Post-Occupancy Evaluation:
Three schools from Greater Toronto

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ABSTRACT: This paper evaluates the real performance of three school buildings in terms of energy and indoor environmental performance. Real energy performance based on actual energy audits is compared to predicted energy consumption obtained from simulations. Considerable efforts were made during the design process of all schools to satisfy the clients and occupants needs and to deliver buildings which are energy efficient, environmentally conscious and provide inspiring environment and comfort for their occupants. Two schools are LEED certified. For the purposes of this study, an occupant (meaning staff and students) comfort and satisfaction questionnaires were developed in order to assess the indoor environmental performance. Comfort in the indoor environment was also evaluated trough a series of field measurements. The results of the developed questionnaire were compared to benchmarks for Canadian schools compiled by CaGBC, other similar surveys and results obtained from field measurements.
Keywords: Post-Occupancy Evaluation, elementary schools, energy consumption, indoor environment, occupant comfort

INTRODUCTION

The acceptance of climate change by scientists, politicians and general public have led to adoption of conservations measures of all resources, energy, water and materials. The primary concern for some time has been focused on energy efficiency because it is relatively easy to determine the cost of implementation of energy saving measures and determine the payback period on the investment. In Canada, there have been many government supported initiatives both in commercial and residential sector which promoted higher energy efficiency standard than that prescribed by the Codes. The introduction of air tight building envelopes in the 1980's without sufficient ventilation requirements resulted in poor indoor air quality and gave birth to a "sick building" syndrome. The investigations by health and social researchers, architectural and business professions helped to define the comfort zone of people who occupy buildings. The overwhelming growth of applications for LEED and GreenGlobe certification of projects in all commercial sectors as well as recent trends in residential construction resulted in growth of other measures which impact our environment besides the energy production and its use and quality of indoor air environment. The cost of projects adopting various levels of environmental strategies is marginally to significantly above the cost of regular projects. The additional cost can often be mitigated by full life cycle analysis but the question which remains is related to actual performance and overall environmental impact. In order to assist designers and clients to adopt appropriate mix of strategies which will result in efficient and environmentally sound design it is necessary to evaluate performance of new buildings as well as retrofits. These evaluations are significant in determining benchmark for resource use and effectiveness of environmental strategies. The protocol used for the performance evaluation is known as Post-Occupancy Evaluation (POE). Despite the fact that POE's have been around since 1970s, there is a general lack of feedback on real performance of buildings.

In North America, schools can consume up to 25% more energy than is necessary [1]. In addition, schools in Canada account for 11% of the total energy used by the institutional/commercial sector [2] and are the second highest consumers of energy in this sector. Indoor environmental quality in school buildings is very important but there are limited studies [3]. The effects of school indoor environmental quality on student performance have been demonstrated repeatedly through various scientific studies. Several studies conducted in the United Stated, showed that the test scores tend to be higher in classrooms with daylighting while good air quality in schools is associated with improved attendance and reduced health problems, confirming that the performance of students is affected by the environment they are taught in [4].

The main goal of this study was to provide feedback on efficient building design, operational methods in educational buildings and environmental impact of modern schools, two of them LEED certified. The lessons learned are to be disseminated to designers and school boards to assist them to select environmental strategies for new facilities which are effective and performing as anticipated. The findings of this study should contribute to the new generation of green building systems. This paper reports on the first part of the study which deals with POEs. The second part which is close to completion deals with the environmental impact of each project.

METHODOLOGY

The following approach was adopted.

1. Development of Post-Occupancy Evaluation Protocol suitable for elementary school staff and student was necessary due to lack of standardized surveys for educational buildings.
2. Review of documentation and site visit. Analysis of the drawings and documentation available for the selected projects was followed by on site visits and interviews with building operating staff.
3. Field monitoring of indoor air quality (temperature, relative humidity, CO_2 levels) in selected areas and lighting study.
4. Collection of information on actual consumption of electricity and gas of buildings involved in this study.
5. Analysis of all collected data.
6. Discussion on results and comparison to other similar studies.

Description of projects involved in the study The descriptions of three school building investigated are summarized in Tables 1 and 2 (see table 2 at the end).

Table 1: General information about buildings investigated

Facility	Treated Floor Area *(m^2)*	Occupancy *(no of students)*	LEED Certification	Year opened
School 1	5554	682 [1)]	Yes	2005
School 2	3780	300	No	2006
School 3	5490	619	Yes	2007

[1)] Occupancy was greater in the first two years of operations; 05/06: 868 students, 06/07: 962 students

All schools were recently completed and have gone through one year of commissioning. The two LEED certified schools are approximately of the same size and are elementary schools (junior kindergarten to grade 8). School 2 was design for specific needs of grade 4 to 8 students who are talented in arts.

