharp, 1998):

$$\overline{EUI}_{a,i} = \beta_0 + \sum_{j=1}^{m} \beta_j x_{j,i} + \varepsilon_i \quad \forall i = 1, \dots, n \tag{5}$$

where

$\overline{EUI}_{a,i}$is the actual value of average EUI for i^{th} observation, kWh/m^2

i is the specific number of the observation

β_0 is the intercept

$\beta_1 \dots \beta_m$ are unknown coefficients

$x_{1i} \dots x_{mi}$are predictors for i^{th} observation

ε_i is the random error for i^{th} observation

By using the least square method in which $\sum_{i=1}^{n} \varepsilon_i^2$ is minimized, a regression equation of $EUI_{predict}$ can be obtained for all observations (Chung, 2011). The regression equation with least square estimation is given below:

$$\overline{EUI}_p = b_0 + b_1 x_1 + b_2 x_2 + b_3 x_3 + \cdots + b_p x_p \tag{6}$$

where

$\overline{EUI}_p$ is the predicted EUI, kWh/m^2

Since not all energy factors are used in the regression analysis, a manual selection process is carried out to satisfy the conditions of regression. Among all the collected energy factors, six discrete factors are filtered out or replaced by others. The total area factor is removed due to its existence in the unit of EUI. Other area is renamed "portable existence" and becomes a categorical input. As a newly developed energy factor, building age is calculated using four existing factors: original year built, original building area, year of each additional construction, and additional area each time. The formulas to define the calculated building age is given below:

$$\text{Building Construction Year} = \sum (Y_i \times \frac{A_i}{\sum_{i=0}^{n} A_i}) \ \forall \mathrm{i} = 1, \ldots \mathrm{n} \tag{7}$$

$$\text{Building Age} = \text{Current Year} - \text{Building Construction Year} \tag{8}$$

where

i is the number of times for school to be under construction

Y_i is the year of construction for each school building

A_i is the added area due to each school building renovation, m^2

The regression steps are specifically developed and demonstrated in Figure 6. These steps incorporate five assumptions that need to be satisfied for regression analysis. The five assumptions are listed below (Chatterjee and Hadi, 2015): (1) Existence of linear relationship between each independent variable and dependent variable; (2) No multicollinearity between independent variables; (3) Satisfaction of multivariate normality; (4) Satisfaction of homoscedasticity; and (5) Independence of observation among residuals. After obtaining the final regression equation with some most representative predictors, the regression residuals can be calculated by applying $\overline{EUI_a}$ minus $\overline{EUI_p}$.

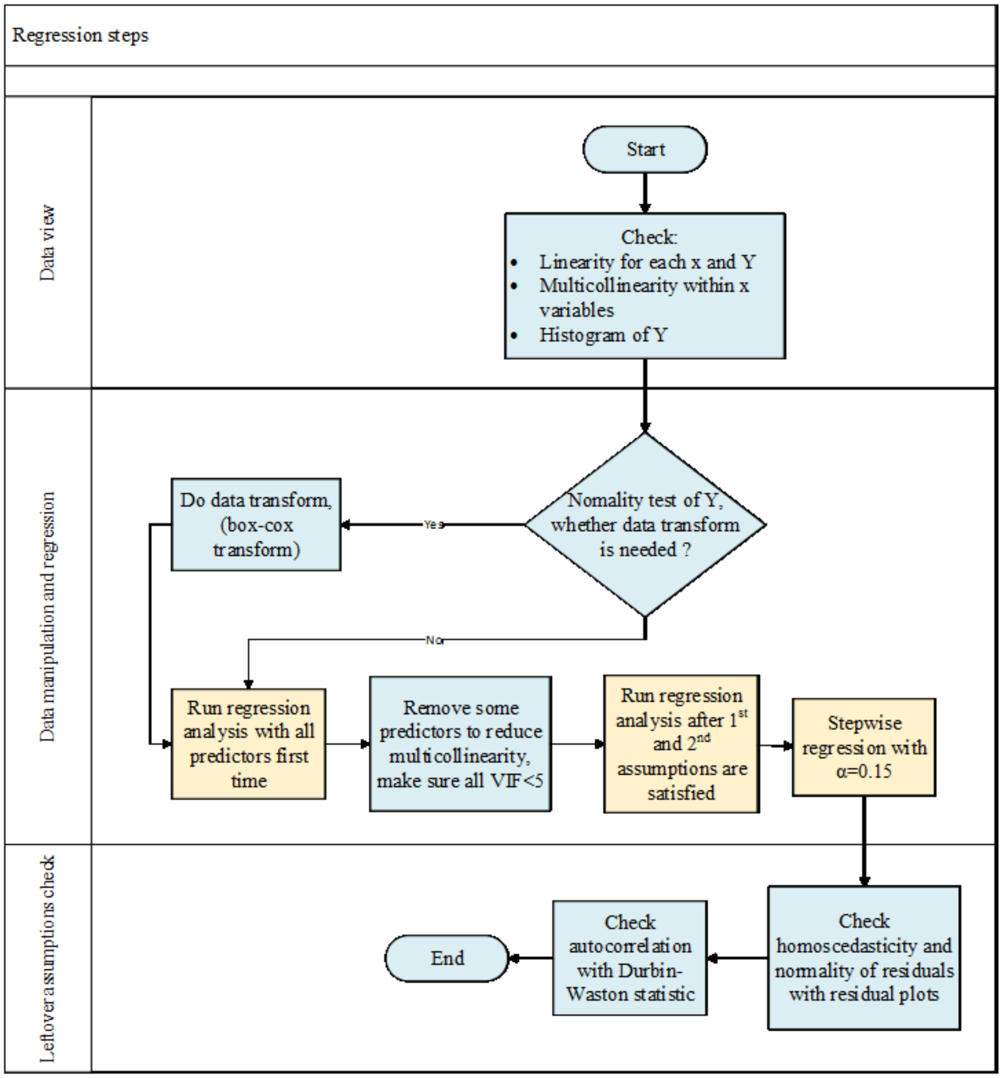


Figure 6. Regression steps

The schools under investigation are categorized in terms of the top and bottom 15% of regression residuals. In regression analysis, it should be noted, the selection of schools depends not only on percentile range. In order to be selected, a given school must appear at least once in one of the metrics in simple descriptive statistics. Finally, a union set of the results from both the simple descriptive and regression is required in order to finalize the list of selected schools.

3.3 Electricity Cost Analysis and GHG emissions

For each school, monthly electricity cost is the sum of energy cost and delivery cost. Based on the utility bills provided by ECSD, Equations (9) and (10) summarize the composition of the two costs, respectively.

Monthly electricity cost ($) = Unit price of electricity ($/kWh) × Monthly electricity consumption (kWh) + Unit price of line loss ($/kWh) × Monthly electricity loss in transmission and distribution (kWh) + Cost adjustments in previous months ($) (9)

Monthly delivery cost ($) = TC + DC + LAF + MR (10)

where

TC: Transmission Charges

DC: Distribution Charges

LAF: Local Access Fee

MR: Monthly Riders

To further investigate the electricity cost, electricity cost analysis is conducted based on on-site meter data and utility bills from the 18 meters. Database tables are accordingly created in Microsoft Access with the on-site meter data and utility bills. SQL code is applied to extract the relevant information for each of the 18 meters, such as monthly delivery cost, monthly energy cost, monthly electricity demand, and dates and times when monthly electricity demand exists. The SQL code is shown in Appendix A.

After extracting data, a comparison between monthly delivery cost and monthly energy cost is conducted. In utility bills, the costs of each component of the monthly delivery cost are given directly, and there are no explanations regarding how each component is calculated. This necessitates further exploration of the composition of the delivery cost.

According to ECPOR's tariff schedule, delivery cost can be calculated based on different criteria of monthly electricity demand (EPCOR Energy Services, 2018). Within each criterion, formulas for each component of the delivery cost are summarized. A verification of the delivery cost formula is achieved by calculating the ratio between the calculated monthly delivery cost and the monthly delivery cost given in the utility bill. The monthly total electricity cost can then be determined based on the fixed unit price of electricity. Equations (13) to (15) provide a systematic measurement for school operators to calculate and predict the savings in electricity cost after implementing efficiency measures in schools.

Since the electricity demand in kW also contributes to the billing cost, understanding the electricity demand profile can help school operators to manage and reduce associated costs. Therefore, the time period during which monthly electricity demand is highest needs to be obtained. In addition, a user interface is created in Microsoft Access. With this tool, school operators can enter utility bill data and view the specific monthly electricity consumption and related costs more conveniently.

Besides electricity cost, GHG is another measure of electricity consumed. In order to easily quantify the savings in GHG emissions while simultaneously improving school building energy performance, Equation (11) is developed with electricity-specific emission factors (ESEF) and global warming potential (GWP) factors for CO_2, CH_4, and N_2O (Brander et al., 2011; Environment and Climate Change Canada, 2017; Nature Resources Canada, 2012). As a result, emissions in tonnes of CO_2 equivalent can be calculated based on the electricity consumption in kWh.

Electricity-Specific GHG Emissions (t of CO_2 eq) = Electricity Consumption (kWh)

$$\times (\mathrm{ESEF}_{\mathrm{CO_2}} + \mathrm{ESEF}_{\mathrm{CH_4}} \times \mathrm{GWP}_{\mathrm{CH_4}} + \mathrm{ESEF}_{\mathrm{N_2O}} \times \mathrm{GWP}_{\mathrm{N_2O}}) \times 10^{-3} \tag{11}$$

where

$\mathrm{ESEF}_{\mathrm{CO_2}}$ = 0.196459189 kg CO_2/kWh

$\mathrm{ESEF}_{\mathrm{CH_4}}$ = 0.00000245670 kg CH_4/kWh

$\mathrm{ESEF}_{\mathrm{N_2O}}$ = 0.00000259486 kg N_2O/kWh

$\mathrm{GWP}_{\mathrm{CH_4}}$ = 25

$\mathrm{GWP}_{\mathrm{N_2O}}$ = 298

3.4 Proposed Monitoring Plan

Based on the given preferences and the energy benchmarking result, a real-time monitoring plan is prepared for the selected school. Research of existing sensor options is conducted comparing four products using a decision matrix. The eGauge monitoring system is chosen due to its lower cost, higher accuracy, and more convenient user interface. Data collected from real-time monitoring system can be used to analyze existing problems in electrical equipment operation and electrical equipment efficiency. A survey questionnaire is also prepared for the future site visits which can additionally assist with this real-time monitoring. The results of the real-time monitoring system and the survey can be used by school operators to determine the causes of low energy efficiency and propose solutions accordingly. In the future, other schools in ECSD can choose among and adapt the efficiency measures conducted for the selected school.

CHAPTER 4 IMPLEMENTATION

In this chapter, the implementation of the proposed methodology is discussed in detail. After analyzing the historical data of schools and proceeding with the building energy benchmarking, a thorough understanding of school energy use is obtained. Energy-related costs are analyzed in detail and the quantification of the electricity-specific GHG emissions is developed. By applying the proposed real-time monitoring system, energy efficiency measures towards the electrical energy use can be conducted during the operational phase of schools to reduce operating costs. In the future, school facility operators can utilize the energy management framework developed in this research to increase energy efficiency, easily calculating and analyzing electricity cost savings and GHG emissions by continuously monitoring and conducting energy-efficient measures.

4.1 Introduction

This case study describes the detailed energy management approach developed for Edmonton Catholic School District (ECSD) for the purpose of reducing electricity consumption. According to climate zones defined by ENERGY STAR (effective February, 2015), Edmonton (53.5444° N, 113.4909° W) is located in Zone 2 with a Celsius-based annual Heating Degree Days (HDD) range from 3,500 to 6,000 (NRCan, 2018b). It is one of the coldest cities in Canada, with a winter season spanning from November to March (Government of Canada, 2018). With an average temperature −10.4 °C in January (Government of Canada, 2018), and only 7 to 10 hours daylight length during winter months, a significant amount of energy is required for heating and lighting during the winter season.

ECSD is a member of the Alberta School Boards Association (ASBA) and owns and operates 86 active schools according to 2017 statistics. In the present case study, the electricity consumption of each school site is recorded using on-site electrical meters (92 meters in total, since six of the schools feature two meters per site rather than one). ECSD operates 12 different school types spanning preschool to senior high: pre-k-9, pre-k-6, pre-k-1, k-6, k-8, k-9, k-12, 9-12, 7-9, 7-12, 2-6, and 10-12.

It should be noted that, although all the schools use natural gas as the energy source for their main heating systems, due to the scope of this research only the electricity consumption of the schools is analyzed. With the data analysis of school energy consumption and energy-related costs, building energy benchmarking, and a proposed real-time monitoring system, this framework is the first of its kind in Alberta for investigating and reducing the electricity consumption in school buildings.

4.2 Evaluation of Schools' Electricity Consumption

In this section, basic information about ECSD's portfolio of school facilities and historical electricity consumption data are collected and carefully analyzed. Electricity consumption patterns are identified in order to gain a better understanding of the schools' energy performance. An energy benchmarking process using two different methods is conducted in order to categorize the schools under consideration and select the pilots.

4.2.1 Historical Data Collection and Analysis

To understand better the manner in which the schools under consideration consume electricity, the first step is to collect basic information about the schools, as well as their historical electricity consumption data. First, basic information for every active school is extracted from the 2016 Miniplans and 2015 Utilization Reports in ECSD’s servers. Twenty-three factors in total which may affect electricity consumption are identified. It should be noted that the number of students and number of staff used in the analysis are for the year 2016/2017. “Core area” refers to the main school area, while “other area” consist of portable rooms plus the adjoining corridors that connect them to the “core area”. The “site area” covers all areas on school property, including the parking lot and green space. The “total area” which is considered the main electricity consuming area in this research is the sum of the “core area” and “other area”. It is used to calculate the EUI.

Twenty-three identified factors from school basic information are listed below:

- Total gym area
- Total gym capacity
- Total classroom area
- Core area
- Elevator existence
- Computer room area
- Site area
- Number of Staff
- Number of Students
- Number of wired computers
- Number of wireless computers
- Other area
- Number of gyms
- Number of portable classrooms
- Number of normal classrooms
- Number of floors
- Number of other portables
- Number of computer rooms
- Total area
- Original year built
- Original building area
- Year of each additional construction
- Area of each additional construction

School historical electricity information is given in two forms, the utility bill and on-site meter data. For 84 of the schools, electricity billing information is available for the period, June, 2012 to May, 2017. The two new schools have the invoice information available for the period Sep., 2016, to May, 2017.

From the utility bills, the monthly electricity consumption and related costs are determined. For each school, the monthly electricity consumption specified in the utility bill includes the actual electricity consumption, the electricity loss during transmission and distribution, and the meter-reading adjustments from previous months. The monthly cost includes the cost of electricity consumption and the related electricity delivery cost. Figures 7 and 8 illustrate the monthly electricity consumption for years 2015 and 2016. (Since 2015 invoice information is not available for the two new schools and their invoice information for 2016 is incomplete, they are not included in the following two figures.) There is no major change in electricity consumption between seasons, except in July and August when schools are closed for summer holiday. The curve for School 62 (the upper-most trendline in the figure) deviates from the rest of the schools significantly because of its extremely high electricity consumption.

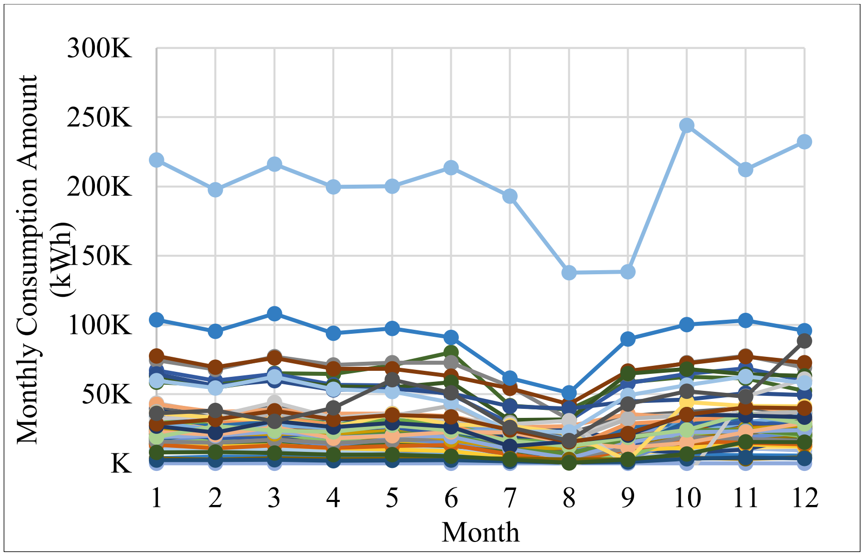


Figure 7. Monthly electricity consumption for 84 schools in 2015

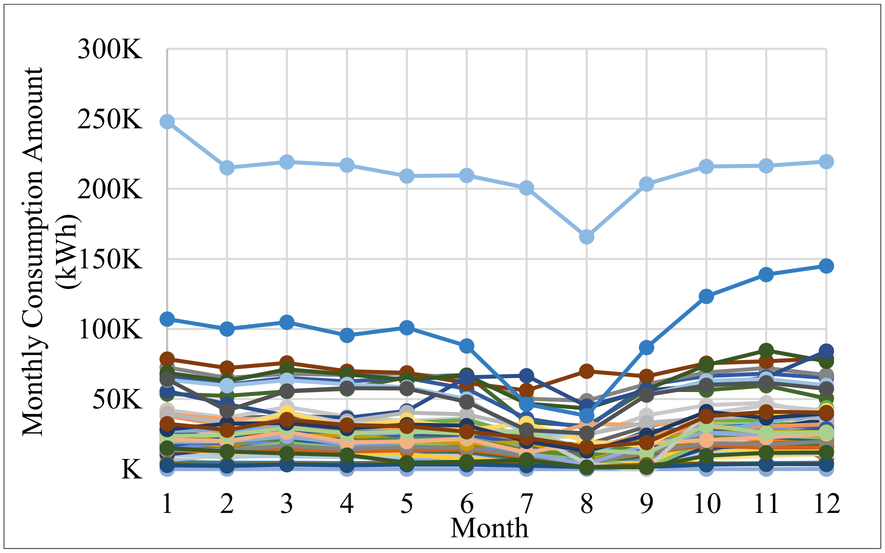


Figure 8. Monthly electricity consumption for 84 schools in 2016

Figure 9 shows the annual electricity consumption for ECSD in 2015 and 2016. The consumption in 2016 is around 2.5% (661,036 kWh) more than that in 2015. Since more heating demand in winter also raises electricity consumption, electricity consumption is normalized by HDD for a more meaningful comparison. As can be seen in Table 1, there is a 5.95% increase in weather-normalized electricity consumption from 2015 to 2016, which demonstrates even a larger increase than the original consumption value.

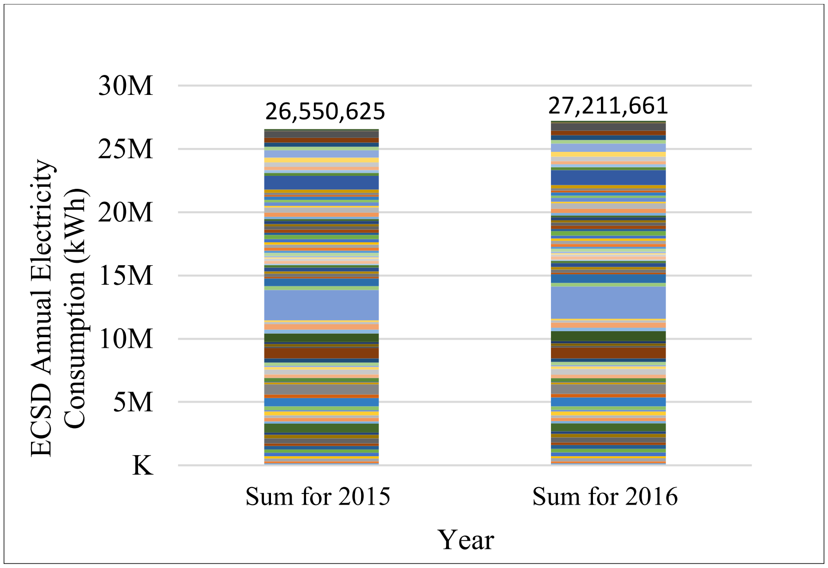


Figure 9. Comparison of 2015 ECSD total electricity consumption to 2016 ECSD total electricity consumption

Table 1. Weather-normalized annual electricity consumption

Year	Annual HDD (°C × days)	Annual Electricity Consumption (kWh)	kWh per Degree Day
2015	4618[a]	26,550,625.00	5749.38
2016	4467[a]	27,211,661.00	6091.71
% increase		2.49%	5.95%

a. From Amateur Weather Statistics for Edmonton

Apart from the utility bills, on-site meter data is also available for all the schools under consideration, with the exception of the two newly-built schools. The data is for the period June, 2016, to June, 2017, in 15-minute intervals and in hourly intervals, respectively. Among the 92 meters, 72 provide hourly-interval data and 18 of them provide 15-minute-interval data. The use of the on-site data can verify the electricity consumption trends observable in the utility bill as well as show the electricity usage pattern in specific intervals. As an example, one of the school is selected to demonstrate the daily and hourly electricity consumption situation (Figures 10 and 11). As can be seen in Figure 10, the electricity consumption on weekends is significantly lower than the consumption on weekdays. The dips in weekday curves correspond to the statutory holidays and peaks on the weekends are due to weekend school activities. Ten days in June are used to plot the pattern of hourly electricity consumption for this school, as illustrated in Figure 11. The peak of electricity consumption is observed to be approximately during school operating hours (from 7 a.m. to 4 p.m.). After the school operating hours, some peaks also exist which can be explained as some after-hour school activities. A flat trend of electricity consumption is shown on the weekend of the fourth and fifth of June. Comparing to the weekdays, much less electricity is consumed on weekends.

