A METHODOLOGY TO EVALUATE THE EFFECTS OF SCHOOL BUILDINGS’ OCCUPANCY AND USAGE ON THEIR ENERGY CONSUMPTION

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Abstract: Buildings contribute 20 to 40% of the world’s energy consumption, making the need to regulate and minimize their energy use a priority. Although several parameters can have an impact on buildings’ energy use, the impact of buildings’ occupancy and usage seems to have been rarely investigated in the literature. This paper presents a methodology for the detailed assessment of building occupancy and usage, focusing on school buildings specifically. The methodology is part of an ongoing study aiming to evaluate the effects of school buildings’ occupancy and usage on their energy consumption, focusing on Manitoba school buildings. It is being conducted by the University of Manitoba Construction Engineering and Management Group in collaboration with the Government of Manitoba Public Schools Finance Board and Manitoba Hydro’s Customer Engineering Department. An extensive literature review was carried out to identify relevant methods used to evaluate occupants’ behaviour and energy use. The review showed how the few studies that have developed such methods focused on commercial or residential buildings, with little emphasis on school buildings specifically. The methodology and study aim to investigate overall building occupancy, as well as real-time usage of specific indoor spaces using surveys, interviews, visual observations and document analysis. The methodology focuses on 1) comparing building occupancy and usage across old, middle-aged, and new green schools 2) evaluating the effects of overall building occupancy on overall energy consumption, and 3) evaluating the effects of occupants’ behaviour and usage on space-level electricity consumption. It complements a previously developed methodology aiming to evaluate historical energy data and real-time electricity consumption in specific school spaces. The two methodologies will be validated by applying them at the building level to a sample of thirty-one schools in Manitoba and at the space-level to three representative schools. Once complete, the study is expected to provide a tool that researchers and industry practitioners can use to improve their schools’ energy efficiency and thus improve their schools’ design, construction, operation and maintenance.

1 INTRODUCTION

The rapid increase in energy consumption around the world makes the need to regulate its use across various industries a priority, the building industry being the most important of all (Pérez-Lombard et al. 2008). 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 et al. 2012). Green buildings can on average be 25 to 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 & Peuportier 2012; Kats et al. 2003;
Torcellini et al. 2004; Mohamed H. Issa et al. 2011), with ones surprisingly showing how green buildings can use more energy than conventional ones (e.g. Scofield 2009; Menassa et al. 2012). These results reinforce the need to close the gap between new buildings’ actual and expected performance and their actual performance in comparison with older buildings’ (Hancock & Stevenson 2009).

Several factors can affect energy consumption in buildings. For example, buildings’ location and surrounding climate can significantly influence its use of energy for heating and cooling (Yu Zhun Jerry et al. 2011). Additionally, building-related characteristics such as its size and orientation, can directly affect its energy use. Other factors with an impact on energy use include building systems and their operation and indoor environmental quality (Yu et al. 2011). However, one of the key factors rarely studied is occupants’ behaviour and usage (Yu et al. 2011). Due to the subjective nature of this factor, it is often overlooked or estimated at best.

The goal of this paper is to present a comprehensive methodology for quantifying buildings’ occupancy and usage, focusing on school buildings in particular. It is part of a study conducted by the Construction Engineering and Management Group at the University of Manitoba in collaboration with the Manitoba Public School Finance Board and Manitoba Hydro’s Customer Engineering Department to evaluate energy consumption in relation to building usage and occupancy in Manitoba’s schools in Canada. As the study is still in progress and the methodology is currently being deployed, the paper will only focus on presenting it, not the results of its validation. This methodology will aim to evaluate 1) buildings’ overall occupancy in a sample of old, middle-aged and new green schools and 2) space-level occupants’ usage in three schools. This is to investigate the effects of occupancy and usage on building-level energy consumption and space-level electricity consumption.

