A PROTOCOL TO EVALUATE SCHOOL BUILDINGS' ENERGY CONSUMPTION

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Buildings contribute 20 to 40% of the world’s energy consumption, making the need to regulate and minimize their energy use a priority. A standard protocol was developed by the University of Manitoba Construction Engineering and Management Group to evaluate energy consumption across a sample of Manitoba schools in collaboration with the Manitoba Public School Finance Board. The protocol aims to evaluate school buildings' overall historical energy consumption and real-time electricity consumption at the space level. An extensive literature review was carried out to identify relevant parameters, methods and instruments to evaluate buildings’ energy use. The protocol identifies school data parameters as well as historical energy data and real-time electricity data parameters to be collected, related methods and recommended values for these parameters. The protocol is currently being validated through its practical application to the sample of Manitoban schools identified. This protocol is expected to be useful to future researchers looking to evaluate other school buildings in other locations and enable buildings operators and managers to track their buildings’ energy performance.

Keywords: electricity consumption, energy consumption, evaluation protocol, school.

INTRODUCTION

The rapid increase in energy use around the world raises concerns about the depletion of finite natural resources (Perez-Lombard *et al*. 2007) and thus the need to regulate this use across various industries, the building industry being the most important of all. This is because the building industry currently accounts for 20-40% of energy use worldwide (Issa *et al*. 2011), representing therefore an excellent opportunity to achieve large scale energy reductions, especially with the development of the green building industry (Azar and Menasa 2012). Green buildings can on average be 25-30% more energy efficient than conventional ones (Kats *et al*. 2003). This is despite a number of research studies showing different results (e.g. Thiers and Peuportier 2012, Kats *et al*. 2003, Torcellini *et al*. 2006, Issa *et al*. 2011), with ones surprisingly showing how green buildings can use more energy than conventional ones (e.g. Scofield 2002, Menassa *et al*. 2011). These results reinforce the need to close the gap between new buildings’ actual and expected performance and their performance in comparison with older buildings (Hancock and Stevenson 2009).

The goal of this paper is to present a comprehensive protocol for evaluating historical and real-time energy consumption, focusing on school buildings in particular. It is part of a study conducted by the Construction Engineering and Management Group at the

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University of Manitoba in collaboration with the Manitoba Public School Finance Board to evaluate energy consumption in relation to building usage and occupancy in Manitoba schools in Canada. As the study is still in progress and the protocol is currently being deployed, the paper will only focus on presenting the protocol, with no validation of it. The study and protocol will aim to 1) evaluate buildings' overall energy consumption in a sample of old, middle-aged and new green schools and 2) evaluate space-level electricity consumption across a smaller sample. This is to investigate the effects of energy efficiency measures and green certification on building and space-level energy consumption.

PROBLEM OVERVIEW

Developing this protocol entailed identifying relevant research using several databases such as Scopus and Science Direct and reviewing a total of thirty research studies specifically investigating energy consumption in green buildings. Other studies evaluating energy consumption in buildings in general were also identified, the aim being to review the protocols and standards used in them. The vast majority of identified studies collected energy consumption data for whole buildings either using utility bills (e.g. Oates and Sullivan 2012, Diamond *et al*. 2011) or by installing metering systems for overall buildings' energy consumption (e.g. Zhu *et al*. 2009, Li *et al*. 2006). However, only one of the identified studies sub-metered specific building spaces (Jain *et al*. 2013), revealing the lack of research focusing on specific building spaces' energy consumption, possibly due to the large amount of resources this requires. In this study, apartments were sub metered from the main distribution panel highlighting the large discrepancies between their electricity consumption although they are in the same buildings. For space-level energy consumption, a different study by Menezes *et al*. (2011) relied on other detailed measurement techniques. This study entailed compiling electricity consumption data from plug monitors providing half-hour usage profiles for equipment inside the spaces such as computers and printers. It revealed a strong correlation between occupants behaviour and plug-loads electricity consumption in building spaces. The wide variety of methods and techniques used in previous studies raises challenges in replicating and validating these studies in different contexts. Therefore, this protocol aims to address this limitation in the literature by evaluating overall building energy consumption for a group of schools using utility bills. It provides a simple method to demonstrate trends in the whole buildings' energy consumption which can be replicated in different contexts. An additional optional part of the protocol involves evaluating space-level energy consumption for only few representative buildings using power meters. This is because of the cost involved in installing advanced sub-meters in all buildings and the limited resources availability.