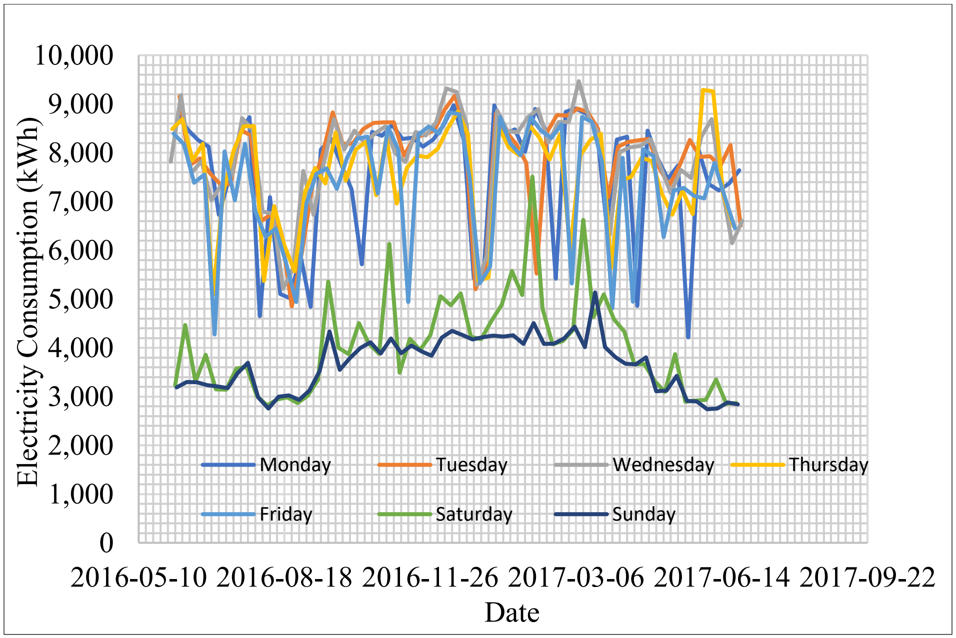


Figure 10. School daily electricity consumption

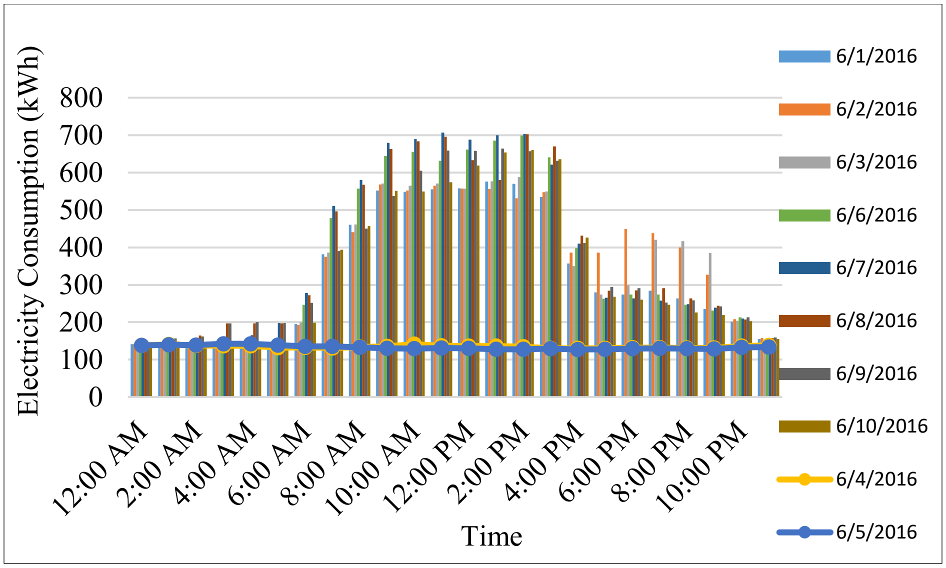


Figure 11. School hourly electricity consumption

When meter-reading adjustments from previous months are negligible, the current month's electricity consumption specified in the utility bill will be higher than the on-site meter data. This is because the electricity loss during transmission and distribution are always included in the utility bill's consumption. Four schools, in Figure 12, are selected to demonstrate this point. On the other hand, some schools have large meter-reading adjustments from previous months. These adjustments can significantly affect current month's electricity consumption. This can be viewed in one of the school in the upper left of Figure 12. The findings also show that annual electricity consumption for each school from utility bill will not deviate significantly from the real-time data, usually around 2% to 3% higher than the on-site meter data.

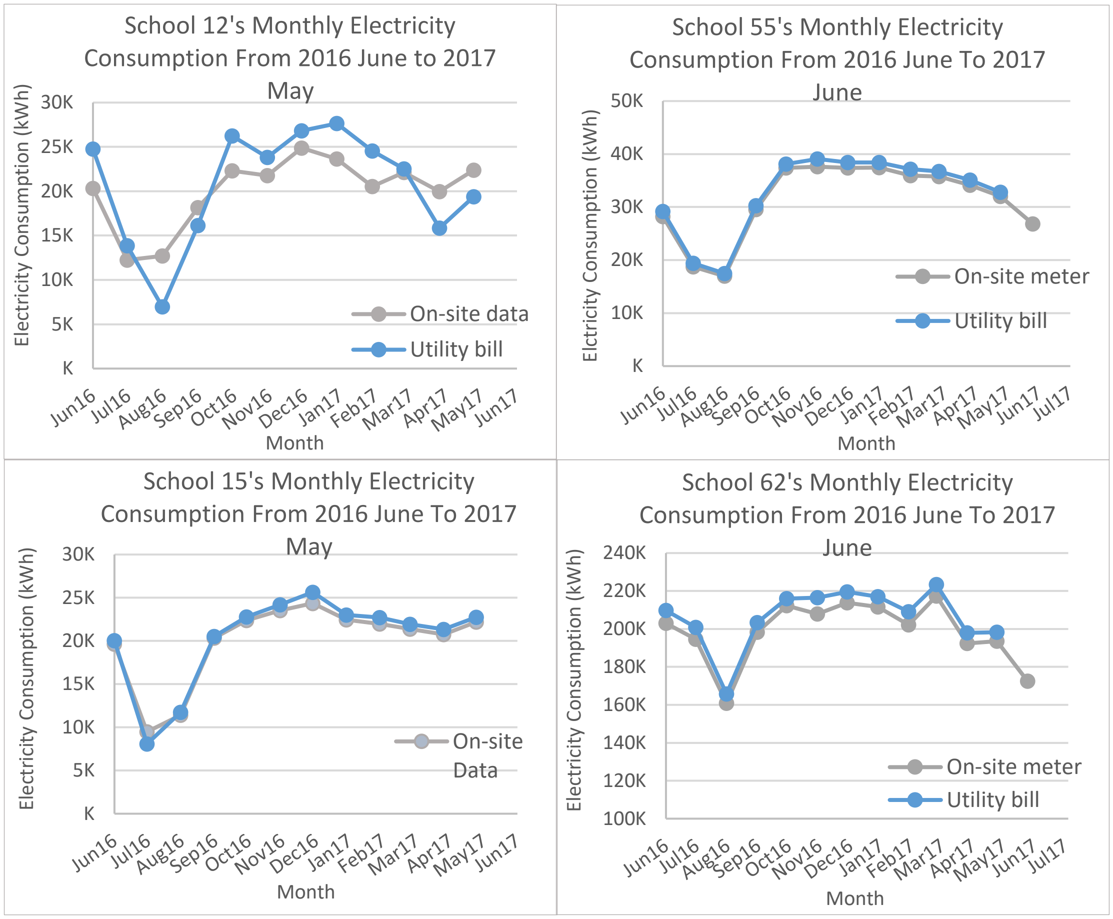


Figure 12. Monthly electricity consumption using on-site data and utility bill

Among the six schools that have two meters on site instead of one, four of them feature a meter for measuring the electricity consumption of portable rooms and the other for measuring the electricity consumption of the rest of the school. This gives a good opportunity to investigate the consumption difference between the school core area and the portables. As shown in Table 2, for each of these four schools, a higher EUI is observed in the portable rooms than in the core area of the school. School 29, for instance, has an extremely high portable EUI based on the six portables measured by meter 1. Because of the assumption that calculated portable EUI is the same for all portables, a low electricity consumption for the core area is obtained using Equation (3), which results in a low value of the core area EUI.

Table 2. Comparison between portables and core school area

School Name	Core Area EUI (kWh/m^2)	Portable EUI (kWh/m^2)
School 29	22.60	154.83
School 28	72.67	81.25
School 37	66.80	67.66
School 66	60.02	65.45

4.2.2 Building Energy Benchmarking

To identify buildings with relatively low energy performance and build the baseline for all school buildings, an energy benchmarking process is conducted. Simple descriptive and multiple linear regression are the two methods applied to build the benchmark in this research. Because ECSD has twelve school types and cannot be clearly divided into Primary, Junior high, and Senior high, all schools are analyzed as a whole.

4.2.2.1 Energy Use Intensity

EUI is used in the energy benchmarking process as the energy efficiency indicator. With the coefficient of determination larger than 0.9, Figure 13 shows a strong positive correlation between the electricity consumption and school total area. For each school, the average EUI is the average value of the 2015 and 2016 EUIs. They are, respectively, calculated using the annual kWh sum from the utility bill divided by the given school's total area. Using @Risk (McLafferty, 1987), a normal distribution function is fitted to the dataset of average EUIs. In this metric, the mean value 60.51 kWh/m^2 of all schools' average EUI is selected as the benchmark. The probability distribution curve is shown in Figure 14, while Table 3 gives the mean and median values of average EUIs.

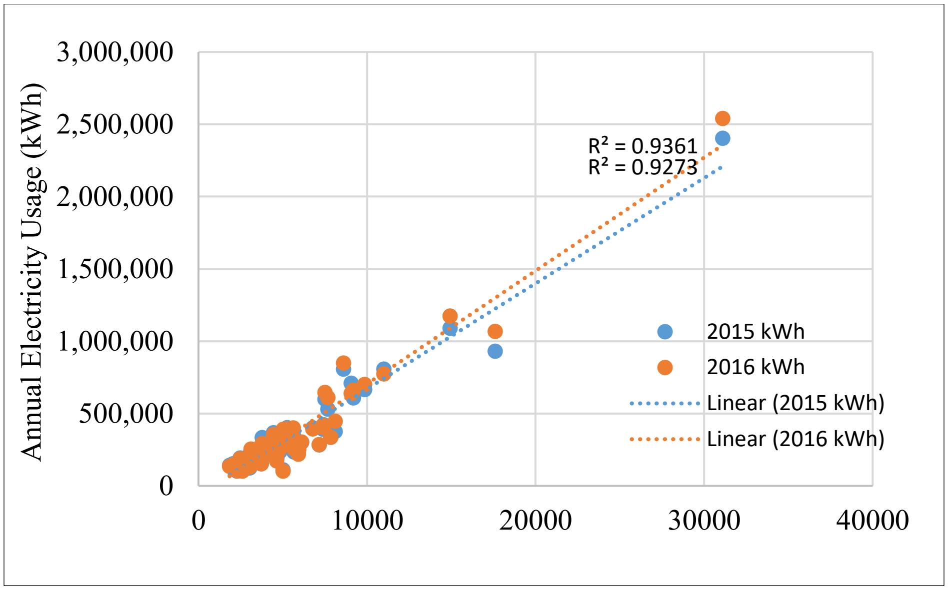


Figure 13. Annual electricity usage versus school total area

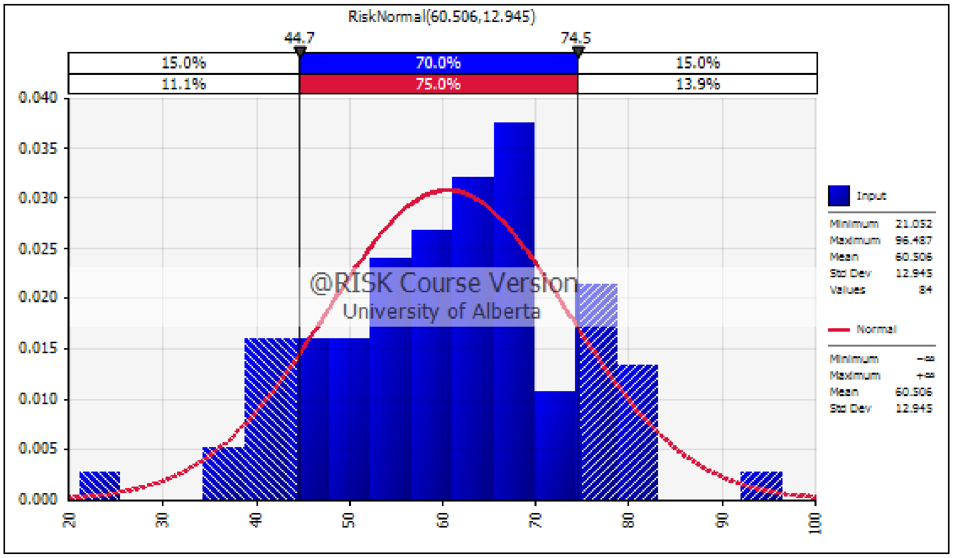


Figure 14. Fitted distribution for average EUIs

Table 3. 2015 and 2016 EUI values for ECSD

EUI Values (kWh/m^2)	**2015 EUIs (84 schools)**	**2016 EUIs (84 schools)**	**Average EUIs for 2015 and 2016**
Mean	60.19	60.82	60.51
Median	60.67	60.41	61.68
Std dev	12.92	13.26	12.95

To benchmark within the school board, EUI residuals are calculated for each school by deducting 60.51 kWh/m^2 from each school's average EUI. Schools with top or bottom energy performance can be identified based on the percentile range of the residual distribution. In this research, the top and bottom percentile ranges are set to be 0–15th (bottom) and 85th–100th (top). Figure 15 illustrates the EUI residual distribution and schools which are partitioned in the top and bottom 15%. Schools in red text represent schools with higher kWh consumption per unit area, while, on the contrary, schools with less kWh consumption per unit area are highlighted in green text.

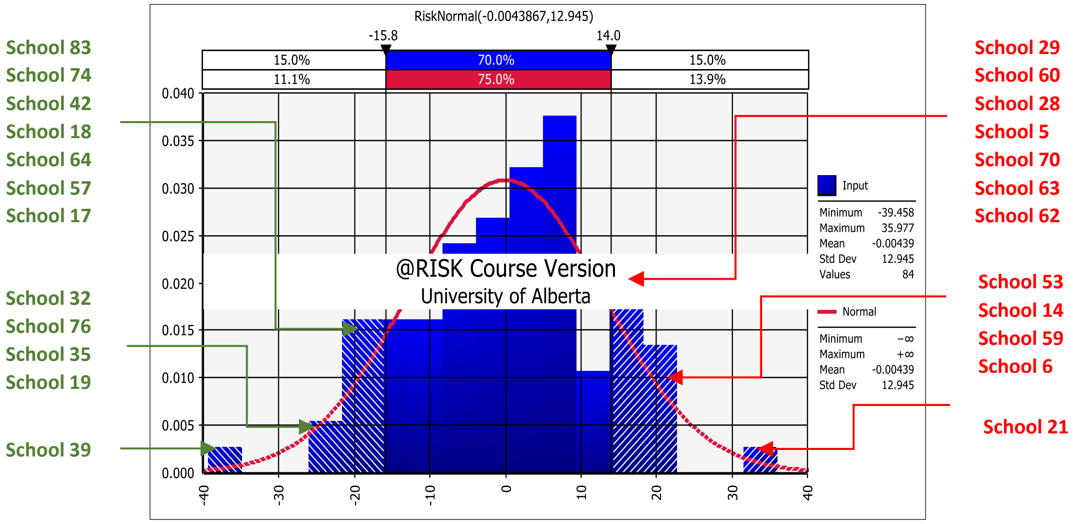


Figure 15. Distribution of EUI residuals

4.2.2.2 Comparison with Existing Benchmarks

To understand the energy performance of ECSD, a comparison of electrical EUIs can be done with existing benchmarks. With fossil-thermal energy as the main heating source, electrical EUIs are calculated from two national surveys and several school boards, as shown in Table 4. As can be seen in the table, the ECSD benchmark is less than the Canadian school average value from the 2009 SCIEU (NRCan, 2013). It is also smaller than the U.S. school average value from the 2012 CBECS (U.S. Energy Information Administration, 2016). Although Manitoba has similar climatic conditions, there schools of all different building ages have an average electrical EUI of 99.3 kWh/m^2 (Ouf and Issa, 2017), which is also higher than the ECSD benchmark. Less electrical EUIs are observed for schools in Ontario, Vancouver, and England, attributable to their warmer climates (Hong et al., 2013; Toronto and Region Conservation Authority, 2016; Vancouver School Board, 2017). The result of the comparison with some existing benchmarks positions ECSD with a relatively good energy performance.

Table 4. Existing benchmarks

Data source	School information	Data type	Electrical EUI
SCIEU 2009	Canada grade K-12	Average	80.1
CBECS 2012	US grade K-12	Median	89.3
Ontario School Boards 2017	Elementary schools	Target	59.2
	Secondary schools	Target	80.7
Schools in England (2010-2012)	Elementary schools	Median	43.0
	Secondary schools	Median	50.0
Manitoba Public School Finance Board (Schools in Winnipeg and its outskirts 2004-2012)	Grade K-12 (schools constructed before 1959)	Average	56.6
	Grade K-12 (schools constructed within 1960-1989)	Average	115.0
	Grade K-12 (schools constructed after 1990)	Average	126.3
Vancouver School board (2014-2015)	Elementary schools	Average	37.8
	Secondary schools	Average	48.0
Edmonton Catholic School District (2015-2016)	Grade K -12	Median	61.7
		Average	60.5

4.2.2.3 Electricity Consumption per Student

In the simple descriptive method, electricity consumption per student is also applied to build the school board's benchmark. This metric is not as representative as EUI of the energy efficiency due to its smaller coefficient of determination, which is around 0.75. Figure 16 demonstrates the relationship between annual electricity usage and the number of students in 2015 and 2016 as well as the corresponding coefficient of determination. In Figure 16, School 62 is an outlier to the fitted linear line, hence it is excluded in the following calculation. For each school, the average value of kWh consumption per student is based on 2015 and 2016 values. Figure 17 demonstrates the fitted distribution curve of the average kWh per student for 83 schools. It is a right-skewed log-logistic distribution curve with a representative median value. In this metric, due to the right skewness of the distribution, the median value 620.26 kWh per student of the distribution is chosen to be the benchmark. Table 5 demonstrates the values of kWh per student for the years 2015 and 2016.

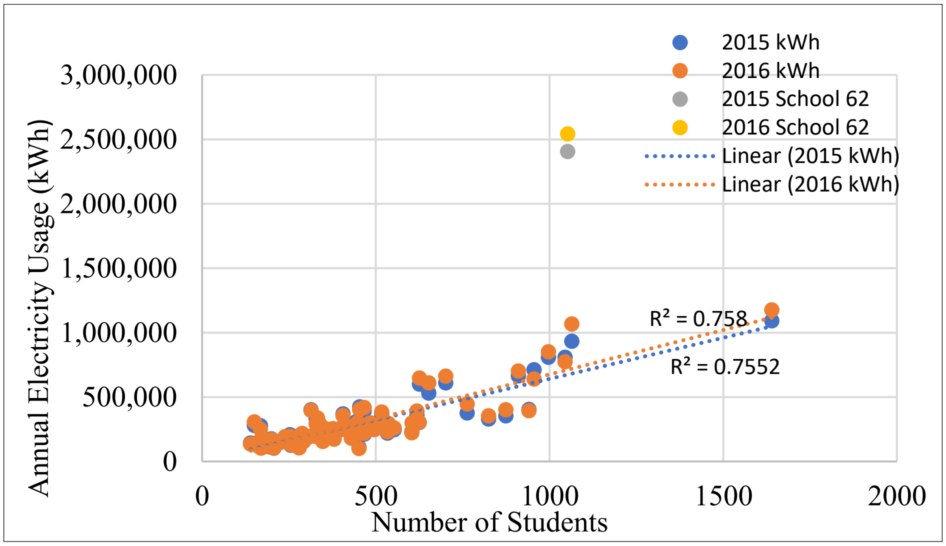


Figure 16. Annual electricity usage versus number of students

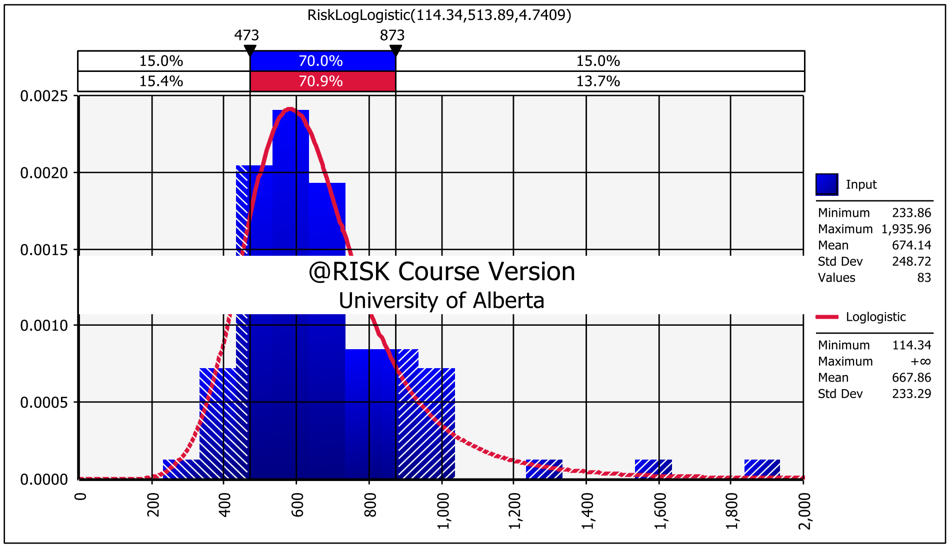


Figure 17. Fitted distribution for average kWh per student

Table 5. 2015 and 2016 kWh per student for ECSD

kWh per student	2015 kWh per student (83 schools)	2016 kWh per student (83 schools)	Average kWh per student for 2015 and 2016
Mean	671.21	677.06	674.14
Median	625.89	618.57	620.26
Std dev	248.06	251.74	248.72

As with the EUI metric, residuals are calculated for each school in kWh per student. The residual distribution is also plotted with the percentile range set to be the top 15% and bottom 15%. As can be seen in Figure 18, as with EUI, school names in red text have a higher level of kWh consumption per student and school names in green text have a lower level of kWh consumption per student. The school which is an outlier due to its extremely high value is added back to the list of schools with higher kWh consumption per student.