2 BACKGROUND

Over the past decade, several studies found large differences in the energy consumed by similar buildings, speculating about the contribution of building occupants to these differences (e.g. Ridley et al. 2014; Guerra-Santin et al. 2013). In addition, several studies showed that green buildings do not perform as intended with respect to energy efficiency (e.g. Oates et al. 2012; Menassa et al. 2012; Berkeley & Grove 2011). In many instances, actual energy use exceeded these buildings’ energy models, raising concerns about the accuracy of these models. The models usually relied on predicted average occupant behaviour to predict the buildings’ energy consumption (Guerra-Santin et al. 2009), leading some studies to conclude that actual occupant behaviour may produce significantly different results.

A study by Klein et al. (2012) monitored the use of appliances in active and stand-by modes in an office building over a two week period. Active mode denoted times at which appliances (e.g. desktop computer) were used by building occupants, whereas stand-by mode denoted times at which appliances were not used but were turned on. The study found that 38% of total energy consumed by these appliances was consumed in stand-by mode and therefore, that simple actions such as turning off appliances when not in use, can result in 38% energy savings. (Klein et al. 2012).

Another study by Al-Mumin et al. (2003) surveyed the occupants of 30 residences about their occupancy patterns and their usage of electrical appliances and found an increase of 21% from what was originally estimated. The study found that annual electricity consumption could drop down by 39% with more energy-efficient behaviour (Al-Mumin et al. 2003). Gill et al. (2010) incorporated the Theory of Planned Behavior (TPB) in his survey to establish a relationship between wasteful energy-use and general lack of interest in energy efficiency. The study concluded that occupant behaviour can account for 51%, 37%, and 11% of the variation in heat, electricity, and water consumption, respectively, in residential dwellings.

A number of studies (Hart 1989; Jin et al. 2011) used different methods to evaluate the effect of occupant behaviour on building energy consumption. For example, Yu Zhun Jerry et al. (2011) collected end-use energy consumption, referred to as non-intrusive load monitoring and used it with three data mining techniques: cluster analysis, classification analysis, and association rules mining to analyze occupant behaviour. Another method by Zhou et al. (2008) involved using continuous video monitoring and intelligent video processing to analyze occupant behaviour. Zeiler et al. (2014) used the number of Wi-Fi
connections in building spaces as a proxy for occupancy patterns. Because of the non-applicability of the method to certain settings such as elementary and middle-school buildings where most occupants are not usually connected to Wi-Fi, other studies (Spataru & Gillott 2011) used Radio-frequency Identification technology (RFID) to map the occupancy patterns within buildings. Others (Yun & Lee 2014) used infrared motion detectors to analyze occupants movements. Despite their accuracy, these methods are expensive for large-scale deployments. Moreover they only provide data about occupants’ presence in certain spaces but not necessarily their behaviour or interaction with electrical appliances.

Many studies (e.g. Steemers & Manchanda 2010, Chiou 2009 and Chen et al. 2013) used surveys, such as time-of-use and residential energy consumption surveys for that purpose. Other studies (e.g. Ridley et al. 2014; Pinheiro & Heitor 2014; Durand-Daubin 2013) used walk-throughs and semi-structured interviews. Although these methods can provide more in-depth information about occupants’ behaviour and usage patterns, they can be qualitative in nature and rely on respondents’ ability to remember their actions which raises concerns about their accuracy. Therefore, they are better suited as complimentary methods to the more quantitative ones.

3 RESEARCH METHODOLOGY

Approximately, one hundred and fifty relevant studies were reviewed as part of this study. Of these, only fifty five specifically investigated the effect of occupants’ usage on building energy consumption. The others evaluated occupant behaviour in general. The methodology developed for this study to evaluate historical occupancy and real-time usage in schools at the building and space-level relied in part on methods found in the literature.

3.1 Methodology Development

Four school divisions in Manitoba are participating in this research study, providing a total population of 129 schools. The study involved using a stratified random sampling and Neyman proportional allocation process to select the sample of thirty-one schools to be analyzed based on their age and size. This is to create three categories of schools, with 14 schools representing old schools built on or before 1959, 13 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 were similar to the ones used by the United States Commercial Buildings Energy Consumption Survey (CBECS 2003). The stratified random sampling process also aimed to include schools of different sizes, varying between 10,000 and 100,000 ft². Because of the limited resources, cost and manpower available, one school from each age category was selected for space-level occupancy analysis. The third school, representing new schools, is also the only school in Manitoba currently certified to the Canadian Leadership in Energy and Environmental Design (LEED) Rating System. This school will highlight the effect of LEED certification on schools’ real-time usage if any.