Current literature also shows how most studies focused on commercial and institutional buildings (e.g. Adalberth *et al*. 2001, Turner and Frankel 2008), possibly due to the size of the investments made in these two building sectors. Some of the identified studies investigated energy consumption in academic buildings, mostly on university campuses (e.g. Scofield 2009, Martani *et al*. 2012). However, only a small number of studies investigated energy consumption in school buildings (e.g. Issa *et al*. 2012, Robertson and Higgins 2012). In a study by Issa *et al*. (2012), new green schools in Toronto were found to consume 37% more electricity than older and energy retrofitted schools, but 41 to 56% less gas than them, resulting in a 28% decrease in overall energy costs. In contrast, new schools in Albuquerque, New Mexico were found to consume considerably more energy and electricity than older schools, raising concerns about the energy efficient technologies used in these new schools (Robertson and Higgins 2012). These findings highlight the need for more studies on school buildings in order to validate previous studies on them and the need for an in-depth investigation of energy consumed within specific spaces in these schools: needs that this new protocol aims to address.

In addition, current research methods reported in the literature reveal the lack of a standardized approach to evaluating building energy consumption. For instance, the frequency of energy data collection varied depending on the data collection method used. Ten of the thirty studies reviewed on green buildings collected data on a monthly basis using utility bills (e.g. Diamond *et al*. 2006, Menassa *et al*. 2011). However, other studies collected energy consumption data on a minutely basis using advanced metering systems (e.g. Li *et al*. 2006), or during site visits occurring on quarter-annual basis (e.g. Byrd 2012). In a study by Lenoir *et al*. (2012), metering systems installed in the studied building were configured to compile energy consumption data on an hourly-basis. These examples reveal the need to establish comparable methodologies to evaluate buildings' energy consumption data. Therefore, this protocol entails collecting historical energy data on a monthly basis, since this frequency of data collection can be easily replicated in other studies especially if utility bills are used as a source.

Half of the identified studies on green buildings' energy consumption (e.g. Torcellini *et al*. 2006, Brunklaus *et al*. 2010) investigated less than five buildings using a case-study research approach. Although these case studies provided useful evidence about buildings' energy performance, the small sample sizes in many made it difficult to generalize the results to the larger building population. To address this limitation, this study aims to evaluate overall schools' energy consumption in a sample of thirty-one schools selected using Neyman's allocation method to represent all schools in four Manitoba school divisions. The four additional in-depth case studies as part of this study will provide detailed information about schools energy consumption at the space-level.

PROTOCOL DEVELOPMENT

In addition to reviewing previous studies, developing this protocol involved reviewing existing building performance evaluation standards such as the American Society for Testing and Materials (ASTM E2797) and the United States National Renewable Energy Lab (NREL/TP-550-38601, Barley *et al*. 2005). The procedures outlined in these standards were used collectively with the methods reported in the literature to develop a standardized protocol for evaluating historical and real-time energy consumption in schools at the building and space-level respectively.

DATA COLLECTION

Four school divisions are participating in this research study, providing a total population of 129 schools in Manitoba. The study involved using stratified random sampling and Neyman proportional allocation process to select the sample of thirty-one schools to be analysed based on their age and size. This is to create three categories with fourteen schools representing old schools built on or before 1959, thirteen middle-aged schools built between 1960 and 1989, and four new schools built on or after 1990. The cut-off dates used for these schools are similar to the ones used by the United States Commercial Buildings Energy Consumption Survey (CBECS) thus building on previous categorizations of old, middle-aged, and new buildings

(CBECS 2003). The stratified random sampling process used also aims to ensure the inclusion of schools of different sizes, with the size of the schools in the sample varying between 10,000 and 100,000 sq.ft. One school from each age category will be selected for space-level analysis of real-time electricity consumption. A fourth school, the only certified to the Canadian Leadership in Energy and Environmental Design (LEED) Rating System in Manitoba will be subjected to the same space-level analysis to highlight the effect of LEED certification on schools' real-time electricity consumption. The study will focus on evaluating space-level electricity consumption in these four schools because of the limited resources, cost and manpower required to install advanced power meters in each of the thirty-one school.