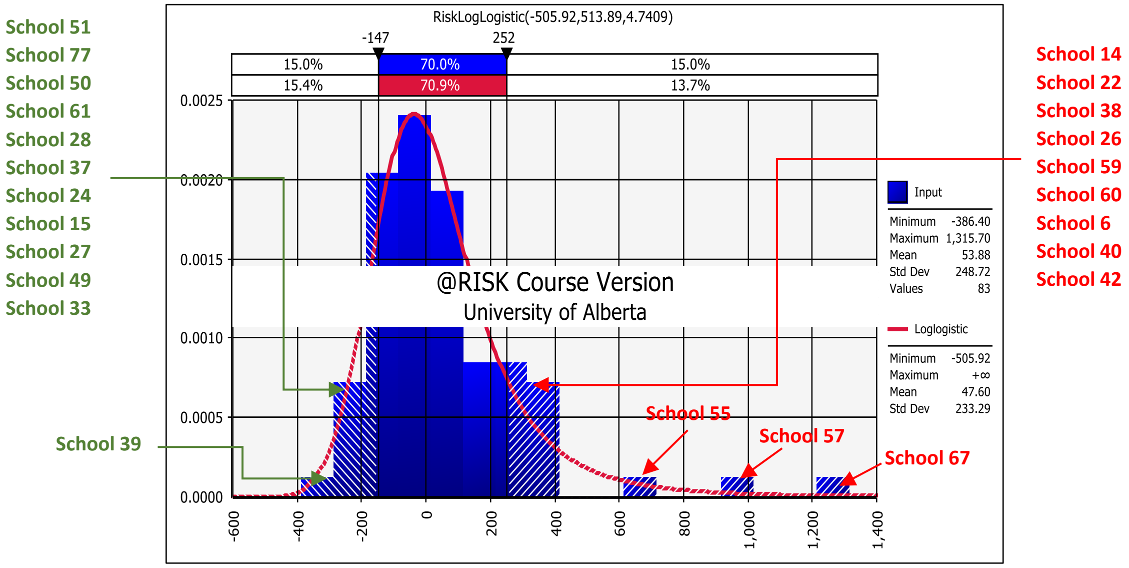


Figure 18. Distribution of residuals in kWh per student

4.2.2.4 Multiple Linear Regression Model

Among the schools analyzed with EUIs and electricity consumption per student, area and number of students are the only factors normalized. Other factors excluded from the simple descriptive method, it should be noted, can affect the electricity consumption as well. In this subsection, a multiple linear regression model is built which offers a solution to include more factors that affect energy consumption. With the regression equation set as the benchmark, regression residuals are calculated for each school to determine schools' energy performance.

Before regression computation in Minitab is carried out, factors are manually filtered to satisfy the conditions of regression. Out of twenty-three identified factors, thirteen of them are ultimately selected as explanatory variables. The selection process of explanatory variables is explained as follows. Among the twenty-two factors, there are six different discrete variables which can be filtered out or replaced. Data consists of counting numbers, especially those along the bound of zero, such as the number of floors, number of other portables are filtered out because of the exclusion of discrete numbers in regression analysis. Number of gyms is replaced by total gym area. Discrete attributes related to classrooms, such as number of portable classrooms and number of normal classrooms, are substituted by total classroom area. Computer room area is used as a replacement for number of computer rooms. Number of students, number of staff, number of wireless computers, and number of wired computers are treated as continuous data. Total area, having already been normalized in the EUI metric, is removed. Since the school buildings under study have been constructed in dispersed years, each additional construction area needs to be weighted to the building construction. Building age is calculated using

Equations (7) and (8). Other area represents the sum area of all portables with the linkage, which is already partially included in the variable, total classroom area. To refine this variable, a categorical variable, portable existence, is applied instead. When the "other area" of a school is larger than zero, this indicates the existence of portables in this school. Table 6 below demonstrates the selected predictors for the multiple linear regression analysis. There are eleven continuous inputs and two categorical inputs. In multiple linear regression, only one dependent variable is present; hence the average EUI based on values from 2015 and 2016 is calculated and set to be the response. Data input for the regression model can be found in Appendix B.

Table 6. Selected predictors for multiple linear regression

Continuous Input		**Categorical Input**
Total Gym Area	Computer Room Area	Portable Existence
Site Area	Number of Wireless Computers	Elevator Existence
Building Age	Total Classroom Area	
Number of Students	Total Gym Capacity	
Number of Staff	Number of Wired Computers	
Core Area		

To obtain the regression benchmark for ECSD's electricity consumption, steps of regression are specifically developed, and all assumptions of regression are carefully examined. In general, there are five assumptions that need to be satisfied (Chatterjee and Hadi, 2015).

The first assumption is to check the linearity between each independent variable and dependent variable. To examine the linearity, scatterplots and Pearson coefficients are applied. Figure 19 shows scatterplots of all eleven numeric predictors with average EUI. Figure 20 is the Pearson coefficient matrix for all variables in the regression. As can be seen from Figure 19 and Figure 20, most of the independent variables demonstrate positive linearity with the response, even though the positive linearity is quite moderate for some relationships. Building age has a negative linearity with the response, and classroom area has no linearity with the response. Multicollinearity between independent variables can also be observed in Figure 20. When two variables are highly correlated, a large value of Pearson R can be observed. In our case, the number of students and number of staff are highly correlated, with a Pearson R of 0.92. Gym capacity is also highly correlated with gym area, with a Pearson R of 0.99.

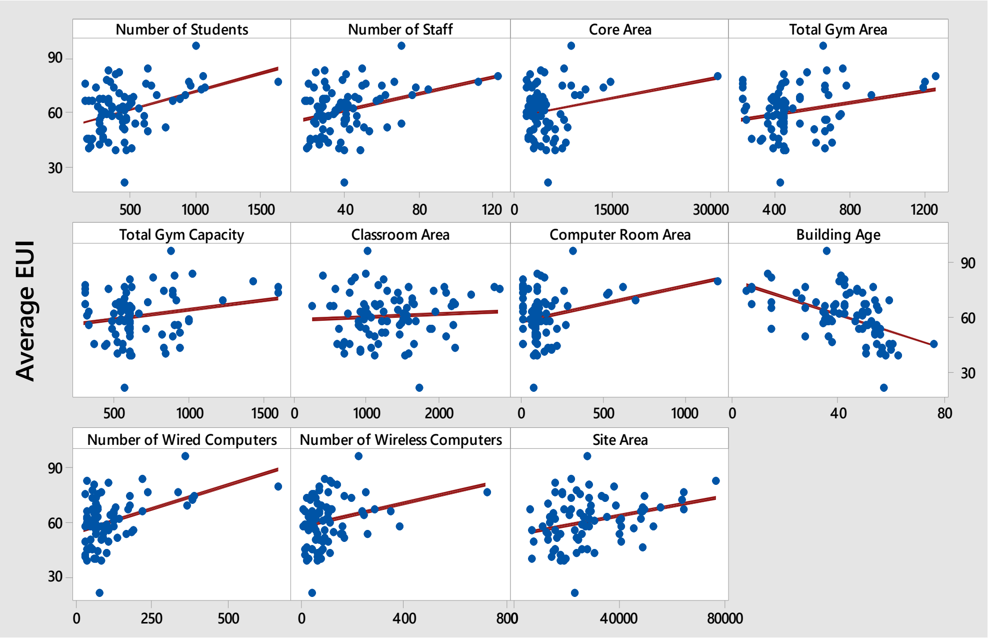
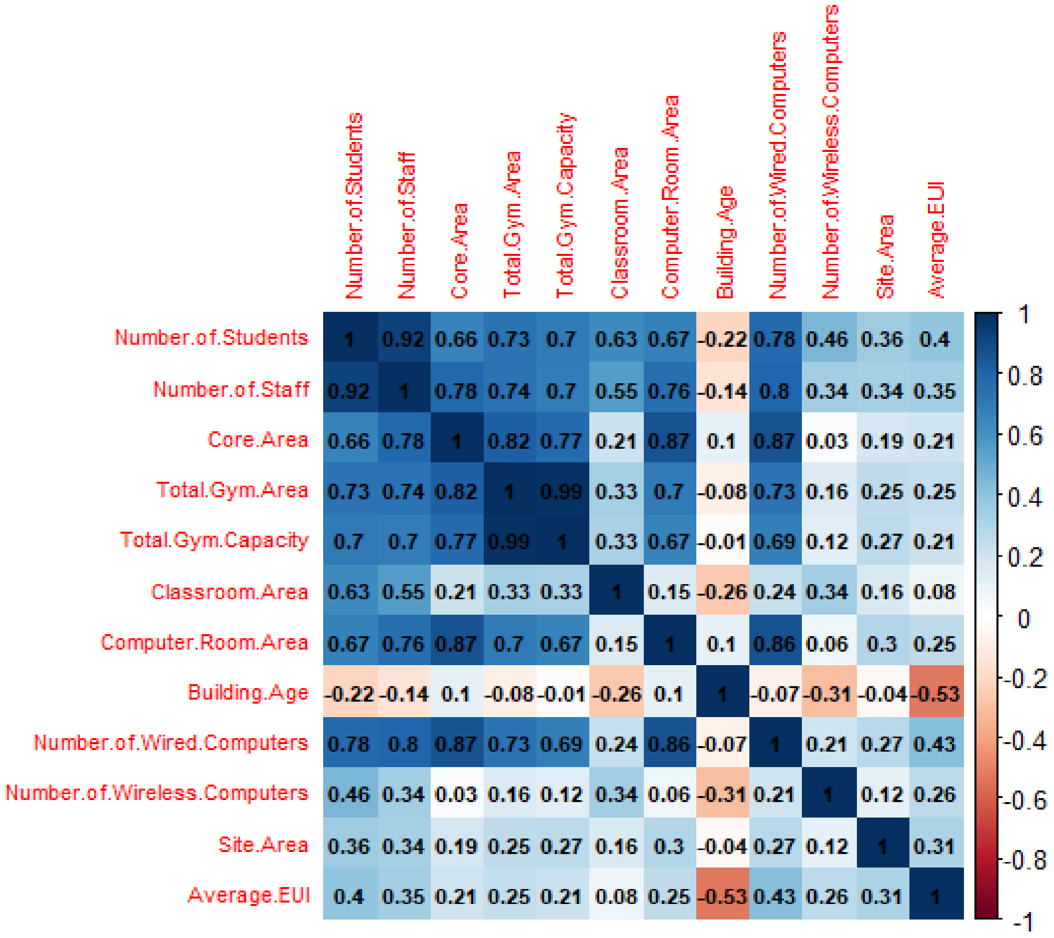


Figure 19. Scatterplots between Average EUI and all numeric predictors



	Number.of.Students	Number.of.Staff	Core.Area	Total.Gym.Area	Total.Gym.Capacity	Classroom.Area	Computer.Room.Area	Building.Age	Number.of.Wired.Computers	Number.of.Wireless.Computers	Site.Area	Average.EUI
Number.of.Students	1	0.92	0.66	0.73	0.7	0.63	0.67	-0.22	0.78	0.46	0.36	0.4
Number.of.Staff	0.92	1	0.78	0.74	0.7	0.55	0.76	-0.14	0.8	0.34	0.34	0.35
Core.Area	0.66	0.78	1	0.82	0.77	0.21	0.87	0.1	0.87	0.03	0.19	0.21
Total.Gym.Area	0.73	0.74	0.82	1	0.99	0.33	0.7	-0.08	0.73	0.16	0.25	0.25
Total.Gym.Capacity	0.7	0.7	0.77	0.99	1	0.33	0.67	-0.01	0.69	0.12	0.27	0.21
Classroom.Area	0.63	0.55	0.21	0.33	0.33	1	0.15	-0.26	0.24	0.34	0.16	0.08
Computer.Room.Area	0.67	0.76	0.87	0.7	0.67	0.15	1	0.1	0.86	0.06	0.3	0.25
Building.Age	-0.22	-0.14	0.1	-0.08	-0.01	-0.26	0.1	1	-0.07	-0.31	-0.04	-0.53
Number.of.Wired.Computers	0.78	0.8	0.87	0.73	0.69	0.24	0.86	-0.07	1	0.21	0.27	0.43
Number.of.Wireless.Computers	0.46	0.34	0.03	0.16	0.12	0.34	0.06	-0.31	0.21	1	0.12	0.26
Site.Area	0.36	0.34	0.19	0.25	0.27	0.16	0.3	-0.04	0.27	0.12	1	0.31
Average.EUI	0.4	0.35	0.21	0.25	0.21	0.08	0.25	-0.53	0.43	0.26	0.31	1

Figure 20. Pearson coefficient matrix for all variables

Since the second assumption in regression analysis is to ensure there is no multicollinearity between independent variables, one independent variable in each correlated pair should be removed in the regression analysis. The process of removing superfluous variables is conducted after several runs of the regression in Minitab based on the value of variance inflation factor (VIF) and the significance of the factor.

The third assumption is to satisfy the multivariate normality, which means that the residuals of the regression need to follow a normal distribution. In order to make sure the third assumption is satisfied, a normality test for the dependent variable is conducted before running the regression. As can be seen from Figure 21, because the P-value is much higher than 0.05, the average EUI follows a normal distribution. Therefore, no Box-Cox transformation of the data is needed.

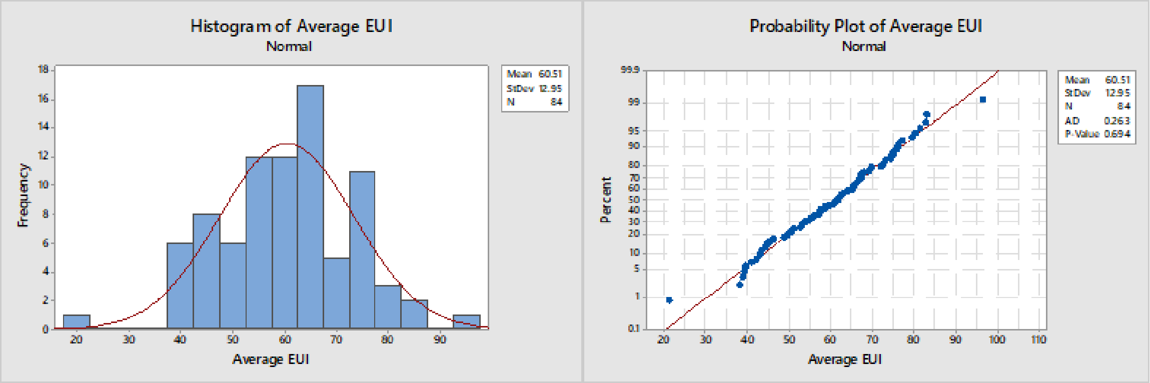


Figure 21. Histogram and probability plot of average EUI

For the first run of the regression analysis using Minitab, all thirteen filtered energy factors are considered as inputs. The report of regression summary can be seen in Appendix C. Most of the input factors are insignificant, with P-values larger than 0.05 and VIF values larger than 10 because of the existence of collinearities between them. For this reason, some factors need to be removed. First, classroom area is removed because it lacks clear linearity with the response. Then, running the regression analysis again, the number of staff is removed due to its insignificant P-value and high VIF (the highest among all variables). To achieve moderate correlation among all dependent variables with VIFs less than 5, three more inputs—total gym capacity, core area, and computer room area—are removed successively based on the running result each time. Once the above five inputs have been removed, the first and second assumption are satisfied. The report of regression summary after removing the five inputs is illustrated in Appendix D**.**

A stepwise regression with α set to be 0.15 is conducted after the five inputs have been removed. There are three significant predictors left in the regression equation—building age, number of wired computers, and site area—and one insignificant predictor—total gym area, with a P-value equal to 0.096. With the coefficient of determination of 49.01%, the regression equation resulting from this stepwise regression is considered as the benchmark for this multiple linear regression model, and it is listed in Equation (12). Instead of applying all 13 factors, just four factors are sufficient to explain most of the variation in average EUI. The report of regression summary after the stepwise regression can be seen in Appendix E.

$$\begin{aligned}\text{Average EUI} = {} & 74.01 - 0.01284\ \text{Total Gym Area} - 0.4434\ \text{Calculated Building Age} \\ & + 0.0581\ \text{Number of Wired Computers} + 0.000186\ \text{Site Area}\end{aligned} \tag{12}$$

At this stage, the remaining three assumptions can be verified. Figure 22 shows the residual plots after the stepwise regression. As can be seen, the normal probability plot and the histogram for residuals both demonstrate the normality, hence the third assumption is realized. The upper right plot shows the residuals do not increase as the fitted values increase, which means residuals are equal across the regression benchmark. Therefore, the fourth assumption, homoscedasticity, is satisfied (Winston and Venkataramanan, 2003). The independence of observations can be seen among the successive residuals in the bottom-right graph in Figure 22. In this plot, there is no specific pattern of residual occurrence, hence residuals in time series are independent from one another (Winston and Venkataramanan, 2003). In addition, a Durbin-Watson value of 1.98628, which is one of the outcomes from the regression summary report in Appendix E, also indicates that no correlations exist among the residuals (Chatterjee and Hadi, 2015). Therefore, the fifth assumption, that there is no autocorrelation between residuals, is fulfilled.

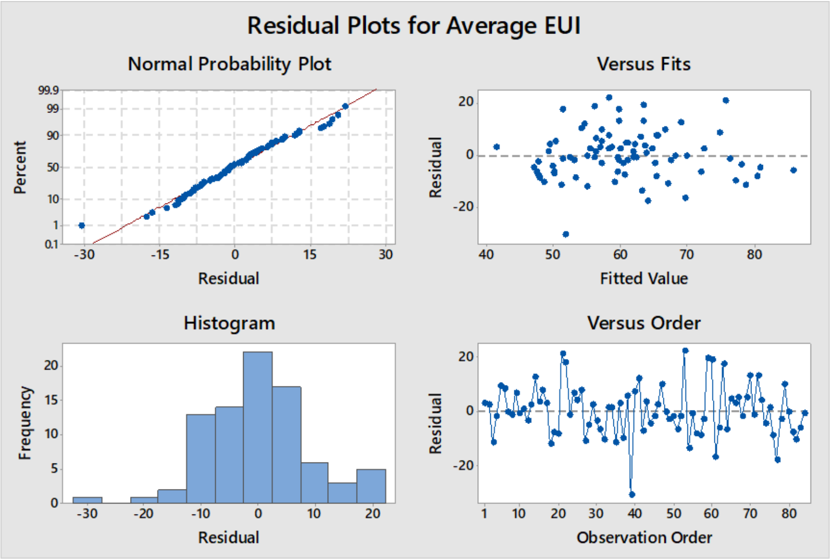


Figure 22. Residual plots of average EUI

4.2.2.5 School Categorization Using Both Methods

In simple descriptive statistics, schools are selected based on the results of intersections between two sets of metrics, EUI and kWh per student. Among the bottom 15% of residuals calculated in both metrics, the intersection only yields one school. Among the top 15% of residuals, five schools in total are filtered out. Tables 7 and 8 show the schools with the top and bottom 15% of residuals in the two metrics applied.

Table 7. Schools with bottom 15% of residuals in two metrics

School Description	**Residuals in kWh/m^2**	**School Name**	**Residuals in kWh/student**
School 39	−39.46	School 39	−386.4
School 32	−22.30	School 51	−248.02
School 76	−21.74	School 77	−237.54
School 35	−21.08	School 50	−207.02
School 19	−20.89	School 61	−200.49
School 83	−19.42	School 28	−197.48
School 74	−18.39	School 37	−189.64
School 42	−17.56	School 24	−185.95
School 18	−17.36	School 15	−163.06
School 64	−17.07	School 27	−160.7
School 57	−16.2	School 49	−152.86
School 17	−16.07	School 33	−149.36

Table 8. Schools with top 15% of residuals in two metrics

School Description	**Residuals in kWh/m^2**	**School Name**	**Residuals in kWh/student**
School 29	14.38	School 14	269.76
School 60	14.40	School 22	283.88
School 28	15.18	School 38	288.08
School 5	315.40	School 26	318.15
School 70	15.72	School 59	330.57
School 63	16.52	School 60	366.99
School 62	19.00	School 6	374.15
School 53	19.66	School 40	382.85
School 14	20.82	School 42	393.18
School 59	22.18	School 55	646.63
School 6	22.52	School 57	946.06
School 21	35.98	School 67	1315.7
		School 62	1727.36

In addition, residuals calculated from the multiple linear regression are used to select schools and it was double checked with two metrics in simple descriptive statistics. As can be seen in Table 9 and Table 10, the selection of schools with different energy performance is based on the top 15% and bottom 15% residuals calculated from multiple regression, as well as whether or not the school appears at least once in one of the metrics in the simple descriptive statistical method.

Table 9. Schools with bottom 15% of regression residuals

School Description	**Regression Residuals**	**Simple Descriptive kWh/m^2**	**Simple Descriptive kWh/student**
School 39	−30.81	✓	✓
School 77	−17.92		✓
School 61	−16.74		✓
School 54	−13.85		
School 18	−11.98	✓	
School 35	−11.63	✓	
School 3	−11.41		
School 27	−11.06		✓
School 82	−10.39		
School 32	−10.31	✓	
School 37	−10.15		✓
School 76	−9.11	✓	

Table 10. Schools with top 15% of regression residuals

School Description	Regression Residuals	Simple Descriptive kWh/m^2	Simple Descriptive kWh/student
School 79	9.61		
School 47	9.88		
School 41	11.79		
School 14	12.19	✓	✓
School 70	12.77	✓	
School 72	12.84		
School 63	17.16	✓	
School 22	17.58		✓
School 60	18.69	✓	✓
School 59	19.25	✓	✓
School 21	20.67	✓	
School 53	21.99	✓	

Therefore, nine schools in the bottom 15% of regression residuals are selected. Also, eight schools in the top 15% of regression residuals are selected. Residuals calculated from simple descriptive statistics and regression are shown in Appendix F.