This methodology will involve evaluating 1) historical occupancy data at the building level (e.g. enrolment figures) in all schools within the sample and 2) real-time occupant usage data at the space-level in the three schools where advanced energy sub-metering systems were also installed. The data collected using this methodology will be correlated to energy consumption data collected at the building-level and electricity consumption collected at the space-level using a different methodology. Figure 1 shows a simple breakdown of data collection using both the energy and usage methodologies.
3.2 Methods Used

At the building-level, the study involved collecting data about the historical energy usage from the utility provider over the past 24 years. Additionally, the school divisions were asked to complete a data collection form for each of the 31 selected schools. These forms collected data about the schools' enrolment figures for each year over the past 24 years as well as the numbers of teachers and staff in each school. The forms also collected data about the numbers of classrooms, gymnasiums and other spaces in these schools, as well as their typical operating hours. This occupancy and occupancy pattern data will be correlated to the schools’ occupancy data in order to determine whether there is a correlation between overall-building occupancy figures and their overall energy consumption.

At the space-level, the study involved installing sub-meters to monitor specific circuits within the schools for one classroom and the gymnasium in each of the three selected schools. Sub-meters were also used to monitor other non-classroom spaces such as one music room in one school and one multi-purpose room in another school. These sub-meters provide electricity consumption data for equipment plug loads and lighting over half-hour intervals. Three different providers were used to source the sub-meters depending on the requirements for each building space and its circuits' configuration.

In order to monitor real-time occupant usage of the selected school spaces, the study will involve using three different methods simultaneously to address the limitations of each method. Figure 2 depicts these methods graphically.
3.2.1 Room Schedules

This method involves collecting room schedules from school administration for six weeks for all classroom and non-classroom spaces used during regular school hours and irregular hours (e.g. evenings and weekends) by their communities. Correlating these schedules with real-time electricity consumption in these spaces will demonstrate the effect of space usage, including usage for non-school functions (e.g. community meetings) on its electricity consumption.

3.2.2 Surveys

The methodology will involve using surveys for real-time usage data collection. Teachers in classroom spaces where sub-metering equipment have been installed will be asked to fill out a daily-use survey over six weeks. This survey will ask about details such as the average duration of using equipment within these spaces. The questions will be tailored to each space listing all the equipment available there. By only indicating an estimated duration in minutes for using each piece of equipment, the respondent will only need 2-3 minutes to fill out each daily-use survey. Table 1 shows a sample of the questions included in the survey.

Table 1: Sample questions from daily-use equipment usage survey

<table>
<thead>
<tr>
<th>Question</th>
</tr>
</thead>
<tbody>
<tr>
<td>Please use your best judgement to estimate the total duration of active use of each of the following equipment today (Only if applicable)</td>
</tr>
<tr>
<td>Projector (if applicable)</td>
</tr>
<tr>
<td>Smart board (if applicable)</td>
</tr>
<tr>
<td>Microwave (if applicable)</td>
</tr>
<tr>
<td>Stereo (if applicable)</td>
</tr>
<tr>
<td>Laptop/computer (if applicable)</td>
</tr>
<tr>
<td>Other (if applicable, please specify)</td>
</tr>
<tr>
<td>For how long were the lights switched off today?</td>
</tr>
</tbody>
</table>

In addition to the daily-use survey, all school teachers and staff will be asked to fill out a more comprehensive general usage and behaviour survey. This survey enquires about their attitudes with respect to energy efficiency and their energy-related behaviour over the period of the study (6 weeks). The general usage and behaviour survey will include questions about the frequency of using spaces and equipment based on the respondents’ location at the school (e.g. classroom, gymnasium) as shown in table 2. The survey results will be correlated to the real-time energy use of each school and evaluated.
across the new LEED-certified school, the middle-aged schools and the older ones. Table 2 provides a sample of the questions that will be administered in the general usage and behaviour survey.

