THE EFFECT OF OCCUPANT BEHAVIOUR ON REAL-TIME ELECTRICITY CONSUMPTION IN SCHOOL SPACES

Abstract
Studies on sustainable and green buildings reveal mixed results regarding their energy performance. While many of these buildings demonstrate significant savings in gas consumption, previous studies indicated their electricity consumption is increasing in comparison with older buildings. These results highlight the importance of investigating parameters influencing buildings’ electricity consumption in order to close the performance gap in new and sustainable buildings. The majority of previous studies focused on commercial or residential buildings emphasizing the need to investigate energy consumption in other building types. Therefore, this study analyzed historical energy consumption in a sample of thirty schools in Manitoba. It indicated the decrease in gas consumption for heating in new schools was counteracted by a statistically significant increase in their electricity consumption. Three cases study schools were then selected for further analysis of electricity consumption. Within each school, one classroom and the gymnasium, as well as spaces with significant community use, were sub-metered to collect real-time electricity consumption data. Occupant behaviour was also monitored simultaneously in these spaces to demonstrate its effect on electricity consumption. Results indicated total electricity consumption increased in the newest school, although sub-metered spaces in older schools showed higher electricity consumption. The study also indicated occupant behaviour influenced variations in electricity consumption between sub-metered classrooms. It is the first to provide in-depth investigations of electricity consumption in Canadian school buildings to identify reasons behind their increased electricity consumption.

Keywords:
Energy Efficiency, School Buildings, Energy Management, Sustainability, Occupancy and Energy Performance

1 Introduction
The building industry accounts for 20-40% of energy use worldwide [1], representing an excellent opportunity to achieve large-scale energy reductions. Advances in sustainable and green building technologies can help decrease their energy use by improving building envelopes and mechanical systems making them 25-30% more energy efficient on average than conventional ones [2]. However, some studies indicated these buildings use more electricity than conventional ones e.g. [3], [4] which may be attributed to occupants’ behaviour [5]. Therefore, closing the gap between actual and expected buildings’ energy performance necessitates considering all parameters influencing buildings’ energy consumption, including those related to occupancy and usage [6]. Previous studies focused on analyzing energy consumption in commercial or residential buildings, highlighting the need to analyze energy consumption in other building types [7]. School buildings represent an excellent opportunity towards increasing overall energy efficiency as they contribute to a considerable part of overall buildings’ energy consumption due to their large number within the
building stock [8]. These buildings "can also be used as communication means towards pupils and their families, thus educating many different society groups about sustainability in the built environment" [8].

In order to evaluate energy performance in Manitoba’s schools, this study entailed analyzing historical energy consumption in a randomly selected sample of thirty schools over 9 years. The analysis revealed newer schools used more electricity than older ones while using less gas annually, reinforcing the need to investigate their electricity consumption in more detail. Therefore, three case study schools in Manitoba, Canada were selected for analyzing their real-time electricity consumption over a period of 4 months. One of these schools was a new Leadership in Energy and Environmental Design (LEED) certified school built in 2009, a middle aged school built in 1968 and an old school building, built in 1951. The analysis entailed studying real-time electricity consumption in school spaces as well as occupant behaviour using several techniques. Specific objectives of this study involved 1) demonstrating the effect of school building age on their energy performance while controlling for school occupancy and floor area 2) demonstrating differences in electricity consumption between the three case-study schools at the building and space levels 3) demonstrating differences in occupant behaviour related to energy consumption in the three case-study schools.

This study is the first to investigate real-time electricity consumption in Canadian school buildings. The analysis of real-time electricity consumption revealed large variations in electricity consumption between these schools which could be attributed to occupants’ behaviour. The study results are, therefore, relevant to school divisions, superintendents and operators looking to decrease schools’ energy consumption by targeting specific occupant activities which contribute to wasteful energy consumption. Since existing buildings represent the vast majority of the current building stock, decreasing occupant-related electricity consumption presents a great opportunity for decreasing the building stock’s overall energy consumption.

2 background

Several studies found large discrepancies in energy consumption between similar buildings, speculating about the contribution of building occupants to these differences e.g. [9], [10]. Many of these studies showed green buildings may not perform as intended with respect to energy efficiency e.g. [1], [11], [12]. In many instances, actual energy use exceeded design estimates from energy models raising concerns about their accuracy especially when predicting occupants’ behaviour. However, relatively few studies investigated the effect of occupants’ behaviour on energy consumption and mostly focused on commercial buildings. The majority of these studies monitored real-time energy consumption to estimate occupant behaviour, with even fewer studies directly monitoring occupant behaviour. In these studies, analysis mostly focused on behaviour related to heating, ventilation and air-conditioning (HVAC) energy consumption as opposed to other end-uses.