To combine schools from both methods, a union of two sets of results is taken to finalize the school list. Two categories of schools are defined as follows. Category A is defined as schools with higher energy performance than the calculated electricity consumption benchmarks. Category B is defined as schools with lower energy performance than the calculated electricity consumption benchmarks. Since there is one school appearing both in simple descriptive and regression, Category A represents the same nine schools from the regression. In Category B, two schools from simple descriptive are added to the eight schools categorized in the regression. Since they are selected from the simple descriptive method, their regression residuals do not follow the trend. The schools in Category A and Category B are shown in Tables 11 and 12, respectively.

Table 11. Category A schools

Category A	**Methods**			**Regression Residuals**
	kWh/m^2	$kWh/student$	*Regression*	
School 39	✓	✓	✓	−30.81
School 77		✓	✓	−17.92
School 61		✓	✓	−16.74
School 18	✓		✓	−11.98
School 35	✓		✓	−11.63
School 27		✓	✓	−11.06
School 32	✓		✓	−10.31
School 37		✓	✓	−10.15
School 76	✓		✓	−9.11

Table 12. Category B schools

Category B	**Methods**			**Regression Residuals**
	kWh/m^2	**kWh/student**	**Regression**	
School 14	✓	✓	✓	12.19
School 70	✓		✓	12.77
School 63	✓		✓	17.16
School 22		✓	✓	17.58
School 60	✓	✓	✓	18.69
School 59	✓	✓	✓	19.25
School 21	✓		✓	20.67
School 53	✓		✓	21.99
School 6	✓	✓		8.15
School 62	✓	✓		−6.31

4.3 Generalization of a Systematic Measurement Based on Electricity Cost Analysis and GHG Emission Analysis

In this section, the influences of electricity consumption on electricity cost and GHG emissions are evaluated. In order to systematically measure these influences in the future, especially when variations such as reductions in electricity consumption occur, formulas are established between electricity cost and GHG emission versus electricity consumption.

In addition, for the convenience of data entry as well as the observance of electricity consumption and related costs from utility bills, a user interface is also created using Microsoft Access.

4.3.1 Electricity Cost Analysis

According to school utility bills, there are two costs for each school, energy cost and delivery cost. Monthly energy cost is mainly determined by the quantity of electricity (kWh) used each month. Despite the minor portion of electricity loss in transmission, distribution, and the meter reading adjustments in previous months, they are also included in the calculation of energy cost. Monthly delivery cost is composed of Transmission Charges (TC), Distribution Charges (DC), Local Access Fee (LAF), and Monthly Riders (MR).

As defined by EPA ENERGY STAR, electricity demand in kW is the highest rate of electricity use for a given billing period (Neida et al., 2018). In this research, electricity demand is only captured in the 15-minute-interval on-site data recorded by 18 meters during the period June, 2016, to June, 2017. With more than 600,000 records, SQL code is applied to extract the monthly electricity demand, the date and time of monthly electricity demand. In addition, energy costs and delivery costs from utility bills are obtained in the monthly interval for the same 18 meters for the purpose of comparison. Because of INNER JOIN operation with the utility bill data, on-site meter data in June, 2017, for those 18 meters cannot be shown; only the data from June, 2016, to May, 2017, are obtained.

A comparison between the monthly delivery cost and monthly energy cost is also conducted. As can be seen from Figure 23, the monthly delivery cost is normally higher than the energy cost. According to the average value of the cost composition in each month, delivery accounts for 60.57% of the total cost. It is also found that, within a given month, electricity demand can appear at different times on different days; therefore, the time period of electricity demand is weighted based on the number of occurrences. Figure 24 shows the count of monthly electricity demand for different times. Based on this, monthly electricity demand is most common between 10 a.m. and 11 a.m. It is also necessary for school operators to focus on and minimize the electricity demand in schools due to its contribution to utility costs.

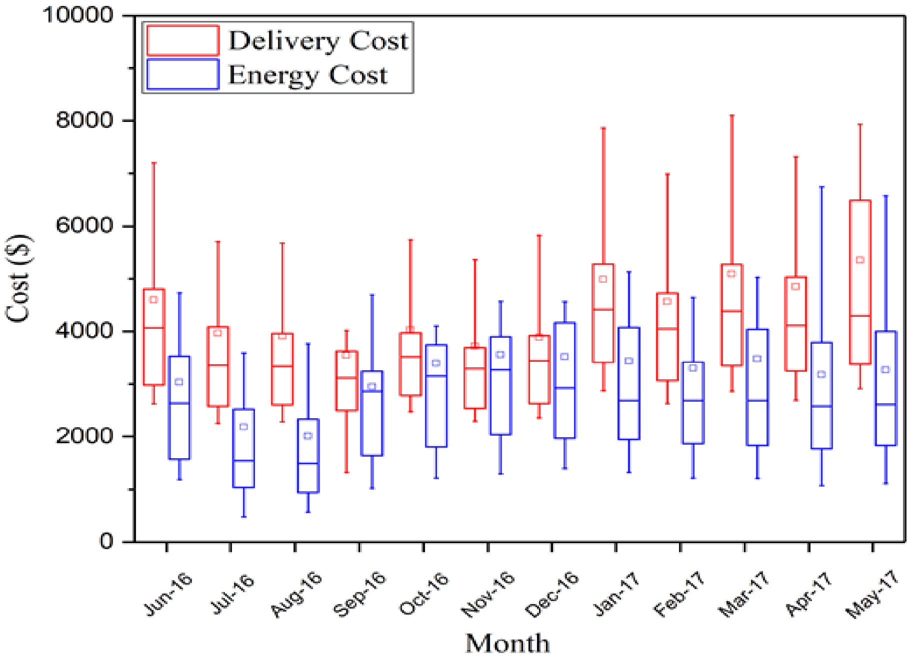


Figure 23. Comparison between delivery cost and energy cost

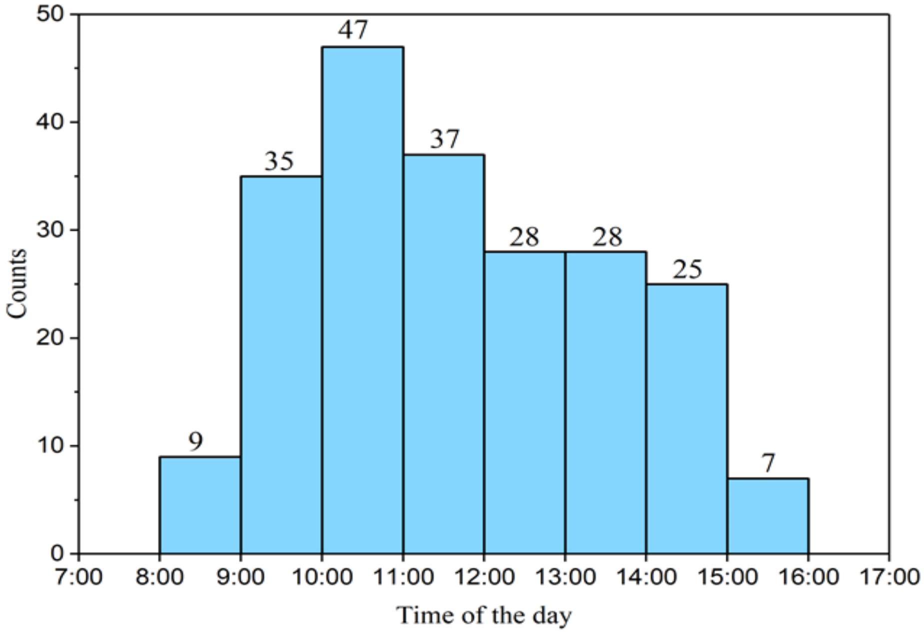


Figure 24. Existence time of electricity demand

4.3.2 Monthly Total Electricity Cost

EPCOR uses the highest electricity capacity demanded during the billing period in kVA to divide the monthly delivery cost into different criteria (EPCOR Energy Services, 2018). There are three criteria that can be used to calculate the delivery cost (EPCOR Energy Services, 2018). For each criterion, formulas to calculate every component of the monthly delivery cost are summarized in Tables 13 to 15 (EPCOR Energy Services, 2018). The tariff prices that are used for these calculations are from the most updated 2017 and 2018 EPCOR tariff schedule (EPCOR Energy Services, 2018). Slight annual variations, it should be noted, can occur.

Table 13. Delivery charges when monthly kVA <50

Delivery Charges ($) when monthly kVA < 50		
Transmission Charges (TC)	Total	$\mathrm{TC} = \frac{\$\ 0.03177}{\mathrm{kWh}} \times \mathrm{MC}^{a}$
Distribution Charges (DC)	Customer Charge (CC)	$\mathrm{CC} = \frac{\$\ 0.32811}{\mathrm{Day}} \times \mathrm{DPM}^{b}$
	Energy Charge (EC)	$\mathrm{EC} = \frac{\$\ 0.02314}{\mathrm{kWh}} \times \mathrm{MC}$
Local Access Fee (LAF)	Total	$\mathrm{LAF} = \frac{\$\ 0.0081}{\mathrm{kWh}} \times \mathrm{MC}$
Total Riders (TR)	Rider G - Balancing Pool Rider	$\mathrm{R_G} = \frac{\$\ 0.00321}{\mathrm{kWh}} \times \mathrm{MC}$
	Rider DJ - DAS True-up Rider	$\mathrm{R_{DJ}} = \frac{\$\ -0.00186}{\mathrm{kWh}} \times \mathrm{MC}$
	Rider J - SAS True-Up Rider	$\mathrm{R_J} = \frac{\$\ 0.00341}{\mathrm{kWh}} \times \mathrm{MC}$
	Rider K - Transmission Charge Deferral Account True-Up Rider	$\mathrm{R_K} = \frac{\$\ 0.00086}{\mathrm{kWh}} \times \mathrm{MC}$

a. MC: Monthly Consumption in kWh
b. DPM: Days Per Month

Table 14. Delivery charges when 50 < monthly kVA <150

Delivery Charges ($) when 50 < monthly kVA < 150		
Transmission Charges (TC)	Demand Charge (DC)	$\mathrm{DC} = \frac{\$\ 0.23070}{\mathrm{kVA} \times \mathrm{Day}} \times \text{Monthly kVA} \times \mathrm{DPM}$
	Energy Charge (EC)	$\mathrm{EC} = \frac{\$\ 0.03177}{\mathrm{kWh}} \times \mathrm{MC}$
Distribution Charges (DC)	Customer Charge (CC)	$\mathrm{CC} = \frac{\$\ 0.82206}{\mathrm{Day}} \times \mathrm{DPM}$
	Demand Charge (DC)	$\mathrm{DC} = \frac{\$\ 0.15144}{\mathrm{kVA} \times \mathrm{Day}} \times \text{Monthly kVA} \times \mathrm{DPM}$
	Energy Charge (EC)	$\mathrm{EC} = \frac{\$\ 0.00442}{\mathrm{kWh}} \times \mathrm{MC}$
Local Access Fee (LAF)	Total	$\mathrm{LAF} = \frac{\$\ 0.0081}{\mathrm{kWh}} \times \mathrm{MC}$
Total Riders (TR)	Rider G - Balancing Pool Rider	$\mathrm{R_G} = \frac{\$\ 0.00321}{\mathrm{kWh}} \times \mathrm{MC}$
	Rider DJ - DAS True-up Rider	$\mathrm{R_{DJ}} = \frac{\$\ -0.00148}{\mathrm{kWh}} \times \mathrm{MC}$
	Rider J - SAS True-Up Rider	$\mathrm{R_J} = \frac{\$\ 0.00518}{\mathrm{kWh}} \times \mathrm{MC}$
	Rider K - Transmission Charge Deferral Account True-Up Rider	$\mathrm{R_K} = \frac{\$\ 0.00088}{\mathrm{kWh}} \times \mathrm{MC}$

Table 15. Delivery charges when 150 < monthly kVA <5000

Delivery Charges ($) when 150 < monthly kVA < 5000		
Transmission Charges (TC)	Demand Charge and OSS Charge (DC & OSS)	DC & OSS = $\frac{\$ 0.381381+\$0.00124}{\text{kW} \times \text{Day}} \times$ Monthly kW × DPM
	Energy Charge (EC)	EC = $\frac{\$ 0.00218}{\text{kWh}} \times \text{MC}$
	Operating Reserve (OR)	OR = 8.18% × MC × \$0.05468/kWh
Distribution Charges (DC)	Customer Charge (CC)	CC = $\frac{\$ 30.49861}{\text{Day}} \times \text{DPM}$
	Demand Charge (DC)	DC = $\frac{\$ 0.07759}{\text{kVA} \times \text{Day}} \times$ Monthly kW × DPM
	Energy Charge (EC)	EC = $\frac{\$ 0.01040}{\text{kWh}} \times \text{MPC}$
Local Access Fee (LAF)	Total	LAF = $\frac{\$ 0.0081}{\text{kWh}} \times \text{MC}$
Total Riders (TR)	Rider G - Balancing Pool Rider	$R_G = \frac{\$ 0.00318}{\text{kWh}} \times \text{MC}$
	Rider DJ - DAS True-up Rider	$R_G = \frac{\$ 0.00318}{\text{kWh}} \times \text{MC}$
	Rider J - SAS True-Up Rider	$R_{DJ} = \frac{\$ -0.00274}{\text{kWh}} \times \text{MPC}$
	Rider K - Transmission Charge Deferral Account True-Up Rider	$R_K = \frac{\$ 0.00073}{\text{kWh}} \times \text{MC}$

a. MPC: Monthly On-peak Consumption in kWh from 8 a.m. to 9 p.m. Monday to Friday

To verify the monthly delivery cost formulas, two assumptions are made: (1) Days Per Month (DPM) is assumed to be 30, and (2) Monthly Peak Consumption (MPC) is assumed to be 90% of total monthly electricity consumption. The ratios for the 18 sites between the existing monthly delivery cost from utility bills and the calculated delivery cost using the delivery cost formulas are plotted in Figure 25. As shown in Figure 25, most of the ratios fluctuate between 0.8 and 1.2, an observation which verifies the delivery cost formulas corresponding to each criterion. The differences between the existing and calculated delivery costs can be explained by the changing tariff prices and the assumptions made. In addition, according to the contract between ECSD and the electrical supplier, a unit electricity cost is used for the period 2016 to 2019. Formulas of monthly total cost can be developed with the combination of unit energy cost and delivery cost. Equations (13) to (15) summarize the total cost for each criterion of the electricity demand. Those formulas can be used by school operators to analyze cost savings based on reductions in electricity consumption and electricity demand.

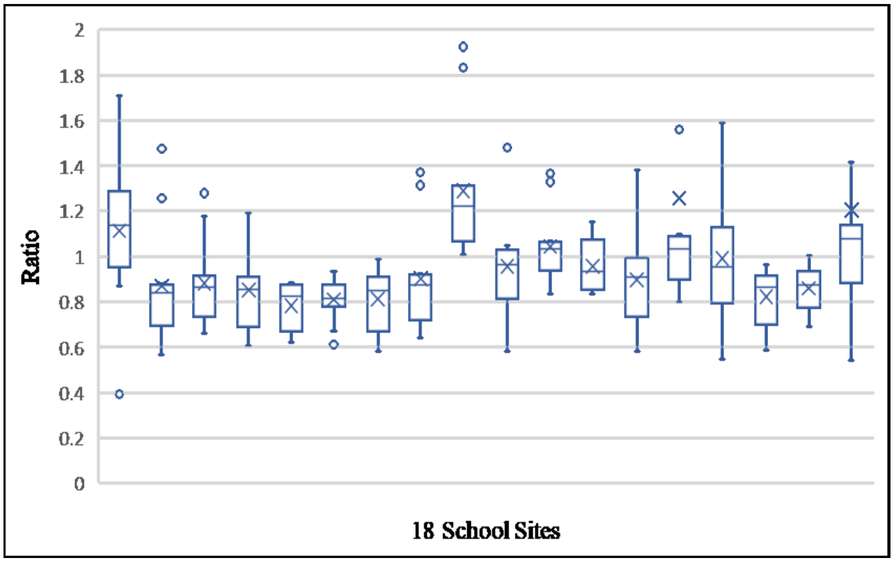


Figure 25. The ratio between the real and the calculated monthly delivery cost

When monthly demand is less than 50 kVA:

$$\text{Total Cost (\$)} = 0.12331 \times \text{MC} + 0.32811 \times \text{DPM} \tag{13}$$

When monthly demand is between 50 and 150 kVA:

$$\text{Total Cost (\$)} = 0.10676 \times \text{MC} + (0.38214 \times \text{Monthly kVA} + 0.82206) \times \text{DPM} \tag{14}$$

When monthly demand is between 150 and 5000 kVA:

$$\text{Total Cost (\$)} = 0.076523 \times \text{MC} + (0.460211 \times \text{Monthly kW} + 30.49861) \times \text{DPM} + 0.00766 \times \text{MPC} \tag{15}$$

4.3.3 Electricity-Specific GHG Emissions

To quantify the reductions in GHG emissions related to the electricity consumed, Equation (11) can be applied. According to Equation (11), by saving 1 kWh of electricity consumed, around 0.2 kg CO_2 eq can be saved. Since implementation of the real-time monitoring system is still in process and the efficiency measures have not yet been applied, a conservative approximation of the savings in CO_2 eq that can be expected is calculated.

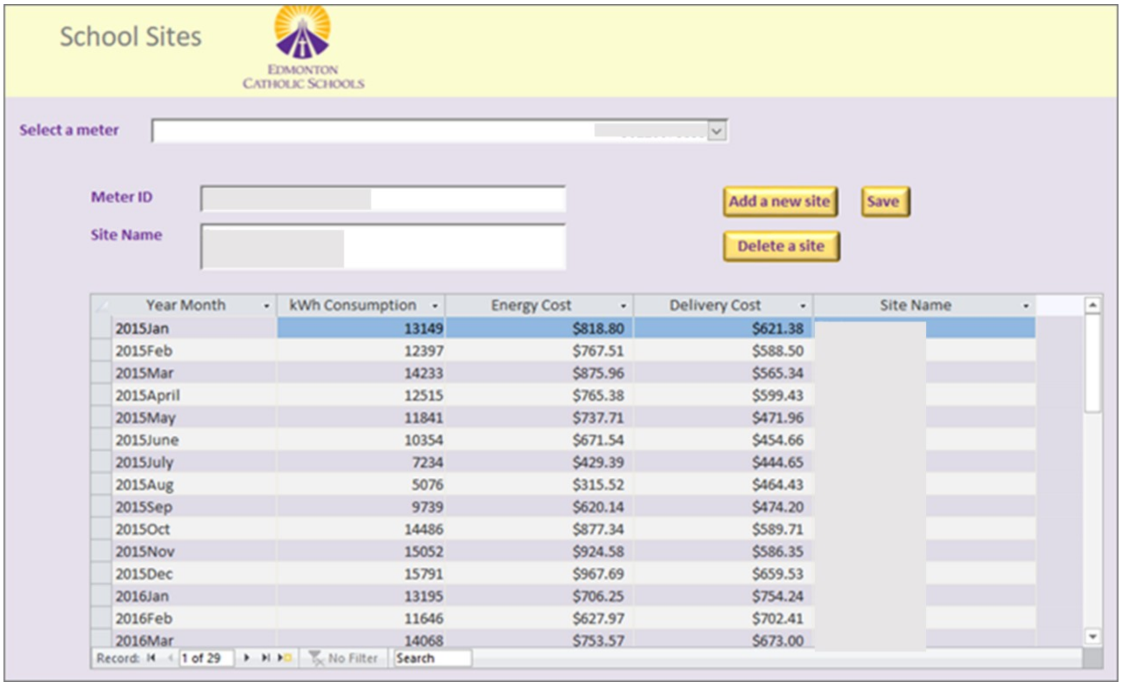
Before calculating the potential savings in CO_2 eq, the savings in electricity consumption need to be estimated. To demonstrate this, a Category B school (School 59) and a medium-energy-efficiency school (School 46) are selected. The savings in kWh of electricity consumption from School 59 can be approximated by multiplying the EUI difference between two schools by its total area. Therefore, based on the calculation result, in converting a Category B school to medium efficiency, 16.5 t CO_2 eq per year in emissions can be saved, representing approximately a 25% reduction. Table 16 below demonstrates the estimated savings in GHG emissions for School 59.

Table 16. Calculation of savings in GHG emissions

School 59's Annual Electricity Consumption (kWh)	**CO_2 Produced (kg)**	**CH_4 Produced (kg)**	**N_2O Produced (kg)**	**Total GHG Produced per Year (tonnes)**
312823	61456.953	19.213	241.896	61.718
School 59's Electricity Consumption Savings (kWh)	**CO_2 Saved (kg)**	**CH_4 Saved (kg)**	**N_2O Saved (kg)**	**Total GHG Saved per Year (tonnes)**
83469.463	16398.343	5.126	64.544	16.468

4.3.4 User Interface

In the existing practice, the monthly delivery cost and energy cost of schools can only be observed from each month's utility bill in a PDF format. As such, it is difficult for school operators to search for a specific school and look at this school's electricity consumption and related costs consecutively. To address this challenge, a user interface is created in Microsoft Access using the information about school sites and the data from the utility bills provided. A screenshot of this user interface is shown in Figure 26. The interface is built based on a database of utility bill information from January, 2015, to May, 2017, for 86 schools. With this interface, school operators can search for a school site using its meter ID and view the specific monthly electricity consumption together with the corresponding costs. New records can also be added by school operators to any existing school sites. Moreover, a new site with new records can also be created within the user interface.



Meter ID [redacted]

Site Name [redacted]

Year Month	kWh Consumption	Energy Cost	Delivery Cost	Site Name
2015Jan	13149	$818.80	$621.38	[redacted]
2015Feb	12397	$767.51	$588.50	[redacted]
2015Mar	14233	$875.96	$565.34	[redacted]
2015April	12515	$765.38	$599.43	[redacted]
2015May	11841	$737.71	$471.96	[redacted]
2015June	10354	$671.54	$454.66	[redacted]
2015July	7234	$429.39	$444.65	[redacted]
2015Aug	5076	$315.52	$464.43	[redacted]
2015Sep	9739	$620.14	$474.20	[redacted]
2015Oct	14486	$877.34	$589.71	[redacted]
2015Nov	15052	$924.58	$586.35	[redacted]
2015Dec	15791	$967.69	$659.53	[redacted]
2016Jan	13195	$706.25	$754.24	[redacted]
2016Feb	11646	$627.97	$702.41	[redacted]
2016Mar	14068	$753.57	$673.00	[redacted]

Figure 26. The user interface to observe the electricity consumption and costs

4.4 Sensor Instrumentation and Monitoring Plan

To find the most appropriate sensor in the current market, a decision matrix is generated for four products under consideration. The total score for each is calculated as the sum of its scores for each of the five standards—cost, availability, accuracy, data visualization, and simplicity of installation. The weight of each standard and the ranking for each company are set subjectively based on the available information of each product manufacturer (CircuitMeter, 2018; eGauge, 2018; Eyedro, 2018; OpenEnergyMonitor, 2018). (The decision matrix is shown in Appendix G.) Since the eGauge system achieves the highest score, it is selected for the real-time monitoring.