Table 2: Sample questions from the general usage and behaviour survey

<table>
<thead>
<tr>
<th>General Attitudes/ Thoughts about Energy Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>To what extent do you agree or disagree with the following statement?</td>
</tr>
<tr>
<td>• The problem of global warming and/or greenhouse effect is real and needs to be addressed immediately</td>
</tr>
<tr>
<td>• Leaving equipment/lighting on when it is not being used can waste a large amount of energy</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>General Attitudes towards Actions to Save Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>To what extent do you agree or disagree with the following statement?</td>
</tr>
<tr>
<td>• I think I use less electricity than other teachers/staff members at the school</td>
</tr>
<tr>
<td>• I know what to focus my attention on when it comes to saving electricity</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Frequency of Using Spaces and Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Please answer the following questions to the best of your knowledge:</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Gym</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Over the past two months, on average, how many days per week is the gym used for, if any?</td>
</tr>
<tr>
<td>• Over the past two months, on average, how many hours per day is the gym used for, if any?</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Plug Loads</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Over the past two months, on average, how many days per week do you use the projector for in the classroom?</td>
</tr>
<tr>
<td>• Over the past two months, on average, how many hours per day do you use the projector in the classroom?</td>
</tr>
</tbody>
</table>

Please indicate how often you unplug the following equipment whenever they are not being used. Please indicate as N/A for appliances you do not typically use at the school

| • Laptop/computer |
| • Projector |
| • Smart Board |

<table>
<thead>
<tr>
<th>Usage Patterns</th>
</tr>
</thead>
<tbody>
<tr>
<td>What is the frequency of these events over the past two months?</td>
</tr>
<tr>
<td>• In my classroom, I use only natural light from the window without switching on the lights</td>
</tr>
<tr>
<td>• I switch off the lights at my workspace whenever I leave</td>
</tr>
<tr>
<td>• I use an electric heater when I feel my workspace is too cold</td>
</tr>
</tbody>
</table>

3.2.3 Observation Forms

In order to compliment data derived from the daily-use survey administered to teachers, point-in-time observations of the state of electrical equipment and space lighting (i.e. on, off, or idle/dimmed) used in specific locations will be conducted at regular intervals over a two week period. An observation form will be developed for that purpose tailored for each space listing all the equipment available there. In addition to giving the three options for observing each state, the sheets will enable the observers’ to write any notes regarding their observations. Two weeks was in general found to provide adequate data about occupants’ usage of indoor spaces in the literature (e.g. Klein et al. 2012). Exact definitions of each state will be identified as per table 3 to avoid human-error when recording these observations. The team will cross validate the observations during a pilot study involving all team members simultaneously to ensure the same understanding of each state definition.

These observations will aim to investigate behaviour as it occurs naturally with no intervention. Therefore, occupants will not have access to the observation form used by the research team to avoid influencing their behaviour. Additionally, the research team will only monitor behavioural activities related to energy consumption. During the visits to the selected locations, it was found that all equipment states can be observed from outside the spaces provided their doors are left open.
Table 3 shows a sample of the observation form used for a classroom space.