This protocol aims to investigate current trends in schools' energy performance in Manitoba by implementing a case-study approach on a representative sample of Manitoba schools. It will involve evaluating: 1) detailed school data capturing the most important parameters that may affect energy consumption, to be administered to all schools within the sample 2) historical energy consumption data at the building level, to be administered to all schools within the sample and 3) real-time electricity consumption data at the space-level, to be administered only to the four case-study schools where advanced power metering systems will be installed.

The evaluation of detailed school data will include documenting parameters believed to influence buildings' energy consumption such as the building shape and footprint, the Heating, Ventilation and Air Conditioning (HVAC) equipment used in there and the green and other energy-related retrofits implemented. This information will be collected for every school building to investigate the effect of these parameters on energy consumption.

The evaluation of historical energy consumption data at the building level will involve reviewing existing standards and codes for energy consumption (e.g. CBECS 2003, NECB 2011, ASHRAE 90.1 2004). Recommended values for each energy parameter will be collected based on green certification programs such as PassivHaus or Building Research Establishment Environmental Assessment Methodology (BREEAM). The average historical energy consumption data provided by the CBECS dataset will be used for benchmarking purposes to evaluate the historical performance of schools against industry standards and average values for similar buildings. A thorough literature review was conducted to identify these standards and values.

The space-level electricity consumption evaluation protocol will involve documenting electricity consumption in a number of predetermined spaces (e.g. classrooms and gymnasiums) within each of the four schools analysed in real-time, and the type of equipment and devices used to collect such data. This protocol will only focus on space-level electricity consumption for lighting, as well as, plug load consumption for equipment. This is because of the significance of these two-use categories, which combined can represent 40% of space-level electricity consumption in schools (CBECS 2003). Moreover, other end-use applications such as space heating utilize other energy sources in some schools (e.g. gas or geothermal energy), raising challenges for comparing their consumption between different schools.

School data

The first data collection form compiles a comprehensive list of all energy-related parameters which may affect schools' energy consumption. Table 1 provides a list of these parameters with an explanation of each when needed.

Table 1: School data collection parameters

School information	Comments/ explanation
School name	N/A
School address	N/A
School key site manager contact name and information	N/A
Number of floors	N/A
Year built	N/A
Number of classrooms	N/A
Number of offices	N/A
Number of other-use spaces	e.g. labs, gym, library
Completion date of last major renovation (if applicable)	N/A
Weekly school operating hours	N/A
Heating source(s)	Type of fuel used for heating
Renewable energy use	(Yes/No)
School footprint	Select from checklist with different possible building shapes
School surroundings	Select from checklist with different possible building attachments
Number of electric meters serving school	N/A
Availability of sub-meters	Indicate number of sub-meters if applicable
On-site renewable energy sources	Select from checklist listing different possible on-site renewable energy sources
Building interior lighting information	Select from checklist listing different possible fixture types
Building exterior lighting information	Select from checklist listing different possible fixture types
Building environmental stewardship information	Select from checklist listing different possible sustainability plans and policies (e.g. sustainable purchasing)
Building HVAC equipment ENERGY STAR rated?	(Yes/No)
Building Hot Water equipment ENERGY STAR rated?	(Yes/No)
Building equipment	List number of computers, copiers and other equipment available in school
Building water efficiency plan in place?	(Yes/No)
Backup Power Supply	e.g. diesel, gas, not available

Historical energy data at the building level

The second data collection form documents historical energy consumption data for all schools. Table 2 lists the performance metrics collected as part of this form and the methods used to collect them. Another table not included in this paper also identifies all recommended values for each performance metric based on several sources identified from the literature eview such as PassivHaus, CBECS, and BREEAM.