Among the ten Category B schools, three are preferred by ECSD Facility Services for the two-year monitoring. The selected schools consist of one high school (School 6), one junior high (School 14), and one primary school (School 53). Based on several site visits to the three schools, information for all existing electrical panels is collected, and three monitoring plans are prepared for each school accordingly, except for School 53, which only has two plans due to its lower number of electrical panels.

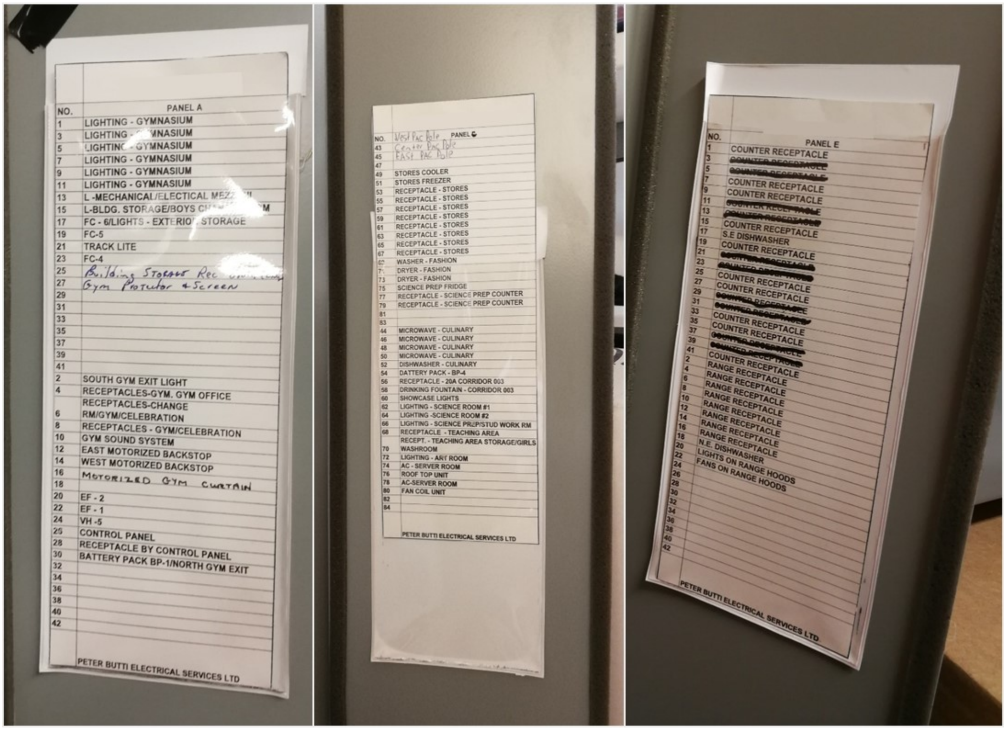
In plan 1, all electrical panels within each school are monitored. After filtering out some less interesting electrical panels, plan 2 retains panels which can cover more rooms with different functions. Plan 3 is the plan with the least number of panels to be monitored. The general description of each monitoring plan is given in Table 17.

Table 17. Monitoring plans for each school

School Description	Panel information	Plan 1	Plan 2	Plan 3
School 6	17 panels (3PH 4W, 120/208V, 225A)	All panels are monitored	Receptacles and lighting in classrooms, staff rooms, library, science rooms, corridor, gym, kitchen	Receptacles and lighting in science rooms, classrooms, staff rooms and gym
School 14	11 Panels (3PH 4W, 120/208V, 225A)	All panels are monitored	Lighting and receptacles in classroom, gym, science room, computer room, library, music room, food and fashion room, corridor	Lighting and receptacles in classroom, library, computer room, food and fashion room, corridor
School 53	7 Panels (3PH 4W, 120/208V, 225A)	All panels are monitored	Mechanical room, lighting and receptacles in classroom, Workroom and office	

Among these three schools, School 14 is the only Category B school appearing in both methods of energy benchmarking. Due to the scope of the project and financial limitations, School 14 is the only school selected for the two-year monitoring plan. Monitoring Plan 1, which involves monitoring all panels, is selected for it to support a full investigation of the space-level electricity consumption.

School 14 is in the Southeast of Edmonton. There are 11 electrical panels inside the school. Based on several school site visits and reviews of AutoCAD drawings, the circuit information and the location of each electrical panel are respectively collected and clarified. For some of the electrical panels, differences in circuit information can be identified between the AutoCAD drawings and school site visits, so corrections of circuit information must be made in accordance with the site visit results. Figure 27 shows the photos taken of some of the electrical panels during school site visits. The detailed circuit information regarding each electric panel is listed in Appendix H. The locations of electrical panels are colour-coded in the main school plan as shown in Appendix I.



NO.	PANEL A
1	LIGHTING - GYMNASIUM
3	LIGHTING - GYMNASIUM
5	LIGHTING - GYMNASIUM
7	LIGHTING - GYMNASIUM
9	LIGHTING - GYMNASIUM
11	LIGHTING - GYMNASIUM
13	L -MECHANICAL/ELECTICAL MEZ[illegible]
15	L-BLDG. STORAGE/BOYS C[illegible]M
17	FC - 6/LIGHTS - EXTERIOR STORAGE
19	FC-5
21	TRACK LITE
23	FC-4
25	Building Storage Rec [illegible]
27	Gym Protector + Screen
29	
31	
33	
35	
37	
39	
41	
2	SOUTH GYM EXIT LIGHT
4	RECEPTACLES-GYM. GYM OFFICE
6	RECEPTACLES-CHANGE RM/GYM/CELEBRATION
8	RECEPTACLES - GYM/CELEBRATION
10	GYM SOUND SYSTEM
12	EAST MOTORIZED BACKSTOP
14	WEST MOTORIZED BACKSTOP
16	MOTORIZED GYM CURTAIN
18	
20	EF - 2
22	EF - 1
24	VH -5
26	CONTROL PANEL
28	RECEPTACLE BY CONTROL PANEL
30	BATTERY PACK BP-1/NORTH GYM EXIT
32	
34	
36	
38	
40	
42	

PETER BUTTI ELECTRICAL SERVICES LTD

NO.	West Pac Pole PANEL C
43	Center Pac Pole
45	EAST PAC Pole
47	
49	STORES COOLER
51	STORES FREEZER
53	RECEPTACLE - STORES
55	RECEPTACLE - STORES
57	RECEPTACLE - STORES
59	RECEPTACLE - STORES
61	RECEPTACLE - STORES
63	RECEPTACLE - STORES
65	RECEPTACLE - STORES
67	RECEPTACLE - STORES
69	WASHER - FASHION
71	DRYER - FASHION
73	DRYER - FASHION
75	SCIENCE PREP FRIDGE
77	RECEPTACLE - SCIENCE PREP COUNTER
79	RECEPTACLE - SCIENCE PREP COUNTER
81	
83	
44	MICROWAVE - CULINARY
46	MICROWAVE - CULINARY
48	MICROWAVE - CULINARY
50	MICROWAVE - CULINARY
52	DISHWASHER - CULINARY
54	DATTERY PACK - BP-4
56	RECEPTACLE - 20A CORRIDOR 003
58	DRINKING FOUNTAIN - CORRIDOR 003
60	SHOWCASE LIGHTS
62	LIGHTING - SCIENCE ROOM #1
64	LIGHTING -SCIENCE ROOM #2
66	LIGHTING - SCIENCE PREP/STUD WORK RM
68	RECEPTACLE - TEACHING AREA
70	RECEPT. - TEACHING AREA STORAGE/GIRLS WASHROOM
72	LIGHTING - ART ROOM
74	AC - SERVER ROOM
76	ROOF TOP UNIT
78	AC-SERVER ROOM
80	FAN COIL UNIT
82	
84	

PETER BUTTI ELECTRICAL SERVICES LTD

NO.	PANEL E
1	COUNTER RECEPTACLE
3	~~COUNTER RECEPTACLE~~
5	~~COUNTER RECEPTACLE~~
7	COUNTER RECEPTACLE
9	COUNTER RECEPTACLE
11	~~COUNTER RECEPTACLE~~
13	~~COUNTER RECEPTACLE~~
15	COUNTER RECEPTACLE
17	S.E DISHWASHER
19	COUNTER RECEPTACLE
21	~~COUNTER RECEPTACLE~~
23	~~COUNTER RECEPTACLE~~
25	COUNTER RECEPTACLE
27	COUNTER RECEPTACLE
29	~~COUNTER RECEPTACLE~~
31	~~COUNTER RECEPTACLE~~
33	COUNTER RECEPTACLE
35	COUNTER RECEPTACLE
37	~~COUNTER RECEPTACLE~~
39	~~COUNTER RECEPTACLE~~
41	COUNTER RECEPTACLE
2	RANGE RECEPTACLE
4	RANGE RECEPTACLE
6	RANGE RECEPTACLE
8	RANGE RECEPTACLE
10	RANGE RECEPTACLE
12	RANGE RECEPTACLE
14	RANGE RECEPTACLE
16	RANGE RECEPTACLE
18	N.E. DISHWASHER
20	LIGHTS ON RANGE HOODS
22	FANS ON RANGE HOODS
24	
26	
28	
30	
32	
34	
36	
38	
40	
42	

PETER BUTTI ELECTRICAL SERVICES LTD

Figure 27. Circuit information in some electrical panels

The equipment purchased from eGauge System LLC is used to monitor the electricity consumption. eGauge core and eGauge Pro are the two main monitoring systems, with 15 channels and 30 channels, respectively. They are composed of an energy meter, data logger, and a web server (eGauge, 2018). With a 50A/0.39″ AC split-core Current Transformer (CT) connection to every circuit within a given panel, monitored power data in V, A, W, kWh, VAr with a minimum one-second interval can be uploaded to the cloud through Ethernet or WiFi. From the built-in user interface, the data can be retrieved online and downloaded for further analysis. Figure 28 shows the equipment used for the electricity consumption monitoring. Three eGauge Core systems, 10 eGauge Pro systems, and 331 CT sensors are purchased for the monitoring of a total of 11 electrical panels in School 14. The summary of panel information and the corresponding systems for each panel are listed in Table 18. When the number of circuits within one panel exceeds the maximum number of channels that eGauge systems can carry, CT sensors are purchased based on the number of channels provided from eGauge systems. Otherwise, the number of CT sensors depends on the number of circuits per panel.

Figure 28. Monitoring equipment

Table 18. Panel information and eGauge systems for School 14

Panel	Main Purpose	Number of Circuits Per Panel	eGauge Core	eGauge Pro	CT sensors required
A	Gym lighting and receptacle	28		1	28
B	Lighting in classroom and library, receptacles in classroom, library and computer room	39		1	30
C	Lighting in music room and classroom, receptacles in classroom and music room	30		1	30
D	Lighting, receptacles in office and classroom and corridor	69		2	60
E	Food and fashion room	32		1	30
F	Mechanical room boilers and fans, gym receptacles	24		1	24
G	Receptacles in science room, flex room, store room, food and fashion room, science room lighting	60		2	60
H	Fabrication room	13	1		13
J	Science Room receptacles	26		1	26
CPA	Parking lot	20	1		15
CPB	Parking lot	23	1		15
	Sum	364	3	10	331

Based on the real-time monitoring of all electrical panels in School 14, the breakdown of electricity use can be obtained. School operators can use this energy disaggregation result to identify target areas for energy efficiency improvement. The continuous data collection from the real-time monitoring system can provide opportunities to approach energy savings in the equipment operation and equipment efficiency. The two aspects are explained as follows.

To identify electricity-saving opportunities in equipment operation, electricity consumption patterns from the same circuit at different times can be compared. With the control variables such as weather, outside temperature, natural light strength, and class schedule, the differences in the consumption patterns which are attributable to inappropriate electricity-using habits can be further analyzed using site observation. To assist with the site visit, a survey focused on lighting, HVAC and domestic hot water, electrical devices, and occupant behaviour is administered (Infrastructure.alberta.ca, 2018; Mohamed, 2017; National Energy Education Development, 2016; NRCan, 2012b). The survey is provided in Appendix J.

Efficiency improvements in some electrical equipment can also be suggested based on the analysis of the consumption patterns in different rooms within the same period. The target locations should have similar sizes, functions, and the same operating schedules. To explain the differences that exist between the electricity consumption patterns, equipment in the target locations need to be carefully examined. Inefficient and high electricity-contributed appliances can thus be identified.

CHAPTER 5 CONCLUSION

5.1 Research Results

This thesis presents a framework for an electrical energy management system for schools to evaluate the efficiency of electricity use during school operation. The energy management system is composed of four parts: (1) historical data analysis for general electricity consumption patterns; (2) energy benchmarking for categorization of school energy performance; (3) systematic measurement for outcomes of energy consumption; and (4) a real-time monitoring plan for identification of opportunities for efficiency improvement.

In this research, to better understand the energy performance of schools, based on the data from utility bills and on-site meters, electricity consumption patterns are plotted at different time intervals. According to the monthly plots, no major electricity consumption change can be found between seasons except for the months during the summer holiday. From 2015 to 2016, an increase in total annual electricity consumption of ECSD schools is observed, and that increase is more pronounced when the consumption is weather-normalized. Based on the on-site meter data, the peak hours of school electricity consumption are determined to be between 7 a.m. and 4 p.m. The electricity consumption during weekends and statuary holidays is found to be much less than the electricity consumption during weekdays. The comparison between utility bill data and on-site meter data demonstrates that the annual consumption specified in the utility bill will be 2% to 3% higher than the on-site meter data due to the electricity loss during transmission and distribution. EUI as the energy efficiency indicator (expressed in kWh/m^2) is calculated for portable rooms and core school area. It is found that portable rooms are less energy-efficient than the core area.

To categorize schools, energy benchmarks for schools in ECSD are established with simple descriptive statistics and a multiple linear regression model. In simple descriptive statistics, two metrics (annual electricity consumption per area and annual electricity consumption per student) are calculated for all the schools in order to plot the probability distributions. The mean and median of the two distributions are respectively considered as the energy benchmarks for each of the metrics. In multiple linear regression, to satisfy five assumptions, specific regression steps are developed. Four energy factors which can mostly explain the variations in electrical EUI have remained after the stepwise regression from 13 input factors. For both energy benchmarking methods, the top and bottom 15% of the calculated residuals are set as a guideline to categorize schools by energy performance. The final results of the school categorization are the union set of results from both energy benchmarking methods. A comparison of electrical EUI with existing benchmarks is also carried out which shows that ECSD has a relatively good energy performance when compared to schools in the other areas.

Electricity costs and GHG emissions are the two major outcomes of electricity consumption. Monthly electricity cost is composed of two portions, delivery cost and energy cost. The monthly delivery cost exceeds the monthly energy cost with a share of 60.57%. Since delivery cost is also related to the monthly electricity demand in kW, the electricity demand of schools is also investigated. It is found that the monthly electricity demand always occurs between 10 a.m. and 11 a.m. For this timeframe, it is noted, it is important for school operators to apply strategies for load management which can help reduce the delivery cost. Based on EPCOR's tariff schedule, a formula is developed for electricity cost versus monthly electricity consumption and monthly electricity demand. Another equation is calculated relating GHG emissions to electricity consumption. A user interface in Microsoft Access is also created for the purpose of easy data entry from utility bills and ready observation of electricity consumption and related costs.

To identify opportunities to improve school energy efficiency, a real-time monitoring plan is developed. Based on energy benchmarking results and the school board's preferences, a junior high school (School 14) is chosen to be implemented with an intrusive load monitoring system. All its 11 electrical panels are monitored using eGauge sensor instrumentation. A monitoring plan targeting the problems existing in equipment operation and efficiency is proposed accordingly. A site visit survey which can assist with the monitoring plan is also prepared.

5.2 Research Contributions

In this research, a portfolio of school facilities is categorized based on energy benchmarking. The identification of opportunities to approach energy savings within the selected school can be subsequently applied using real-time monitoring. This proposed framework of energy management can be continually used by school operators to improve the energy efficiency of school buildings. It constitutes pioneering research in Alberta to apply statistics and real-time monitoring to investigate school energy performance. The contributions of this research are summarized as follows:

- Validation between historical data sources is conducted and electricity consumption patterns for ECSD schools are obtained.

- Schools are categorized based on the energy benchmarks specifically generated for ECSD.
- The outcomes of electricity consumption, such as the electricity cost and GHG emissions, can be systematically measured with the developed formulas.
- A plan for an intrusive load monitoring system and a site visit survey are proposed in order to identify electricity-saving opportunities.

5.3 Research Limitations

The limitations of this research are summarized below:

- Only a limited number of energy factors can be identified from the school basic information considered. With more information provided, factors such as indoor temperature set point, percent of lighting by incandescent or fluorescent lights, and number of freezers or refrigerators etc. can be identified.
- Electricity is the only energy source considered in this study. Without including natural gas consumption, the energy benchmarking tool ENERGY STAR Portfolio Manager cannot be applied since it requires all types of energy consumed by the building.
- The tariff rates embedded in the delivery cost can be subject to slight variations from year to year, hence the coefficients in the formula of monthly total cost of electricity needs to be adjusted accordingly.
- The time of electricity demand is based on the data of 18 on-site meters. The rest of the meters, which record the consumption in hourly intervals, do not collect power data.

- Due to the scope of the project, only one school can be installed with the real-time monitoring system, hence no comparison between schools can be conducted.

5.4 Recommendations for Future Studies

With the aim of optimizing building energy efficiency during the operational phase, this research can be used as a reference for school operators to conduct building energy management. Recommendations for future studies are listed below:

- After obtaining and analyzing the real-time data, energy conservation strategies can also be implemented in other category B schools. The payback for the whole school board can thus be estimated.
- Renewable resources such as solar energy can also be incorporated into school operation.
- Given that natural gas is the energy source for heating in the schools under consideration in the case study, natural gas consumption can also be added to future energy saving research.
- More schools can be furnished with the real-time monitoring instrumentation so that the EMIS of the school board will be more complete, specific problems for each monitored school can be addressed, and the comparison between schools can be carried out.
- Teachers and students can be engaged in this project. A culture of energy conservation can be created in schools, increasing student awareness of energy management issues.

References

Abubakar, I., Khalid, S., Mustafa, M., Shareef, H. and Mustapha, M. (2017). Application of load monitoring in appliances’ energy management – A review. *Renewable and Sustainable Energy Reviews*, 67, pp. 235-245.

Amateur Weather Statistics for Edmonton, Alberta. (2018). *Weather Dashboard for Edmonton*. [online] Available at: https://edmonton.weatherstats.ca/charts/hdd-yearly.html [Accessed 1 Jun. 2018].

Brander, M., Sood, A., Wylie, C., Haughton, A. and Lovell, J. (2011). *Technical Paper | Electricity-specific emission factors for grid electricity*. [online] ecometrica. Available at: https://ecometrica.com/assets/Electricity-specific-emission-factors-for-grid-electricity.pdf [Accessed 18 May 2018].

Burlig, F., Knittel, C., Rapson, D., Reguant, M. and Wolfram, C. (2017). *Machine Learning from Schools about Energy Efficiency*. [online] Energy Policy Institute at the University of Chicago. Available at: https://epic.uchicago.edu/sites/default/files/School_Main.pdf [Accessed 9 Aug. 2018].

Burman, E., Hong, S., Paterson, G., Kimpian, J. and Mumovic, D. (2014). A comparative study of benchmarking approaches for non-domestic buildings: Part 2 – Bottom-up approach. *International Journal of Sustainable Built Environment*, 3(2), pp. 247-261.

Chatterjee, S. and Hadi, A. (2015). *Regression analysis by example*. 5th ed. Somerset: Wiley, pp. 57-89.

Chung, W. (2011). Review of building energy-use performance benchmarking methodologies. *Applied Energy*, 88(5), pp. 1470-1479.

CircuitMeter. (2018). *Products Archive*. [online] Available at: https://www.circuitmeter.com/technology/products/ [Accessed 7 Feb. 2018].

City of Edmonton. (2018). *ENERGY STAR Portfolio Manager Toolkit*. [online] Available at: https://www.edmonton.ca/programs_services/documents/PDF/LBERD-ESPMToolkit.pdf [Accessed 2 May 2018].

Deb, C. (2017). *Development of an automated energy audit protocol for office buildings*. Ph.D. National University of Singapore.

eGauge. (2018). *eGauge product Catelog*. [online] Available at: http://www.egauge.net/media/images/pdfs/egauge-product-catalog-2018.pdf [Accessed 16 May 2018].

ENERGY STAR. (2016). *Portfolio Manager Quick Start Guide*. [online] Available at: https://www.energystar.gov/sites/default/files/tools/Portfolio%20Manager%20Quick%20Start%20Guide_0.pdf [Accessed 28 Apr. 2018].

ENERGY STAR. (2018). *The difference between source and site energy*. [online] Available at: https://www.energystar.gov/buildings/facility-owners-and-managers/existing-buildings/use-portfolio-manager/understand-metrics/difference [Accessed 8 Feb. 2018].

Environment and Climate Change Canada. (2017). *Global Warming Potentials*. [online] Available at: http://www.ec.gc.ca/ges-ghg/default.asp?lang=En&n=CAD07259-1&pedisable=true [Accessed 12 May 2018].

EPCOR Energy Services. (2018). Tariffs, Terms & Conditions. [online] Available at: https://www.epcor.com/products-services/power/rates-tariffs-fees/Pages/power-tariffs-terms-and-conditions-edmonton.aspx [Accessed 25 May 2018].

Eyedro. (2018). *Electricity Monitors for Home and Business*. [online] Available at: http://eyedro.com/ [Accessed 7 Feb. 2018].