Studies that measured actual real-time energy consumption entailed sub-metering specific building spaces, mostly with no further breakdown of end uses. For example, [13] sub-metered floors within six commercial buildings and found 56% of their energy was consumed during non-business hours without specifying end-uses contributing to this finding. Similarly, [14] found 23% of the energy consumed by workstations in two office buildings occurred during non-business hours. After providing individual and group feedback to office employees regarding energy consumption, the study indicated power density in individual workspaces could decrease by 7-11% when occupants were informed about their energy consumption. [15] also showed that providing individual and group feedback to building occupants regarding their energy consumption improved buildings’ energy-efficiency. Despite their strengths, these studies did not investigate specific end-uses with the highest effect on buildings’ energy consumption and consequently their energy-efficiency.

For studies which investigated the effect of occupancy on buildings’ energy consumption, they mostly estimated this effect using statistical methods. [16] Investigated energy consumption in a sample of 80 residential buildings over two years by grouping similar buildings into clusters using seven parameters not related to occupant behaviour. Using cluster analysis and grey-relational techniques, the study found significant variations in energy consumption among similar
buildings and attributed these variations to occupant behaviour. Other studies used energy modelling tools to determine the effect of occupancy on energy consumption. By modifying occupancy input parameters in energy models, [17] concluded that occupancy could change annual energy consumption by 69 to 177% depending on building type and climate region. [18] found the relative standard deviation due to modelling extreme occupant actions can amount to 47%. Despite the value of these studies, most of them focused on how occupants affected HVAC energy consumption through occupant actions such as the use of blinds, window operations or clothing adjustments. However, these studies did not investigate the effect of occupants on real-time electricity consumption.

3 Method

This study entailed collecting data regarding schools’ floor areas, dates of construction, number of students and teachers, as well as grade levels from 126 schools in four school divisions in Manitoba. The information was used to randomly select, using stratified random sampling and Neyman proportional allocation technique, a representative sample of thirty schools to be analyzed at a 90% confidence level. This is to create three groups of schools, with thirteen 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 including one LEED-certified school. The cut-off dates used for these schools were based on the dates used by the United States Commercial Buildings Energy Consumption Survey (CBECS 2003) for reporting energy consumption in buildings by year constructed. The study involved collecting and analyzing historical monthly gas and electricity consumption quantities and billing costs for these schools for the period between 2004 and 2013 to evaluate the effect of building age on energy consumption.

One school was then selected from each age category for analysis of total building electricity consumption, as well as space-level lighting and plug load consumption. Simultaneously, several tools were used to study occupant behaviour in spaces where electricity consumption was monitored. These tools included 1) sensors for logging half-hourly durations of light use and occupancy status in classrooms 2) observations of equipment and light use in school spaces 3) daily surveys completed by teachers documenting daily equipment use in classrooms. The monitored spaces were a south-facing classroom between grades 4 to 7, the gymnasium and one space typically used outside regular work hours in each school. Sub-meters were installed to monitor all lighting and plug loads circuits for the selected spaces in order to measure electricity consumption at half-hour intervals for the period between January and June 2015. Total building half-hourly electricity consumption was also obtained by downloading data from advanced utility meters in each school. Figure 1 shows a summary for the data collected for this study.

Figure 1: Summary of data collection methods.

Data analysis involved normalizing energy consumption by floor areas at the building and space-levels. Analysis of Covariance (ANCOVA) was used to investigate differences in annual electricity, gas and total energy consumption between the three age categories, after controlling for floor area and the number of occupants. For statistically significant differences, post hoc least significant difference (LSD) tests were used to assess the difference in means between every two age groups. Half-hourly electricity consumption data was used to calculate and compare the average daily electricity consumption for the entire schools, as well as classrooms between old, middle aged and new schools. Non-parametric tests were used to compare half-hourly electricity consumption between the three schools as this data did not follow normal distribution on a frequency plot.

Results presented in this paper focused on 1) analyzing the differences between the three school-age groups regarding their monthly electricity and gas consumption. 2) analyzing the differences in total building half-hourly electricity consumption between the three case-study schools 3) analyzing the differences in half-hourly electricity consumption for classrooms lighting between three case-study schools 4) analyzing the differences in light use durations between the three classrooms.
4 results