<table>
<thead>
<tr>
<th>Observation</th>
<th>State Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weather</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Completely Clear</strong> = No clouds at all in-sight</td>
</tr>
<tr>
<td></td>
<td><strong>Partial Clouds</strong> = One or more clouds in sight,</td>
</tr>
<tr>
<td></td>
<td><strong>Completely Cloudy</strong> = clouds completely covering the sky, i.e. little-to-no sunlight</td>
</tr>
<tr>
<td>Blinds in use</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>No</strong> = Blinds are completely up (window completely cleared)</td>
</tr>
<tr>
<td></td>
<td><strong>Partial</strong> = Blinds are down but not covering the entire window,</td>
</tr>
<tr>
<td></td>
<td><strong>Full</strong> = Blinds are covering the entire window</td>
</tr>
<tr>
<td>Equipment</td>
<td></td>
</tr>
<tr>
<td>Projector in use</td>
<td><strong>No</strong> = Projector is not being used and is unplugged</td>
</tr>
<tr>
<td></td>
<td><strong>Idle</strong> = Projector is plugged in and on-standby but not projecting anything at the moment</td>
</tr>
<tr>
<td></td>
<td><strong>Yes</strong> = Projector is being used to project something on the board or project a blank blue screen</td>
</tr>
<tr>
<td>Microwave in use</td>
<td><strong>No</strong> = Microwave is not being used and is unplugged</td>
</tr>
<tr>
<td></td>
<td><strong>Idle</strong> = Microwave is plugged in and on-standby but not being actively used</td>
</tr>
<tr>
<td></td>
<td><strong>Yes</strong> = Microwave is being actively used</td>
</tr>
<tr>
<td>Computer in use</td>
<td><strong>No</strong> = Computer is not being used or is unplugged</td>
</tr>
<tr>
<td></td>
<td><strong>Idle</strong> = Computer is on standby or sleep mode, screensaver or blank screen is on but laptop is plugged in</td>
</tr>
<tr>
<td></td>
<td><strong>Yes</strong> = Computer is being actively used or screen is on</td>
</tr>
<tr>
<td>Stereos / Speakers in use</td>
<td><strong>No</strong> = Stereo is unplugged</td>
</tr>
<tr>
<td>Fan in use</td>
<td><strong>Idle</strong> = Stereo is plugged in but not being used</td>
</tr>
<tr>
<td></td>
<td><strong>Yes</strong> = Stereo is being actively used</td>
</tr>
<tr>
<td>Other equipment in use</td>
<td><strong>No</strong> = equipment is unplugged</td>
</tr>
<tr>
<td></td>
<td><strong>Idle</strong> = equipment is plugged in but not being used</td>
</tr>
<tr>
<td></td>
<td><strong>Yes</strong> = equipment is actively being used</td>
</tr>
<tr>
<td>Lighting</td>
<td></td>
</tr>
<tr>
<td>Classroom Lights</td>
<td><strong>Off</strong> = All classroom lights are off except emergency lights</td>
</tr>
<tr>
<td></td>
<td><strong>Dimmed</strong> = Some classroom lights are on and some are off (as long as at least one light bulb is switched off not due to malfunction but using a specific light switch)</td>
</tr>
<tr>
<td></td>
<td><strong>On</strong> = All classroom lights are on</td>
</tr>
</tbody>
</table>

4 DATA ANALYSIS

The study will entail comparing historical occupancy data across old, middle-aged and new schools in order to highlight historical trends in occupancy in each of the three categories. The analysis will also involve correlating historical occupancy data to the schools’ historical energy consumption. This is to highlight the relationship between occupancy figures and energy consumption at the building level.

At the space level, the study will involve comparing space-level usage data for classrooms and gymnasiums across the three schools. The study will also compare the results derived using each of the three methods (e.g. daily-use surveys and observations sheets) to determine the accuracy and validity of each. The data collected using each method will be correlated to real-time electricity consumption to demonstrate the effect of specific occupant activities on energy consumption.
5 CONCLUSION

The collected occupancy and usage data for all schools will be correlated to their energy consumption data. This is to demonstrate the relationship between occupancy, usage and buildings’ energy consumption: a topic seldom investigated in the literature. One of the key contributions of this study is its novel methodology which relies on the use of a number of different methods. Correlating the results derived using each method should improve the research community and industry’s understanding of energy use in school buildings. The significance of the study also stems from its evaluation of school buildings in particular as opposed to the more common evaluation of office and residential buildings.

This methodology for evaluating occupancy and usage in schools should serve as a tool that future researchers and practitioners can apply in different contexts to evaluate school buildings in other locations. The methodology can also be used by school operators to identify occupant activities with the most impact on schools’ energy consumption and that can thus reduce it the most. It can also allow for more efficient space-utilization of the schools.

One of the most significant limitations of this methodology is its heavy reliance on human resources which can make it challenging to implement. This can be mitigated by implementing only parts of it through the use of only one of the methods making it up.

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References