Federspiel, C., Zhang, Q. and Arens, E. (2002). Model-based benchmarking with application to laboratory buildings. *Energy and Buildings*, 34(3), pp. 203-214.

Google Maps (2018). Available at: https://www.google.com/maps/ [Accessed 17 Jul. 2018].

Government of Canada (2018). *Canadian Climate Normals*. [online] Available at: http://climate.weather.gc.ca/climate_normals/ [Accessed 27 Apr. 2018].

H. Eto, J., Turiel, I., Akbari, H., Benoit Lebot, B. and Heinemeier, K. (1990). An Investigation of the Use of Prototypes for Commercial Sector EUI Analysis. In: *ACEEE 1990 Summer Study on Energy Efficiency in Buildings*.

Harrigan, M. (2014). *Including Students in Your School's Energy Program*. [online] SouthEast Education Network. Available at: http://www.seenmagazine.us/Articles/Article-Detail/ArticleId/4371/Including-Students-in- [Accessed 10 Jul. 2018].

Hong, S., Paterson, G., Burman, E., Steadman, P. and Mumovic, D. (2013). A comparative study of benchmarking approaches for non-domestic buildings: Part 1 – Top-down approach. *International Journal of Sustainable Built Environment*, 2(2), pp. 119-130.

Hong, S., Paterson, G., Mumovic, D. and Steadman, P. (2014). Improved benchmarking comparability for energy consumption in schools. *Building Research & Information*, 42(1), pp. 47-61.

Hooke, J., Hart, D. and Landry, B. (2004). *Energy management information systems*. [Ottawa]: Office of Energy Efficiency of Natural Resources Canada, pp. 53-85.

Infrastructure.alberta.ca. (2018). *Government of Alberta Ministry of Infrastructure: Edmonton Catholic Separate School District No. 7*. [online] Available at: http://www.infrastructure.alberta.ca/821.htm [Accessed 30 May 2018].

International Energy Agency. (2005). *Energy Statistics Manual*. [online] Available at: https://webstore.iea.org/energy-statistics-manual [Accessed 14 May 2018].

International Energy Agency. (2017). *Key World Energy Statistics*. [online] Available at: https://www.iea.org/publications/freepublications/publication/KeyWorld2017.pdf [Accessed 16 Jun. 2018].

International Energy Agency. (2017). *World Energy Outlook*. [online] Available at: https://www.iea.org/weo2017/ [Accessed 25 Apr. 2018].

Issa, M., Attalla, M., Rankin, J. and Christian, A. (2010). Detailed analysis of electricity, water, and gas consumption quantities and costs in Toronto's public schools. *Canadian Journal of Civil Engineering*, 37(1), pp. 25-36.

Issa, M., Attalla, M., Rankin, J. and Christian, A. (2011). Energy consumption in conventional, energy-retrofitted and green LEED Toronto schools. *Construction Management and Economics*, 29(4), pp. 383-395.

McLafferty, S. (1987). *@RISK*. New York: Palisade Corporation.

Mohamed, O. (2017). *The Effect of Occupancy on School Buildings' Energy Consumption in Manitoba*. Ph.D. thesis, University of Manitoba.

Mohareb, E. (2014). *Improving Energy Efficiency in Alberta's Buildings*. Calgary: The Pembina Institute.

Montgomery, D., Peck, E. and Vining, G. (2013). *Introduction to Linear Regression Analysis*. 5th ed. Hoboken, New Jersey: Wiley, pp. 389-391.

National Energy Education Development. (2016). *School Energy Survey Student Guide*. [online] Available at: http://www.need.org/files/curriculum/guides/energysurveystudent.pdf [Accessed 5 Feb. 2018].

Natural Resources Canada (2001). *Benchmarking Guide for School Facility Managers*. Ottawa: Office of Energy Efficiency.

Natural Resources Canada (2001). *Best Practices Guide for School Facility Managers*. Ottawa: Office of Energy Efficiency.

Natural Resources Canada (2012). *ecoENERGY Efficiency for Buildings*. Office of Energy Efficiency.

Natural Resources Canada (2012). *Survey of Commercial and Institutional Energy Use Detailed Statistical Report*. Ottawa: Office of Energy Efficiency.

Natural Resources Canada (2013). *Survey of Commercial and Institutional Energy Use: Establishments 2009 Summary report*. Ottawa: Office of Energy Efficiency.

Natural Resources Canada (2015). *Energy Management Best Practices Guide For Commercial and Institutional Buildings*. Ottawa: Office of Energy Efficiency.

Natural Resources Canada (2016). *Energy Efficiency Trends in Canada 1990 to 2013*. Ottawa: Office of Energy Efficiency.

Natural Resources Canada (2018). *Energy Fact Book 2016–2017*. Energy and Economic Analysis division of the Energy Policy branch.

Natural Resources Canada (2018). *Climate zones: windows, doors and skylights*. [online] Available at: http://www.nrcan.gc.ca/energy/products/categories/fenestration/13954 [Accessed 26 Apr. 2018].

Natural Resources Canada. (2018). *Commercial and Institutional Sector, Alberta, Table 3: Secondary Energy Use and GHG Emissions by Activity Type*. [online] Available at: http://oee.rncan.gc.ca/corporate/statistics/neud/dpa/showTable.cfm?type=CP&sector=com&juris=ab&rn=3&page=0 [Accessed 20 May 2018].

Natural Resources Canada (2018). *Electricity facts*. [online] Available at: http://www.nrcan.gc.ca/energy/facts/electricity/20068 [Accessed 19 May 2018].

Natural Resources Canada (2018). *Energy benchmarking: the basics*. [online] Available at: http://www.nrcan.gc.ca/energy/efficiency/buildings/energy-benchmarking/building/18260 [Accessed 7 May 2018].
Natural Resources Canada. (2018). *Energy Efficiency in Buildings*. [online] Available at: http://www.nrcan.gc.ca/publications/commercial/5945 [Accessed 15 May 2018].

Natural Resources Canada (2018). *What's new with ENERGY STAR Portfolio Manager?* [online] Available at: http://www.nrcan.gc.ca/energy/efficiency/buildings/energy-benchmarking/update/15938 [Accessed 28 Apr. 2018].

Neida, B., Shelin, Z., and Regan, S. (2018). *Electric Demand-Tacking kW to Drive Savings.* U.S. Environmental Protection Agency (EPA), ENERGY STAR.

Ohta, T. (2009). *Energy Carriers and Conversion Systems With Emphasis On Hydrogen*. 1st ed. Oxford, U.K: Eolss Publishers, pp. 1-10.

OpenEnergyMonitor. (2018). *System Overview*. [online] Available at: https://guide.openenergymonitor.org/setup/ [Accessed 8 Feb. 2018].

Ouf, M. and Issa, M. (2017). Energy consumption analysis of school buildings in Manitoba, Canada. *International Journal of Sustainable Built Environment*, 6(2), pp. 359-371.

Ouf, M., Issa, M., and Merkel, P. (2016). Analysis of real-time electricity consumption in Canadian school buildings. *Energy and Buildings*, 128, pp. 530-539.

Pérez-Lombard, L., Ortiz, J. and Pout, C. (2008). A review on buildings energy consumption information. *Energy and Buildings*, 40(3), pp. 394-398.

Piper, J. (1999). *Operations and Maintenance Manual for Energy Management*. 2nd ed. New York: Routledge, pp. 11-47.

Ridi, A., Gisler, C. and Hennebert, J. (2014). A Survey on Intrusive Load Monitoring for Appliance Recognition. In: *22nd International Conference on Pattern Recognition*. IEEE, pp. 3702–3707.

Ritchie, H. and Roser, M. (2018). *Energy Production & Changing Energy Sources*. [online] Our World in Data. Available at: https://ourworldindata.org/energy-production-and-changing-energy-sources [Accessed 25 Jul. 2018].

Ryan, B., Ryan, T. and Joiner, B. (1972). *Minitab*. The Pennsylvania State University: Minitab, Inc.

Sharp, T. (1996). Energy Benchmarking in Commercial Office Buildings. In: *ACEEE 1996 Summer Study on Energy Efficiency in Buildings*.

Sharp, T. (1998). Benchmarking Energy Use in Schools. In: *Proceedings of the ACEEE 1998 Summer Study on Energy Efficiency in Buildings (3)*. pp. 305--316.

Toronto and Region Conservation Authority (2016). *Rating Ontario School Boards' Energy Efficiency: Top Energy Performing Boards Report*. Toronto: Sustainable Schools.

Toronto and Region Conservation Authority (2016). *Rating Ontario School Boards' Energy Efficiency: Top Energy Performing Boards Report*. Toronto: Sustainable Schools.

U.S. Department of Energy (2010). *Energy Efficiency Trends in Residential and Commercial Buildings*. Office of Energy Efficiency and Renewable Energy, pp. 3-17.

U.S. Department of Energy (2018). *Unlocking Innovative Design for Better Schools*. [online] Available at: https://energy.gov/eere/buildings/articles/unlocking-innovative-design-better-schools [Accessed 3 Jun. 2018].

U.S. Department of International Economic and Social Affairs (1982). *Concepts and Methods in Energy Statistics, with Special Reference To Energy Account and Balances.* [online] New York. Available at: https://unstats.un.org/unsd/publication/SeriesF/SeriesF_29E.pdf [Accessed 30 Jun. 2018].

U.S. Energy Information Administration. (2016). *Table PBA4. Electricity consumption totals and conditional intensities by building activity subcategories, 2012*. [online] Available at: https://www.eia.gov/consumption/commercial/data/2012/c&e/cfm/pba4.php [Accessed 29 May 2018].

U.S. Energy Information Administration (2017). *International Energy Outlook Executive Summary*. U.S. Department of Energy.

Vancouver School Board (2017). *Strategic Energy Management Plan (SEMP): 2013/14 – 2017/18*. Vancouver.

Winston, W. and Venkataramanan, M. (2003). *Operations research*. 4th ed. Pacific Grove, CA: Thomson, pp. 11-42.

Yoshino, H., Hong, T. and Nord, N. (2017). IEA EBC annex 53: Total energy use in buildings—Analysis and evaluation methods. *Energy and Buildings*, 152, pp. 124-136.

Zoha, A., Gluhak, A., Imran, M. and Rajasegarar, S. (2012). Non-Intrusive Load Monitoring Approaches for Disaggregated Energy Sensing: A Survey. *Sensors*, 12(12), pp. 16838-16866.

Appendices

Appendix A: SQL code to extract electricity demand and other related information

Query 1

```
SELECT [School Sites].SiteName, Max([15 min data].kW) AS MaxOfkW, Sum([15 min data].kWh)
            AS SumOfkWh, [Utility Bill].YearMonth
FROM ([School Sites] INNER JOIN [15 min data] ON [School Sites].MeterID = [15 min
            data].SiteName) INNER JOIN [Utility Bill] ON [School Sites].MeterID = [Utility
           Bill].SiteName
WHERE ((([Utility Bill].Mmonth)=MonthName(Month([15 min data].MonitoringDate),True) Or
            ([Utility Bill].Mmonth)=MonthName(Month([15 min data].MonitoringDate),False)) And
            (([Utility Bill].Myear)=CStr(Year([15 min data].MonitoringDate))))
GROUP BY [School Sites].SiteName, [Utility Bill].YearMonth;
```

Query 2

```
SELECT [Utility Bill].YearMonth, [School Sites].SiteName, [15 min data].MonitoringDate, [15 min
           data].MonitoringTime, [15 min data].kW, [15 min data].kVA, [Max-kwh].SumOfkWh,
           [Utility Bill].kWhConsumption, [Utility Bill].DeliveryCost, [Utility Bill].ConsumptionCost
FROM [Max-kwh], ([School Sites] INNER JOIN [15 min data] ON [School Sites].MeterID = [15 min
           data].SiteName) INNER JOIN [Utility Bill] ON [School Sites].MeterID = [Utility
           Bill].SiteName
WHERE ((([School Sites].SiteName)=[Max-kwh].SiteName) And (([15 min data].kW)=[Max-
           kwh].MaxOfkW) And (([Utility Bill].YearMonth)=[Max-kwh].YearMonth) And (([Utility
           Bill].Mmonth)=MonthName(Month([15 min data].MonitoringDate),True) Or ([Utility
           Bill].Mmonth)=MonthName(Month([15 min data].MonitoringDate),False)) And (([Utility
           Bill].Myear)=CStr(Year([15 min data].MonitoringDate))))
ORDER BY [School Sites].SiteName, [15 min data].MonitoringDate, [15 min
             data].MonitoringTime
```

Appendix B: Data input for multiple linear regression model

Site decription	Student	Staff	Core area m^2	Total gym area m^2	Total gym capacity	Classroom area m^2	Computer room area m^2	Building age	Number of wired computers	Number of wireless computers	Site Area m^2	Elevator existence	Portables existence
School 1	293	34	1577	444.0	592	1053.7	74.6	35.2	31	107	13000	No	Yes
School 2	328	29	2727	223.0	297	1098.9	89.6	50.0	66	102	64600	No	Yes
School 3	517	45	4066	536.0	714	2195.3	124.7	14.0	128	90	55700	No	Yes
School 4	956	59	8637	660.5	881	1927.6	243.9	46.8	386	163	49500	Yes	Yes
School 5	1640	112	14524	1196.4	1595	2772.3	612.6	53.0	336	249	64600	Yes	Yes
School 6	626	49	7497	761.0	1015	966.3	81	13.0	215	86	21083	Yes	No
School 7	911	76	9852	683.3	911	1448	694.3	53.2	364	70	38600	Yes	No
School 8	439	50	4813	445.0	593	1196.6	74.5	53.3	84	85	15400	Yes	No
School 9	409	32	3240	418.6	558	1625.1	0	26.0	64	53	12000	No	Yes
School 10	454	40	2958	490.5	654	1480.5	71.4	40.0	60	51	47600	No	Yes
School 11	504	39	3808	458.7	611	1552.2	94.7	27.0	56	100	24600	No	Yes
School 12	411	26	3953	445.9	595	726.7	133.7	41.8	137	92	40600	No	Yes
School 13	407	30	3892	356.7	476	1668.2	105	46.2	80	156	10000	No	Yes
School 14	406	23	4443	569.0	759	829.7	129.2	14.0	101	111	14900	No	No
School 15	553	44	3078	451.1	601	1495.6	93.4	34.8	55	41	14900	No	Yes
School 16	369	29	2552	430.2	574	1415.3	0	24.0	65	192	21400	No	Yes
School 17	288	28	4657	269.7	360	1653.6	0	75.8	31	37	14900	No	No
School 18	447	30	5655	617.7	823	1054	170.1	50.4	100	107	30100	Yes	No
School 19	511	36	7165	667.9	841	1555.5	68.3	50.5	60	73	5900	No	No
School 20	605	46	3776	740.2	987	1569.2	159.8	36.0	121	381	52800	No	Yes
School 21	997	70	8592	655.5	874	983.2	309.5	35.0	356	218	27200	Yes	No
School 22	702	61	9191	918.1	1225	1368	189	59.3	175	67	28900	Yes	No
School 23	443	34	4354	445.9	595	1533.2	70.6	47.0	121	76	39700	Yes	Yes
School 24	430	36	1920	408.6	545	1230.5	53.8	38.0	34	49	13100	No	Yes
School 25	200	18	2281	445.9	595	523.4	88.5	42.0	60	37	48100	No	Yes
School 26	1065	78	13544	1193.5	1592	2094.2	527.5	49.0	382	49	34100	Yes	Yes
School 27	468	40	3065	446.2	595	1463.3	73	34.0	96	43	45000	No	Yes
School 28	941	66	3405	531.0	559	445.6	88	7.0	232	721	18000	No	Yes
School 29	619	51	3044	433.0	456	1272.1	0	7.0	67	44	18000	No	Yes
School 30	653	49	7264	781.0	820	1264.6	88	5.0	176	37	33100	No	Yes
School 31	332	37	3202	435.0	580	975	0	14.0	123	62	14100	No	Yes
School 32	457	48	5932	455.2	607	1084.4	60.9	62.2	79	12	18100	Yes	No
School 33	281	27	2625	374.6	500	1022.3	75.9	55.9	43	50	12100	No	No
School 34	470	38	2357	444.1	592	1937.9	73.5	34.0	65	35	26000	No	Yes
School 35	170	18	2610	385.5	514	667.4	68.6	55.9	55	21	19200	No	No
School 36	354	24	3772	445.9	595	958.74	0	49.0	120	23	34900	No	Yes
School 37	875	58	3405	530.8	559	601.8	136	7.0	169	278	18200	No	Yes
School 38	454	39	7426	668.9	924	2199.4	77.3	54.1	105	85	14700	No	No
School 39	452	39	4849	421.5	562	1709.5	64.4	56.9	75	34	22300	No	Yes

School 40	170	20	2223	445.9	595	475.9	75.1	42.0	59	7	28100	No	Yes
School 41	279	28	2222	375.3	498	954	98.4	42.2	54	2	5600	No	Yes
School 42	332	37	7833	702.3	936	2225.1	153.7	56.1	98	53	23000	Yes	No
School 43	496	47	2690	408.8	545	1651	97.6	38.9	51	112	49000	No	Yes
School 44	207	26	1991	418.0	557	746	0	59.0	38	76	27300	No	Yes
School 45	345	33	2687	406.8	542	932.9	0	36.9	64	4	26300	No	Yes
School 46	264	25	2565	234.1	312	953.1	84.6	48.9	57	31	30000	Yes	Yes
School 47	484	41	4577	445.9	595	1427.8	66.4	55.3	112	240	20600	Yes	Yes
School 48	467	40	7392	671.9	896	1435	256	50.4	187	19	6100	No	No
School 49	348	27	1744	392.7	525	1266.4	141	35.0	29	1	28300	No	Yes
School 50	825	56	3662	445.9	595	2171	276.3	38.2	123	341	48600	No	Yes
School 51	604	70	3363	356.7	476	1866.6	0	47.3	64	253	39800	No	Yes
School 52	763	62	8103	696.1	929	1239.3	141.3	54.1	131	164	23400	No	No
School 53	377	40	2223	445.9	595	1211.6	0	42.0	56	135	28300	No	Yes
School 54	625	52	4376	665.1	887	2102.2	70	35.7	105	79	40300	No	Yes
School 55	314	40	6783	748.3	998	1494.4	40	34.6	99	35	25300	Yes	No
School 56	1045	85	10646	667.4	890	2431.2	512	42.9	381	30	63800	Yes	Yes
School 57	168	23	5938	331.3	442	1144.3	0	54.3	51	36	25400	Yes	No
School 58	164	20	2535	413.7	552	562.4	84.7	60.3	51	7	14900	Yes	Yes
School 59	329	28	3783	676.1	902	378.6	101	40.4	30	105	76800	No	No
School 60	140	19	1845	223.0	297	542.8	26	47.0	24	34	24300	No	No
School 61	534	39	3235	422.8	581.9	1890.3	73.2	14.0	87	150	12200	No	Yes
School 62	1053	123	31090	1262.4	1419	771.8	1194	40.2	669	62	37400	Yes	No
School 63	307	38	1520	223.0	297	1140.9	0	41.9	51	66	23300	Yes	Yes
School 64	194	20	2610	324.8	433	655.5	203.3	59.8	68	69	14600	No	No
School 65	330	27	2322	392.7	524	1106.9	0	34.8	34	231	28700	No	Yes
School 66	356	36	2139	372.5	497	990.3	69.7	40.0	34	97	28300	No	Yes
School 67	151	17	4448	409.4	546	232	167	54.0	215	60	20200	No	No
School 68	276	30	2338	426.0	568	869.8	74	37.0	45	4	26500	No	Yes
School 69	239	27	3023	241.5	322	906.8	54.8	50.9	67	31	26100	No	No
School 70	340	28	3245	459.2	612	1568.6	0	27.0	78	95	15000	No	Yes
School 71	448	42	5917	606.0	808	1433.8	81.3	53.7	80	64	23700	Yes	No
School 72	224	22	1649	224.4	299	753.8	0	44.0	51	14	28300	No	Yes
School 73	260	23	3296	528.3	704	590.2	67.7	55.6	61	156	17400	No	No
School 74	256	25	3030	416.2	555	886.3	176	59.7	27	4	17200	Yes	No
School 75	265	24	2508	446.5	595	1204.2	92.9	52.3	63	44	40600	No	Yes
School 76	380	39	4638	445.9	595	1529	81.3	57.5	33	58	17100	No	No
School 77	280	26	1860	390.3	520	674.2	69	37.0	44	17	48600	No	Yes
School 78	435	22	4603	448.1	597	888.7	74.3	53.3	182	116	11300	Yes	No
School 79	253	27	2698	221.1	295	1173	80.8	49.7	71	98	21400	No	Yes
School 80	451	41	2987	391.6	522	1611.5	79	31.2	71	88	48500	No	Yes
School 81	537	46	5336	449.7	600	980.4	208.9	49.0	161	56	25600	No	No
School 82	262	31	2110	445.1	593	1081.8	83	26.8	26	95	6700	No	Yes
School 83	194	19	3728	449.0	600	890.7	126.8	56.5	29	53	13900	No	No
School 84	257	27	3023	241.5	322	869.7	54.8	50.9	63	49	22400	No	No

Appendix C: The report of the first-time run of the regression analysis

Method

Categorical predictor coding	(1, 0)

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	13	7663.6	589.51	6.61	0.000
Student	1	44.1	44.14	0.49	0.484
Staff	1	2.4	2.44	0.03	0.869
Core area	1	1.9	1.85	0.02	0.886
Total gym area	1	198.8	198.83	2.23	0.140
Total gym capacity	1	167.5	167.50	1.88	0.175
Classroom area	1	526.2	526.19	5.90	0.018
Computer room area	1	61.5	61.50	0.69	0.409
Building age	1	2069.5	2069.47	23.19	0.000
Number of wired computers	1	330.4	330.44	3.70	0.058
Number of wireless computers	1	4.5	4.49	0.05	0.823
Site Area	1	345.3	345.33	3.87	0.053
Portables existence	1	6.3	6.28	0.07	0.792
Elevator existence	1	16.8	16.77	0.19	0.666
Error	70	6245.5	89.22		
Total	83	13909.1			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
9.44570	55.10%	46.76%	36.53%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	80.27	7.49	10.71	0.000	
Student	0.0110	0.0157	0.70	0.484	15.65
Staff	0.032	0.192	0.17	0.869	12.83