Table 2: Historical energy data collection parameters and methods

Item	Performance metric	Necessary data	Point of measurement/ data source	Frequency	Measurement equipment
1	Functional area	Floor area	Architectural drawings	One time	N/A
2	Total building fuel use (gas)	Fuel consumption	Utility bills/ records	Monthly	Utility meter
3	Building fuel use intensity (gas)	Items 1 and 2	Items 1 and 2	Monthly	N/A
4	Building fuel use cost intensity (gas)	Fuel cost	Utility bills/ records	Monthly	Utility meter
5	Total building electricity use	Electricity consumption	Utility bills/ records	Monthly	Utility meter
6	Building electricity use intensity	Items 1 and 5	Items 1 and 5	Monthly	N/A
7	Building electricity use cost intensity	Electricity costs	Utility bills/ records	Monthly	Utility meter
8	Total building electricity Production	Renewable electricity generation	Wire between PV panel and main panel	Monthly	Utility meter
9	Total building energy use	Items 2 and 5	Items 2 and 5	Monthly	N/A
10	Total building energy use intensity	Items 1 and 9	Items 1 and 9	Monthly	N/A
11	Total building energy cost intensity	Items 4 and 7	Items 4 and 7	Monthly	N/A

Real-time energy data at the space level

The third data collection form compiles real-time energy use data at the space level. Table 3 lists the performance metrics collected using this form, as well as the methods used to collect it. Another table that is not included in this paper also lists all recommended values for each metric in the literature where applicable based on identified standards such as European Standard (CEN/TC 169 N 0618. 2006), American Society for Heating Refrigerating and Air Conditioning Engineers (ASHRAE 90.1 2004), and the National Energy Code for Buildings in Canada (NECB 2011)

Table 3: Space-level energy data collection parameters and methods

Item	Performance metric	Necessary data	Point of measurement/ data source	Frequency	Measurement equipment
1	Gross interior space area	Floor area	Architectural drawings	One time	N/A
2	Installed lighting energy use	Controlled lighting circuits	Distribution panel	Time-series	DENT® power meters
3	Installed lighting energy use intensity	Items 1 and 2	Items 1 and 2	Monthly	N/A
4	Plug-in lighting energy use	Numbers, power ratings and their consumption	Visual inspection/ interviews/ line voltage	time-series	Plug monitors by KillAWatt®
5	Plug-in lighting energy use intensity	Items 1 and 4	Items 1 and 4	Monthly	N/A
6	Total building lighting energy use	Controlled lighting circuits	Distribution panel	Time-series	DENT® power meters
7	Total building lighting energy use intensity	Items 1 and 6	Items 1 and 6	Monthly	N/A
8	Plug loads energy use	Energy consumed in plugs or plug load circuits	Distribution panels/ individual plugs	Time-series	DENT® power meters or plug monitors by KillAWatt®
9	Plug loads energy use intensity	Items 1 and 8	items 1 and 8	Monthly	N/A
10	Installed lighting power density	Number of light fixtures, power ratings, and floor areas	Visual inspection/ interviews	One time	N/A

DATA ANALYSIS

This research will entail comparing historical energy consumption data across old, middle-aged and new schools. The average energy consumption data for each category of schools will be further compared against recommended values compiled from different sources identified in the literature review. The analysis will also highlight historical trends in energy consumption for schools in each of the three categories.

The analysis will involve correlating historical energy consumption data to specific parameters and school attributes shown in Table 1 collected through the school information form. This will aim to highlight the effect of certain parameters and energy-efficiency retrofits on buildings' overall energy consumption.

At the space level, the research involves comparing average space-level electricity consumption data between the selected schools against recommended values shown in table 5. It also entails comparing electricity-use data in rooms of similar types in different schools. The analysis will also correlate average room electricity consumption for lighting and equipment to specific parameters and school attributes collected using the school information form, thus identifying the parameters with the most impact on space level electricity consumption.

CONCLUSION AND FUTURE WORK

The collected energy consumption data for the overall sample of schools and for specific spaces in four detailed case-study schools will be correlated to occupancy patterns and usage data from the same schools. This essential part of the research aims to demonstrate the relationship between occupancy, usage and buildings' energy consumption; a topic seldom investigated in the literature.

The standardized protocol for evaluating energy consumption in schools is an essential tool for future research since it can be applied in other locations and for other school buildings. The protocol also provides a set of measurable performance indicators that can be used by buildings operators and managers to track their buildings' performance. The protocol also identifies recommended values for these indicators, thus enabling the benchmarking of buildings' energy performance against set standards.

One of the limitations of this protocol is that it doesn't capture all end-use electricity consumption at the space-level. However, the two items reported in this protocol (i.e. lighting and plug loads) collectively represent approximately 40% of total electricity consumption and can be easily compared and benchmarked against other schools.

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