Historical energy consumption in Manitoba’s schools

Figure 2 shows the average annual electricity consumption increased from old (n = 13, 56.57 ± 19.8 KWh/m²/year), to middle aged (MA) (n = 13, 116.26 ± 48.7 KWh/m²/year), to new (n = 4, 126.27 ± 29 KWh/m²/year) school buildings. However, the average annual gas consumption followed the opposite trend where it decreased from old (n = 12, 20.59 ± 9.8 m³/m²), to middle aged (n = 12, 16.58 ± 7 m³/m²), to new (n = 3, 12.66 ± 3.5 m³/m²) school buildings, in that order. These results were in-line with previous studies which also showed new buildings used more electricity than older ones while using less gas annually e.g. [3], [4]. ANCOVA test results showed a statistically significant difference in electricity consumption quantities (F (2, 25) = 5.22, p < .05), but not in gas consumption quantities (F (2, 25) = 100.53, p = 0.264) between the three building age groups. Post-hoc LSD tests showed a statistically significant differences in electricity consumption quantities only between old schools and new schools, and between old schools and middle-aged ones, prompting further analysis of real-time electricity consumption.

Figure 2: Annual electricity and gas consumption in Manitoba schools.

Electricity consumption in case-study schools

The analysis of the real-time building electricity consumption in the three case-study schools was in line with findings from the randomly selected school groups as shown in Figure 3. The new school used on average 48% more electricity on a daily basis (0.54 ± 0.24 KWh/m²/day) than the middle aged school (0.31 ± 0.12 KWh/m²/day) which used on average 82% more electricity on a daily basis than the old school (0.17 ± 0.03 KWh/m²/day). The non-parametric Kruskal-Wallis H test showed statistically significant differences in total half-hourly electricity consumption between the three schools ($X^2(3) = 279.089, p < .005$).
Electricity consumption in case-study classrooms

Classrooms’ electricity consumption in the three case-study schools did not follow the same trend as their total building electricity consumption. Daily plug load and lighting electricity consumption was highest in the old school’s classroom (18.15 ± 12.04 Wh/m²/day, and 32.1 ± 31.02 Wh/m²/day respectively), and lowest in the middle-age school (3.82 ± 4.33 Wh/m²/day and 7.68 ± 10.18 Wh/m²/day respectively) as shown in Figure 4. The new school’s classroom, on the other hand, consumed on average 8.88 ± 4.45 Wh/m²/day for plug loads and 11.71 ± 12.23 Wh/m²/day for lighting.

Light sensors data in case-study classrooms

Although sub-meters data indicated the old school classroom was the highest consumer of electricity for lights per unit area, data from the installed light sensors revealed a different story. The average daily duration for which lights were switched on
was lowest in the old school classroom (253 ± 163 minutes/day) which increased to 328 ± 212 minutes/day in the new school classroom, and 417 ± 322 minutes/day in the middle aged classroom. Data from light sensors was verified by plotting average half-hourly electricity consumption for lighting in classrooms as shown in Figure 5. These plots indicated lights were typically switched on until 10:30 PM in the middle aged classroom unlike other schools where they were switched on only until around 4:30 PM. School visits also confirmed teachers in the middle-aged school left the lights on for custodial staff, who typically tuned them off at the end of their night shifts highlighting energy saving potential by adjusting occupant behaviour. These results indicated while occupant behaviour may influence light use durations, the type of fixtures and light density within classrooms may have been the ultimate drivers for classrooms’ lighting electricity consumption. The results indicate installing energy-efficient lighting systems would result in significant savings in the older schools’ electricity consumption for lighting which was at least double the consumption in newer schools.

![Figure 5: Average half-hourly electricity consumption for classroom lights.](image)

5 CONCLUSION

Results from this study highlighted the increase in electricity consumption in new school buildings in Manitoba although their classrooms’ electricity consumption was lower than older schools. Findings of the study indicated occupancy may have played a role in classroom’s electricity consumption for lighting. However, fixture types and installed lighting power density may have been the ultimate drivers behind increased electricity consumption for lights in older classrooms. Nevertheless, the study results shed the light on potential opportunities for increasing energy efficiency through occupancy interventions, such as ensuring lights were only used during regular school hours. The discrepancy between total and classroom-level electricity consumption trends indicated other areas of electricity consumption in schools should be investigated. With increased automation and mechanization in new schools, these technologies may have contributed to increased electricity consumption in new schools. For example, electrically controlled blind were installed for all windows in the new school unlike the two older schools.

This study analyzed space-level electricity consumption in only three out of the randomly selected thirty schools in Manitoba due to resource limitations. Therefore, results could not be generalized to the larger population of Manitoba schools. Future studies should focus on investigating electricity consumption in a larger sample of schools and standardizing sub-metering methods to avoid errors in measuring real-time electricity consumption. Increasing the study period to demonstrate seasonal variations in electricity consumption can also help increase understanding of real-time electricity...
consumption in schools. The shift towards more stringent energy codes for greener, more energy-efficient buildings underscores the need to address new parameters influencing electricity consumption which is increasing in new buildings.

6 References