Core area	0.00016	0.00109	0.14	0.886	16.81
Total gym area	−0.0734	0.0492	−1.49	0.140	91.11
Total gym capacity	0.0468	0.0341	1.37	0.175	70.80
Classroom area	−0.00748	0.00308	−2.43	0.018	2.61
Computer room area	−0.0124	0.0150	−0.83	0.409	6.26
Building age	−0.510	0.106	−4.82	0.000	2.25
Number of wired computers	0.0580	0.0301	1.92	0.058	9.69
Number of wireless computers	0.0030	0.0133	0.22	0.823	1.75
Site Area	0.000160	0.000081	1.97	0.053	1.40
Portables existence					
Yes	0.78	2.92	0.27	0.792	1.90
Elevator existence					
Yes	1.30	2.99	0.43	0.666	1.68

Regression Equation

Average EUI = 80.27 + 0.0110 Student + 0.032 Staff + 0.00016 Core area
− 0.0734 Total gym area + 0.0468 Total gym capacity
− 0.00748 Classroom area
− 0.0124 Computer room area − 0.510 Building age
+ 0.0580 Number of wired computers
+ 0.0030 Number of wireless computers
+ 0.000160 Site Area + 0.0 Portables existence_No
+ 0.78 Portables existence_Yes + 0.0 Elevator existence_No
+ 1.30 Elevator existence_Yes

Fits and Diagnostics for Unusual Observations

Obs	Average EUI	Fit	Resid	Std Resid		
28	75.69	79.54	−3.85	−0.62		X
39	21.05	48.78	−27.73	−3.09	R	
53	80.17	59.62	20.55	2.26	R	
62	79.51	79.51	0.00	0.00		X
77	46.27	66.54	−20.27	−2.24	R	

R Large residual
X Unusual X

Durbin-Watson Statistic

Durbin-Watson Statistic = 2.12970

Appendix D: Report of regression after removing five inputs

Method

Categorical predictor coding (1, 0)

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	8	6890.1	861.27	9.20	0.000
Student	1	20.3	20.28	0.22	0.643
Total gym area	1	166.2	166.24	1.78	0.187
Building age	1	2592.9	2592.92	27.71	0.000
Number of wired computers	1	970.3	970.31	10.37	0.002
Number of wireless computers	1	16.4	16.37	0.17	0.677
Site Area	1	581.6	581.62	6.21	0.015
Portables existence	1	1.6	1.59	0.02	0.897
Elevator existence	1	46.5	46.49	0.50	0.483
Error	75	7019.0	93.59		
Total	83	13909.1			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
9.67400	49.54%	44.15%	33.40%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	75.29	6.15	12.24	0.000	
Student	−0.00408	0.00876	−0.47	0.643	4.65
Total gym area	−0.01204	0.00904	−1.33	0.187	2.93
Building age	−0.4696	0.0892	−5.26 0.000	1.52	
Number of wired computers	0.0584	0.0181	3.22	0.002	3.34
Number of wireless computers	0.0053	0.0127	0.42	0.677	1.51
Site Area	0.000201	0.000080	2.49	0.015	1.30
Portables existence					
Yes	−0.37	2.82	−0.13	0.897	1.68
Elevator existence					
Yes	2.09	2.96	0.70	0.483	1.57

Regression Equation

Average EUI = 75.29 − 0.00408 Student − 0.01204 Total gym area − 0.4696 Building age
+ 0.0584 Number of wired computers
+ 0.0053 Number of wireless computers
+ 0.000201 Site Area + 0.0 Portables existence_No
− 0.37 Portables existence_Yes + 0.0 Elevator existence_No
+ 2.09 Elevator existence_Yes

Fits and Diagnostics for Unusual Observations

Obs	Average EUI	Fit	Resid	Std Resid		
5	75.91	64.91	11.00	1.47		X
21	96.49	76.39	20.10	2.27	R	
28	75.69	82.40	−6.71	−0.99		X
39	21.05	50.31	−29.25	−3.14	R	
53	80.17	57.96	22.21	2.33	R	
59	82.69	64.55	18.14	2.29	R	X
62	79.51	85.92	−6.41	−0.91		X

R Large residual
X Unusual X

Durbin-Watson Statistic

Durbin-Watson Statistic = 2.01645

Appendix E: The report of regression after the stepwise regression

Method

Categorical predictor coding (1, 0)

Stepwise Selection of Terms

α to enter = 0.15, α to remove = 0.15

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	4	6817.3	1704.33	18.99	0.000
Total gym area	1	255.1	255.10	2.84	0.096
Building age	1	3495.2	3495.20	38.94	0.000
Number of wired computers	1	1465.2	1465.18	16.32	0.000
Site Area	1	595.7	595.73	6.64	0.012
Error	79	7091.8	89.77		
Total	83	13909.1			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
9.47469	49.01%	46.43%	41.16%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	74.01	4.64	15.97	0.000	
Total gym area	−0.01284	0.00762	−1.69	0.096	2.17
Building age	−0.4434	0.0711	−6.24	0.000	1.01
Number of wired computers	0.0581	0.0144	4.04	0.000	2.19
Site Area	0.000186	0.000072	2.58	0.012	1.09

Regression Equation

Average EUI = 74.01 − 0.01284 Total gym area − 0.4434 Building age
+ 0.0581 Number of wired computers + 0.000186 Site Area

Fits and Diagnostics for Unusual Observations

Obs	Average EUI	Fit	Resid	Std Resid	
5	75.91	66.62	9.29	1.10	X
21	96.49	75.79	20.70	2.30	R

39	21.05	51.85	−30.80	−3.29	R	
53	80.17	58.16	22.01	2.34	R	
59	82.69	63.41	19.28	2.30	R	X
60	74.91	56.21	18.70	2.01	R	
62	79.51	85.78	−6.27	−0.82		X

R Large residual
X Unusual X

Durbin-Watson Statistic

Durbin-Watson Statistic =   1.98628

Appendix F: Residuals from simple descriptive statistics and multiple linear regression

Site description	Residuals from Simple descriptive kWh/m^2	Residuals from Simple descriptive kWh/student	Residuals from regression kWh/m^2
School 1	−0.91	−91.55	2.68
School 2	6.47	−25.04	2.16
School 3	6.80	105.44	−11.41
School 4	14.03	85.65	−1.86
School 5	15.40	70.52	9.25
School 6	22.52	374.15	8.15
School 7	8.86	129.91	−0.59
School 8	−9.37	−59.58	−1.28
School 9	9.30	59.39	6.75
School 10	0.76	−97.68	−1.04
School 11	4.03	−44.55	0.56
School 12	1.30	0.09	−3.44
School 13	−2.90	−7.23	2.16
School 14	20.82	269.76	12.19
School 15	1.32	−163.06	3.06
School 16	12.47	49.62	7.38
School 17	−16.07	98.41	2.92
School 18	−17.36	−74.36	−11.98
School 19	−20.89	−64.75	−8.01
School 20	−3.43	−127.38	−8.31
School 21	35.98	211.25	20.67
School 22	8.55	283.88	17.58
School 23	0.01	47.27	−1.34
School 24	2.07	−185.95	6.26
School 25	5.64	239.67	4.05
School 26	12.35	318.15	7.37
School 27	−4.41	−160.70	−11.06
School 28	15.18	−197.48	−5.22
School 29	14.38	−11.31	2.31
School 30	13.81	252.35	−3.83
School 31	4.59	119.42	−6.88
School 32	−22.30	−124.24	−10.31
School 33	−10.10	−149.36	1.25
School 34	2.43	−109.54	1.09
School 35	−21.08	−14.91	−11.63
School 36	2.06	92.03	2.55
School 37	6.63	−189.64	−10.15
School 38	−4.98	288.08	5.27
School 39	−39.46	−386.40	−30.81
School 40	5.08	382.85	7.27
School 41	5.95	59.03	11.79
School 42	−17.56	393.18	−7.14
School 43	6.58	−120.21	3.48
School 44	−15.20	−120.54	−4.48
School 45	−1.75	−74.90	−2.26
School 46	0.12	−3.88	2.43
School 47	3.49	−3.71	9.88
School 48	−5.76	246.32	−0.28
School 49	−3.14	−152.86	−3.02
School 50	4.75	−207.02	−2.29
School 51	−7.53	−248.02	−6.61
School 52	−9.74	-81.13	−2.27
School 53	19.66	42.59	21.99
School 54	−11.11	−136.73	−13.85
School 55	−1.86	646.63	−0.87
School 56	11.42	136.13	−8.48
School 57	−16.20	946.06	−9.03
School 58	−15.83	93.76	−3.00
School 59	22.18	330.57	19.25
School 60	14.40	366.99	18.69
School 61	−7.56	−200.49	−16.74
School 62	19.00	1,727.36	−6.31
School 63	16.52	0.00	17.16
School 64	−17.07	−35.83	−6.57
School 65	5.00	−20.97	4.65

School 66	1.17	−83.49	2.95
School 67	5.21	1,315.70	4.66
School 68	−3.04	−26.23	−2.21
School 69	1.69	166.51	5.10
School 70	15.72	222.74	12.77
School 71	−10.49	40.32	−1.45
School 72	12.17	46.54	12.84
School 73	−7.04	57.63	4.11
School 74	−18.39	−121.69	−4.85
School 75	−2.99	35.86	1.20
School 76	−21.74	−147.05	−9.11
School 77	−14.24	−237.54	−17.92
School 78	−6.27	−46.30	−3.05
School 79	6.34	175.34	9.61
School 80	7.44	11.48	−0.32
School 81	−7.80	−96.47	−7.91
School 82	−11.74	−87.29	−10.39
School 83	−19.42	169.33	−6.37
School 84	−5.32	28.93	−0.99

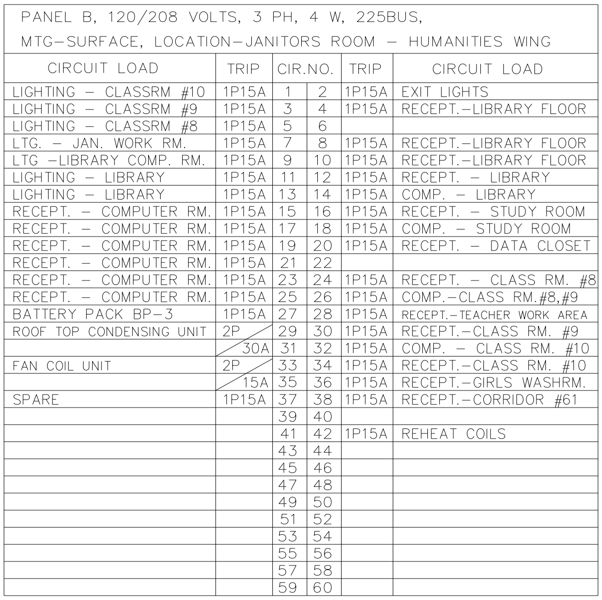
Appendix G: Decision matrix to rank sensors from four companies

Standard	Weight (/10)	Weighting Justification	CircuitMeter Inc		Eyedro Green Solutions		OpenEnergy Monitor		eGauge System LLC		Ranking Justification
			Ranking (/5)	Score	Ranking (/5)	Score	Ranking (/5)	Score	Ranking (/5)	Score	
Cost	8	Cost is important giving the budget of the project	3	24	2	16	5	40	4	32	Total cost per panel from highest to lowest: Eyedro Green Solutions (3.3K) > CircuitMeter (2.9 K) > eGauge Systems (1.4 K)> OpenEnergyMonitor (1.2K)
Availability	5	Availability includes the location of the vendor, the lead time and shipping time, it is relatively important	5	25	5	25	1	5	3	15	OpenEnergyMonitor is the located in England, which is the furtherest. eGuage is located in USA. The closest are CircuitMeter and OpenEnergyMonitor, located in Ontario
Accuracy	10	Accuracy depends on the interval of recording. The less the interval, the more data can be required.	4	40	1	10	3	30	5	50	Recording interval highest to lowest: Eyedro Green Solutions (1 hr) > OpenEnergyMonitor (5 s) > CircuitMeter (2 s) > eGauge Systems (1 s)
Data Visualization	5	If the company provides free user interface based on web and app, the data visulization will be easier, time will be saved for data analysis	4	20	4	20	5	25	5	25	eGuage and OpenEnergyMonitor all have free web user-interface, making data visualization easier, the other two companies have online cloud service, which is not as convenient as eGauge and OpenEnergyMonitor
Simplicity of Installation	5	Simplicity of the system can redue the time of installation, also can reduce labour	3	15	4	20	3	15	3	15	CircuitMeter Inc. have Edmonton's branch, can help with installation but the installion fee is quite high. Eyedro Green Solutions Inc. sell models in a bundle, which makes installation easier than others.
TOTAL SCORES:			124		91		115		137		

Appendix H: Circuits information regarding 11 electrical panels in School 14

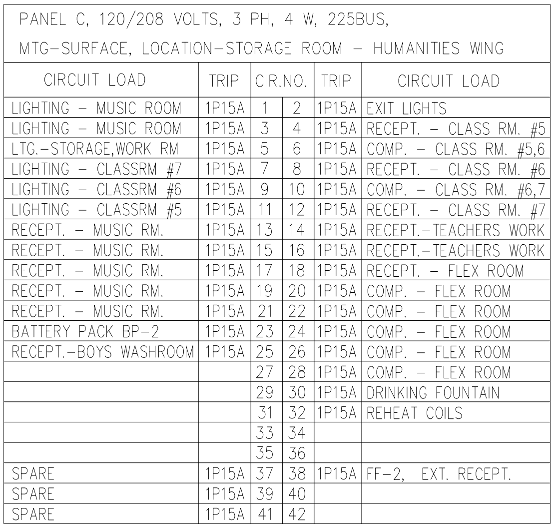
PANEL A, 120/208 VOLTS, 3 PH, 4 W, 225BUS,
MTG-SURFACE, LOCATION-AHU MEZZANINE

CIRCUIT LOAD	TRIP	CIR.NO.		TRIP	CIRCUIT LOAD
LIGHTING – GYM	1P15A	1	2	1P15A	EXIT LIGHTS – GYM
LIGHTING – GYM	1P15A	3	4	1P15A	RECEPTACLES – GYM
LIGHTING – GYM	1P15A	5	6	1P15A	RECEPTACLES – GYM
LIGHTING – GYM	1P15A	7	8	1P15A	RECEPT. GYM/CELEBRATION
LIGHTING – GYM	1P15A	9	10	1P15A	GYM SOUND SYSTEM
LIGHTING – GYM	1P15A	11	12	1P15A	MOTORIZED BACKBOARD (EAST)
LIGHTING-ELEC/MECH RM	1P15A	13	14	1P15A	MOTORIZED BACKBOARD (WEST)
LTG.-BOYS CHG. RM., STORAGE	1P15A	15	16	1P15A	MOTORIZED GYM CURTAIN
FC-6, LTG. EXT. STORAGE	1P15A	17	18	1P15A	
FC-5	1P15A	19	20	1P15A	EF-2, EXH. FAN
TRACK LIGHTING	1P15A	21	22	1P20A	EF-1, EXH. FAN
FC-4	1P15A	23	24	1P15A	UH-5, UNIT HEATER
SPARE	1P15A	25	26	1P15A	CONTROL PANEL
SPARE	1P15A	27	28	1P15A	RECEPT. BY CONTROL PNL
SPARE	1P15A	29	30	1P15A	BATTERY PACK BP-1
		31	32		
		33	34		
		35	36		
		37	38		
		39	40		
		41	42		
		43	44		
		45	46		
		47	48		
		49	50		
		51	52		
		53	54		
		55	56		
		57	58		
		59	60		



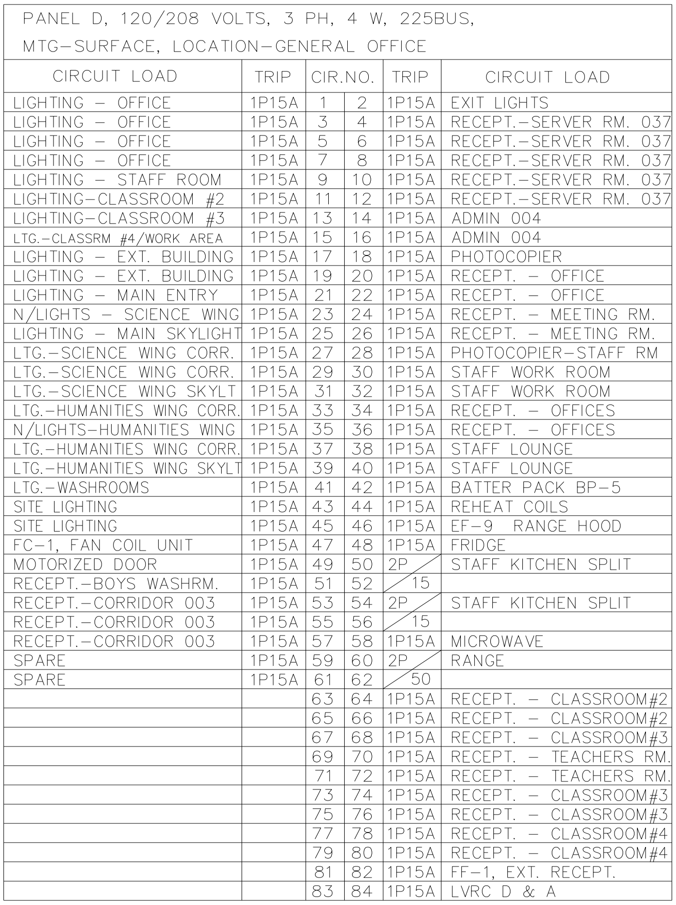
PANEL B, 120/208 VOLTS, 3 PH, 4 W, 225BUS,
MTG-SURFACE, LOCATION-JANITORS ROOM – HUMANITIES WING

CIRCUIT LOAD	TRIP	CIR.NO.		TRIP	CIRCUIT LOAD
LIGHTING – CLASSRM #10	1P15A	1	2	1P15A	EXIT LIGHTS
LIGHTING – CLASSRM #9	1P15A	3	4	1P15A	RECEPT.-LIBRARY FLOOR
LIGHTING – CLASSRM #8	1P15A	5	6		
LTG. – JAN. WORK RM.	1P15A	7	8	1P15A	RECEPT.-LIBRARY FLOOR
LTG -LIBRARY COMP. RM.	1P15A	9	10	1P15A	RECEPT.-LIBRARY FLOOR
LIGHTING – LIBRARY	1P15A	11	12	1P15A	RECEPT. – LIBRARY
LIGHTING – LIBRARY	1P15A	13	14	1P15A	COMP. – LIBRARY
RECEPT. – COMPUTER RM.	1P15A	15	16	1P15A	RECEPT. – STUDY ROOM
RECEPT. – COMPUTER RM.	1P15A	17	18	1P15A	COMP. – STUDY ROOM
RECEPT. – COMPUTER RM.	1P15A	19	20	1P15A	RECEPT. – DATA CLOSET
RECEPT. – COMPUTER RM.	1P15A	21	22		
RECEPT. – COMPUTER RM.	1P15A	23	24	1P15A	RECEPT. – CLASS RM. #8
RECEPT. – COMPUTER RM.	1P15A	25	26	1P15A	COMP.-CLASS RM.#8,#9
BATTERY PACK BP-3	1P15A	27	28	1P15A	RECEPT.-TEACHER WORK AREA
ROOF TOP CONDENSING UNIT	2P	29	30	1P15A	RECEPT.-CLASS RM. #9
	30A	31	32	1P15A	COMP. – CLASS RM. #10
FAN COIL UNIT	2P	33	34	1P15A	RECEPT.-CLASS RM. #10
	15A	35	36	1P15A	RECEPT.-GIRLS WASHRM.
SPARE	1P15A	37	38	1P15A	RECEPT.-CORRIDOR #61
		39	40		
		41	42	1P15A	REHEAT COILS
		43	44		
		45	46		
		47	48		
		49	50		
		51	52		
		53	54		
		55	56		
		57	58		
		59	60		



PANEL C, 120/208 VOLTS, 3 PH, 4 W, 225BUS,
MTG-SURFACE, LOCATION-STORAGE ROOM – HUMANITIES WING

CIRCUIT LOAD	TRIP	CIR.NO.		TRIP	CIRCUIT LOAD
LIGHTING – MUSIC ROOM	1P15A	1	2	1P15A	EXIT LIGHTS
LIGHTING – MUSIC ROOM	1P15A	3	4	1P15A	RECEPT. – CLASS RM. #5
LTG.-STORAGE,WORK RM	1P15A	5	6	1P15A	COMP. – CLASS RM. #5,6
LIGHTING – CLASSRM #7	1P15A	7	8	1P15A	RECEPT. – CLASS RM. #6
LIGHTING – CLASSRM #6	1P15A	9	10	1P15A	COMP. – CLASS RM. #6,7
LIGHTING – CLASSRM #5	1P15A	11	12	1P15A	RECEPT. – CLASS RM. #7
RECEPT. – MUSIC RM.	1P15A	13	14	1P15A	RECEPT.-TEACHERS WORK
RECEPT. – MUSIC RM.	1P15A	15	16	1P15A	RECEPT.-TEACHERS WORK
RECEPT. – MUSIC RM.	1P15A	17	18	1P15A	RECEPT. – FLEX ROOM
RECEPT. – MUSIC RM.	1P15A	19	20	1P15A	COMP. – FLEX ROOM
RECEPT. – MUSIC RM.	1P15A	21	22	1P15A	COMP. – FLEX ROOM
BATTERY PACK BP-2	1P15A	23	24	1P15A	COMP. – FLEX ROOM
RECEPT.-BOYS WASHROOM	1P15A	25	26	1P15A	COMP. – FLEX ROOM
		27	28	1P15A	COMP. – FLEX ROOM
		29	30	1P15A	DRINKING FOUNTAIN
		31	32	1P15A	REHEAT COILS
		33	34		
		35	36		
SPARE	1P15A	37	38	1P15A	FF-2, EXT. RECEPT.
SPARE	1P15A	39	40		
SPARE	1P15A	41	42		



PANEL D, 120/208 VOLTS, 3 PH, 4 W, 225BUS,
MTG-SURFACE, LOCATION-GENERAL OFFICE

CIRCUIT LOAD	TRIP	CIR.NO.		TRIP	CIRCUIT LOAD
LIGHTING – OFFICE	1P15A	1	2	1P15A	EXIT LIGHTS
LIGHTING – OFFICE	1P15A	3	4	1P15A	RECEPT.-SERVER RM. 037
LIGHTING – OFFICE	1P15A	5	6	1P15A	RECEPT.-SERVER RM. 037
LIGHTING – OFFICE	1P15A	7	8	1P15A	RECEPT.-SERVER RM. 037
LIGHTING – STAFF ROOM	1P15A	9	10	1P15A	RECEPT.-SERVER RM. 037
LIGHTING-CLASSROOM #2	1P15A	11	12	1P15A	RECEPT.-SERVER RM. 037
LIGHTING-CLASSROOM #3	1P15A	13	14	1P15A	ADMIN 004
LTG.-CLASSRM #4/WORK AREA	1P15A	15	16	1P15A	ADMIN 004
LIGHTING – EXT. BUILDING	1P15A	17	18	1P15A	PHOTOCOPIER
LIGHTING – EXT. BUILDING	1P15A	19	20	1P15A	RECEPT. – OFFICE
LIGHTING – MAIN ENTRY	1P15A	21	22	1P15A	RECEPT. – OFFICE
N/LIGHTS – SCIENCE WING	1P15A	23	24	1P15A	RECEPT. – MEETING RM.
LIGHTING – MAIN SKYLIGHT	1P15A	25	26	1P15A	RECEPT. – MEETING RM.
LTG.-SCIENCE WING CORR.	1P15A	27	28	1P15A	PHOTOCOPIER-STAFF RM
LTG.-SCIENCE WING CORR.	1P15A	29	30	1P15A	STAFF WORK ROOM
LTG.-SCIENCE WING SKYLT	1P15A	31	32	1P15A	STAFF WORK ROOM
LTG.-HUMANITIES WING CORR.	1P15A	33	34	1P15A	RECEPT. – OFFICES
N/LIGHTS-HUMANITIES WING	1P15A	35	36	1P15A	RECEPT. – OFFICES
LTG.-HUMANITIES WING CORR.	1P15A	37	38	1P15A	STAFF LOUNGE
LTG.-HUMANITIES WING SKYLT	1P15A	39	40	1P15A	STAFF LOUNGE
LTG.-WASHROOMS	1P15A	41	42	1P15A	BATTER PACK BP-5
SITE LIGHTING	1P15A	43	44	1P15A	REHEAT COILS
SITE LIGHTING	1P15A	45	46	1P15A	EF-9 RANGE HOOD
FC-1, FAN COIL UNIT	1P15A	47	48	1P15A	FRIDGE
MOTORIZED DOOR	1P15A	49	50	2P	STAFF KITCHEN SPLIT
RECEPT.-BOYS WASHRM.	1P15A	51	52	15	
RECEPT.-CORRIDOR 003	1P15A	53	54	2P	STAFF KITCHEN SPLIT
RECEPT.-CORRIDOR 003	1P15A	55	56	15	
RECEPT.-CORRIDOR 003	1P15A	57	58	1P15A	MICROWAVE
SPARE	1P15A	59	60	2P	RANGE
SPARE	1P15A	61	62	50	
		63	64	1P15A	RECEPT. – CLASSROOM#2
		65	66	1P15A	RECEPT. – CLASSROOM#2
		67	68	1P15A	RECEPT. – CLASSROOM#3
		69	70	1P15A	RECEPT. – TEACHERS RM.
		71	72	1P15A	RECEPT. – TEACHERS RM.
		73	74	1P15A	RECEPT. – CLASSROOM#3
		75	76	1P15A	RECEPT. – CLASSROOM#3
		77	78	1P15A	RECEPT. – CLASSROOM#4
		79	80	1P15A	RECEPT. – CLASSROOM#4
		81	82	1P15A	FF-1, EXT. RECEPT.
		83	84	1P15A	LVRC D & A

PANEL E, 120/208 VOLTS, 3 PH, 4 W, 225BUS,
MTG–SURFACE, LOCATION–STORAGE ROO (HOME EC. CONTACTOR)

CIRCUIT LOAD	TRIP	CIR.NO.		TRIP	CIRCUIT LOAD
COUNTER RECEPT. CULIN.	2P	1	2	2P	RANGE
	15A	3	4	40A	
COUNTER RECEPT. CULIN.	2P	5	6	2P	RANGE
	15A	7	8	40A	
COUNTER RECEPT. CULIN.	2P	9	10	2P	RANGE
	15A	11	12	40A	
COUNTER RECEPT. CULIN.	2P	13	14	2P	RANGE
	15A	15	16	40A	
S.E. DISHWASHER	1P15A	17	18	1P15A	N.E. DISHWASHER
COUNTER RECEPT. CULIN.	2P	19	20	1P15A	LIGHTS ON RANGE HOODS
	15A	21	22	1P15A	FANS ON RANGE HOODS
COUNTER RECEPT. CULIN.	2P	23	24		
	15A	25	26		
COUNTER RECEPT. CULIN.	2P	27	28		
	15A	29	30		
COUNTER RECEPT. CULIN.	2P	31	32		
	15A	33	34		
COUNTER RECEPT. CULIN.	2P	35	36		
	15A	37	38		
COUNTER RECEPT. CULIN.	2P	39	40		
	15A	41	42		

PANEL F, 120/208 VOLTS, 3 PH, 4 W, 225BUS,
MTG–SURFACE, LOCATION–BOILER ROOM

CIRCUIT LOAD	TRIP	CIR.NO.		TRIP	CIRCUIT LOAD
LIGHTING – GYM STORAGE	1P15A	1	2	1P15A	RECEPT. – GYM
RECEPT. – MECH MEZZ	1P15A	3	4	1P15A	RECEPT. – GYM
UH–4, UNIT HEATER	1P20A	5	6	1P15A	RECEPT. – GYM
DHW–1, DOM. WATER HTR	1P15A	7	8	1P20A	SCOREBOARD
DHW–2, DOM. WATER HTR	1P15A	9	10	1P15A	SPARE
P–8 HTR WTR RECIRC. PUMP	1P15A	11	12	1P15A	FC–3, FAN COIL UNIT
EF–3, EXHAUST FAN	1P15A	13	14	1P15A	FC–2, FAN COIL UNIT
MUA–3 RECEPT. & LIGHTS	1P15A	15	16	1P15A	RECEPT.–GYM STORAGE
BATTERY PACK BP–1	1P15A	17	18	1P15A	SPARE
B1, BOILER	1P15A	19	20	1P15A	RECEPT.–GYM SE
B2, BOILER	1P15A	21	22	1P15A	RECEPT.–GYM STORAGE
GYM UNIT HEATERS	1P15A	23	24		
RECEPT.–HEATING CONTROLS	1P15A	25	26		
LIGHTING – MECH ROOM	1P15A	27	28		
		29	30		
		31	32		
		33	34		
		35	36		
		37	38		
		39	40		
		41	42		

PANEL G, 120/208 VOLTS, 3 PH, 4 W, 225BUS,
MTG–SURFACE, LOCATION–HOME EC. (NO CONTACTOR)

CIRCUIT LOAD	TRIP	CIR.NO.		TRIP	CIRCUIT LOAD
LTG. – HOME EC KITCHEN	1P15A	1	2	1P15A	EXIT LIGHTS
LTG. – HOME EC FASHION	1P15A	3	4	1P15A	RECEPT. – FASHION 043
LTG. – HOME EC FASHION	1P15A	5	6	1P15A	RECEPT. – FASHION 043
LTG.–GRAPHICS TEACHING	1P15A	7	8	1P15A	RECEPT. – FASHION 043
LTG. – FABRICATION	1P15A	9	10	1P15A	RECEPT. – FASHION 043
COMPUTOR GRAPHIC 042	1P15A	11	12	1P15A	RECEPT. – FASHION 043
COMPUTOR GRAPHIC 042	1P15A	13	14	1P15A	RECEPT. – FASHION 043
RECEPT.–SCIENCE RM#1,#2	1P15A	15	16	1P15A	RECEPT. – FASHION 043
RECEPT.–SCIENCE RM#1,#2	1P15A	17	18	1P15A	RECEPT–ART ROOM 034
RECEPT.–SCIENCE RM#1,#2	1P15A	19	20	1P15A	RECEPT–ART ROOM 034
		21	22	1P15A	ART 034/TEACHER WK 029
RECEPT. FLEX ROOM	1P15A	23	24	1P15A	ART 034/TEACHER WK 029
RECEPT. FLEX ROOM	1P15A	25	26	1P15A	ART 034/TEACHER WK 029
		27	28	1P15A	STUDENT WORK RM. 030
RECEPT. FLEX ROOM	1P15A	29	30		
RECEPT. FLEX ROOM	1P15A	31	32		
RECEPT. FLEX ROOM	1P15A	33	34	1P15A	EF–4, EXH. FAN
RECEPT. FLEX ROOM	1P15A	35	36		
REHEAT COIL	1P15A	37	38		
DRINKING FOUNTAIN	1P15A	39	40		
		41	42		
		43	44	1P15A	MICROWAVE–CULINARY
		45	46	1P15A	MICROWAVE–CULINARY
		47	48	1P15A	MICROWAVE–CULINARY
STORES COOLER	1P20A	49	50	1P15A	MICROWAVE–CULINARY
STORES FREEZER	1P20A	51	52	1P15A	DISHWASHER–CULINARY
STORES RECEPTACLE	2P	53	54	1P15A	BATTERY PACK BP–4
	15A	55	56	1P20A	RECEPTACLE–CORR. 003
STORES RECEPTACLE	2P	57	58	1P15A	DRINK FOUNT.–CORR. 003
	15A	59	60	1P15A	SHOWCASE LIGHTS
STORES RECEPTACLE	2P	61	62	1P15A	LIGHTING–SCIENCE RM #1
	15A	63	64	1P15A	LIGHTING–SCIENCE RM #2
STORES RECEPTACLE	2P	65	66	1P15A	LTG.–SCIENCE PREP/STUDY RM.
	15A	67	68	1P15A	RECEPT.–TEACHING AREA
WASHER	1P15A	69	70	1P15A	RECEPT.–TEACHING AREA STORAGE WASHROOM
DRYER	2P	71	72	1P15A	LIGHTING–ART ROOM
	30A	73	74	2P	A/C–SERVER ROOM–RTU
SCIENCE PREP FRIDGE	1P15A	75	76	30A	
SCIENCE PREP COUNTER	1P15A	77	78	2P	A/C–SERVER RM–FAN COIL
SCIENCE PREP COUNTER	1P15A	79	80	15A	
		81	82	1P15A	SPARE
		83	84		

PANEL H, 120/208 VOLTS, 3 PH, 4 W, 225BUS,
MTG–SURFACE, LOCATION–FABRICATION AREA (CONTACTOR)

CIRCUIT LOAD	TRIP	CIR.NO.		TRIP	CIRCUIT LOAD
FABRICATION 040	1P15A	1	2	1P15A	FABRICATION 040
FABRICATION 040	1P15A	3	4	1P15A	FABRICATION 040
FABRICATION 040	1P20A	5	6	1P15A	FABRICATION 040
FABRICATION 040	1P20A	7	8	1P15A	FABRICATION 040
FABRICATION 040	1P15A	9	10	1P20A	FABRICATION 040
FABRICATION 040	1P15A	11	12	1P20A	FABRICATION 040
		13	14	1P20A	TABLE SAW
		15	16		
		17	18		
		19	20		
		21	22		
		23	24		

PANEL J, 120/208 VOLTS, 3 PH, 4 W, 225BUS,
MTG–SURFACE, LOCATION–SCIENCE ROOM

CIRCUIT LOAD	TRIP	CIR.NO.		TRIP	CIRCUIT LOAD
COUNTER RECEPT –	2P	1	2	2P	COUNTER RECEPT –
SCIENCE ROOM #1	15A	3	4	15A	SCIENCE ROOM #2
COUNTER RECEPT –	2P	5	6	2P	COUNTER RECEPT –
SCIENCE ROOM #1	15A	7	8	15A	SCIENCE ROOM #2
COUNTER RECEPT –	2P	9	10	2P	COUNTER RECEPT –
SCIENCE ROOM #1	15A	11	12	15A	SCIENCE ROOM #2
COUNTER RECEPT –	2P	13	14	2P	COUNTER RECEPT –
SCIENCE ROOM #1	15A	15	16	15A	SCIENCE ROOM #2
COUNTER RECEPT –	2P	17	18	2P	COUNTER RECEPT –
SCIENCE ROOM #1	15A	19	20	15A	SCIENCE ROOM #2
COUNTER RECEPT –	2P	21	22	2P	COUNTER RECEPT –
SCIENCE ROOM #1	15A	23	24	15A	SCIENCE ROOM #2
COUNTER RECEPT –	2P	25	26		
SCIENCE ROOM #1	15A	27	28		
		29	30		
		31	32		
		33	34		
		35	36		
		37	38		
		39	40		
		41	42		

PANEL CPA, 120/208 VOLTS, 3 PH, 4 W, 225BUS,
MTG-SURFACE, LOCATION-PARKING LOT

CIRCUIT LOAD	TRIP	CIR.NO.		TRIP	CIRCUIT LOAD
NE. SPLIT RECEPT.-CAR	2P	1	2	2P	NW. SPLIT RECEPT.-CAR
	15A	3	4	15A	
NE. SPLIT RECEPT.-CAR	2P	5	6	2P	NW. SPLIT RECEPT.-CAR
	15A	7	8	15A	
NE. SPLIT RECEPT.-CAR	2P	9	10	2P	NE. SPLIT RECEPT.-CAR
	15A	11	12	15A	
NE. SPLIT RECEPT.-CAR	2P	13	14	2P	SPLIT RECEPT.-CAR
	15A	15	16	15A	
NE. SPLIT RECEPT.-CAR	2P	17	18		
	15A	19	20		
NE. SPLIT RECEPT.-CAR	2P	21	22		
	15A	23	24		

PANEL CPB, 120/208 VOLTS, 3 PH, 4 W, 225BUS,
MTG-SURFACE, LOCATION-PARKING LOT

CIRCUIT LOAD	TRIP	CIR.NO.		TRIP	CIRCUIT LOAD
SW. SPLIT RECEPT.-CAR	2P	1	2	2P	SE. SPLIT RECEPT.-CAR
	15A	3	4	15A	
SW. SPLIT RECEPT.-CAR	2P	5	6	2P	SE. SPLIT RECEPT.-CAR
	15A	7	8	15A	
SW. SPLIT RECEPT.-CAR	2P	9	10	2P	SE. SPLIT RECEPT.-CAR
	15A	11	12	15A	
SW. SPLIT RECEPT.-CAR	2P	13	14	2P	SE. SPLIT RECEPT.-CAR
	15A	15	16	15A	
SW. SPLIT RECEPT.-CAR	2P	17	18	2P	SE. SPLIT RECEPT.-CAR
	15A	19	20	15A	
SE RECEPT.-CAR	1P15A	21	22	2P	SE. SPLIT RECEPT.-CAR
		23	24	15A	

Appendix I: Site visit survey

LIGHTING SURVEY				
Major Lighting Type In the Room	☐ Incandescent	☐ CFL	☐ LED	☐ Others, please specify______
If Flourescent Tube Lightning is Used				
Type of Tubes	☐ T12	☐ T8	☐ T5	☐ Others, please specify______
Type of Ballasts	☐ Magnetic	☐ Electronic	☐ Others, please specify______	
Sensors and Swithches				
Light Dimmer Switches	☐ Installed	☐ Installed, Not Functional	☐ Not Installed	☐ Others, please specify______
Occupancy Sensor	☐ Installed	☐ Installed, Not Functional	☐ Not Installed	☐ Others, please specify______
Photocells for outdoor lighting (Adjust Response to Natural Llight Levels)	☐ Installed	☐ Installed, Not Functional	☐ Not Installed	☐ Others, please specify______
Timer Lights on from ___a.m. to ___p.m.	☐ Installed	☐ Installed, Not Functional	☐ Not Installed	☐ Others, please specify______
Snap switches to turn on/off light individually or as a group	☐ Individually	☐ As a group	☐ Others, please specify______	
Light Level				
Lights Clean or Not	☐ Clean	☐ Dirty	☐ Others, please specify______	
Does Light equip with reflectors or diffusers	☐ Yes	☐ No	☐ Others, please specify______	
Is daylighting fully used	☐ Yes	☐ No	☐ Others, please specify______	
Lighting User Habbit				
Room Occupied or Not when lights on	☐ Occupied	☐ Not Occupied	☐ Others, please specify______	
Are Blinds Open or Closed	☐ Open	☐ Closed	☐ Others, please specify______	
Exit Signs				
Lighting Type for Exit Signs	☐ Incandescent	☐ CFL	☐ LED	☐ Others, please specify______

HVAC & DOMESTIC HOT WATER SURVEY

Heating System

Major Heating System In School ☐ Hot water boiler ☐ Steam boiler ☐ Furnace

Major Energy Source Used for Heating ☐ Natural Gas ☐ Fuel Oil ☐ Electricity

How many hot water **boilers** used for the core area? ____________

How many **furnaces** for the portables?______________

Boilers start operating on _____till_______ (which month)

Furnances start operating on _____till _______(which month)

During heating season: Daytime room temperature setting _______°C Nighttime room temperature setting ______°C

Running hours of boilers per day:______ hours

When the outside temperature drop to____°C, boilers or furnances keep full time running

Cooling System

Major Cooling System In School ☐ Central Air Conditioner ☐ Room Air Conditioners ☐ Evaporative Coolers

Major Energy Source Used for Cooling ☐ Electricity ☐ Other Source

Cooling system starts operating on _____till_______ (which month)

During cooling season: Daytime room temperature setting_______°C Nighttime room temperature setting______°C

Pump for the boiler

How many pumps were used in the heating/cooling system?
Boilers' hot water circulation pumps:_____________
Coil circulation pump: ___________

Describe the type and power of pumps used on site:

Heating terminal units

How many cabinet convectors ? __________________
How many forced flow heaters ? __________________
How many hot water reheat coils ? _________________

Fans and Air handling Units

How many exhaust fans and AHU were used in the ventilation system?
Fans: _________
AHU: _________

Describe the type and power of the fans and AHU:

Heating Control

Heating/Cooling is controlled by: ☐ Pneumatic thermostat and valves control ☐ Electric control ☐ Set-point control by Sensors & Direct Digital Control (DDC)

Temperature of Hot Water in the heating system:

HVAC Renovation

When is the most recent renovation for the HVAC system? ________

Domestic hot water heaters

How many natural gas heaters ? ________________
How many pumps for the domestic hot water heater? ___________________

ELECTRICAL DEVICE SURVEY

Computer

What type of wired computers are used _____________ (Wattage, Energy Star Label, or Energy Guide Label)

What type of wireless computers are used _____________ (Wattage, Energy Star Label, or Energy Guide Label)

Computer operating duration per day: ____hours

Are sceen saver activated? ☐ Yes ☐ No

If yes, how long will screen saver be activated after use? ______________ s/min/hr

Are there automatic turning-off setting for computers? ☐ Yes ☐ No

If yes, when will the computers be turned-off automatically? ______________ am/pm

Vending Machine

How many vending machine are in use in school? _______________

How frequently are they used? ☐ Randomly ☐ Sometimes ☐ Often

What is the wattage of the most common of vending machines in school? ________________watt

Kitchen Appliances

How many lunch room are there in school? _______________

How many cafeteria are there in school? _______________

How many of the shared Kitchen appliances are there in school? Oven: ___________ Griller: ___________

Microwave: ___________ Refrigerator: _________ Kettle: ___________

Is there any other highly electricity-consuming appliances in the lunch room or cafeteria? ☐ Yes ☐ No

If yes, Describe them ____

Classroom Appliances

How many TVs in total are there in school? _______________

What is the wattage of the most common type of TVs in school? ________________watt

How long does it operate everyday? _______hours

How many projectors in total are there in school? _______________

What is the wattage of the most popular type of projectors in school? ________________watt

How long does it operate everyday? ______hours

Is there any other highly electricity-consuming appliances in the classroom? ☐ Yes ☐ No

If yes, Describe them ____

Office Appliances

How many printers/scanners in total are there in school? _______________

What is the wattage of the most common type of printers/scanners in school? ________________

How long does it operate everyday? ______hours

Is there any other highly electricity-consuming appliances in the offices? ☐ Yes ☐ No

If yes, Describe them ____

OCCUPANTS SURVEY

Lighting	
I switch the lights off whenever the students and I leave the classroom.	☐ Never ☐ Sometimes ☐ Often
I will turn off some lights in the classroom when the natural light is strong.	☐ Never ☐ Sometimes ☐ Often
I found the lights on in classrooms while there is no one inside	☐ Never ☐ Sometimes ☐ Often
I found the lights on in the non-instructional spaces (e.g. gym, staff office) while there is no one inside	☐ Never ☐ Sometimes ☐ Often
HVAC	
In the school, I feel the rooms are cold in the winter.	☐ Yes ☐ No
In the school, I feel the rooms are hot in the summer.	☐ Yes ☐ No
Are you available to adjust the room temperature frequnetly ?	☐ Yes ☐ No
Building Envelope	
You will feel the coldness near the windows in the classroom.	☐ Yes ☐ No
What's the frequency that the windows are open in the summer?	_______days a week
Electrical Device	
In the school, I use an portable electric heater to supplement central heating when I feel cold.	☐ Yes ☐ No
In the school, I use a fan to supplement central cooling when I feel hot.	☐ Yes ☐ No
In the school, I use task-lighting on my office desk.	☐ Yes ☐ No
In the school, I have a personal coffee-maker.	☐ Yes ☐ No
In the school, I charge my personal ICT devices e.g. Cell phone, personal computer, ipad etc.	☐ Never ☐ Sometimes ☐ Often
What's the frequency of using the microwaves when you heat lunch?	_____times a week
What's the frequency of using the ovens when you heat lunch?	_____times a week
In the school, I saw the computers are on and screensaver not activated when nobody is using it.	☐ Never ☐ Sometimes ☐ Often