Post-Occupancy Evaluation Protocol Methodology for the Post-Occupancy Evaluation was adopted from EcoSmart Building Performance Evaluation Protocol for Office Buildings which is currently used in Canada [5,6]. Two surveys were developed, one for staff and the other one for students and were implemented. Both groups were asked to rate various building features on a 7-point scale. The results of the surveys are summarized in Figure 1.

Review of documentation In order to evaluate the performance of the three schools, it was necessary to understand design goals and targets, and special design features. The as-built drawings, specifications, documentation and other submissions were studied, followed by visits and interviews with the staff operating the facilities.

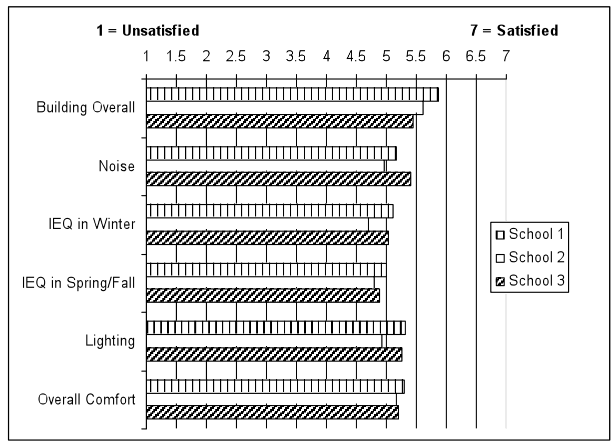

Figure 1: Average scores from Occupant Survey by category

Field monitoring Results of the survey were used to identify spaces where highest and lowest levels of indoor environmental comfort were achieved. These were then subjected to further investigation through field testing. Field measurements were taken in each school in order to assess indoor environmental performance. Temperature and relative humidity was monitored using HOBO Onset Data Loggers, Model Number U12-013. The methodology used for monitoring was loosely based on AHSRAE 55 Standard. In order to evaluate indoor air quality, carbon dioxide levels were monitored using Telaire 7001 sensor. The results are summarized in Figure 2.

Energy consumption Energy consumption is based on monthly electricity and gas meter readings. These figures were tabulated and compared to actual weather data [7] for the corresponding period. The available data were normalized to mean design temperatures and mean heating degree days. The actual consumption for each school was compared with the energy simulation results which were available only for School 1 and School 3. Summary of the normalized energy use for each school investigated is shown in Figure 3.

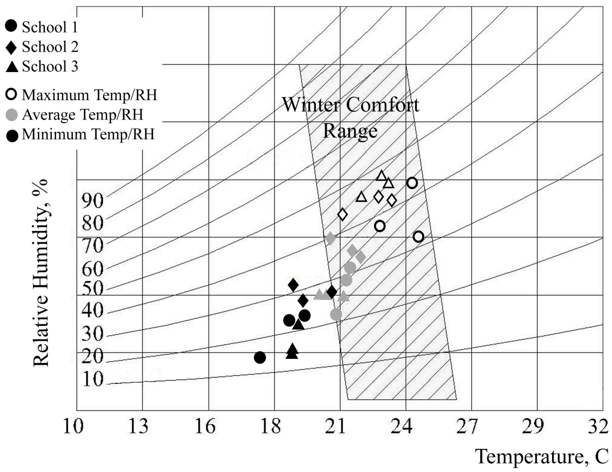

Figure 2: Comfort Levels in Classrooms

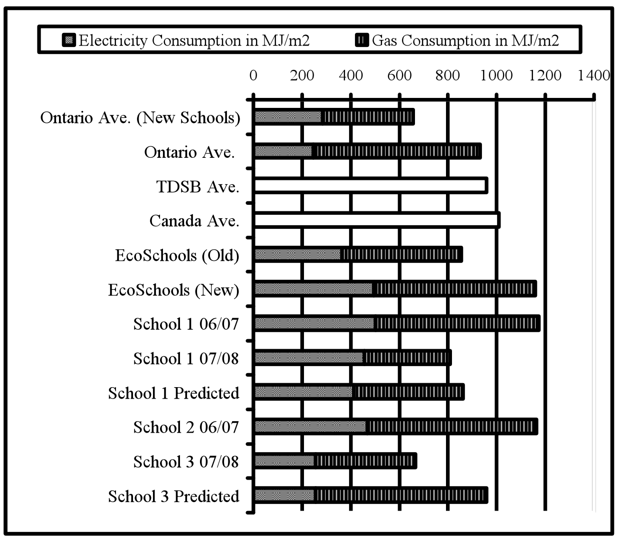

Figure 3: Annual Energy Consumption per meter square

Results of occupant survey A survey of building occupants is essential to understanding their level of satisfaction with the various building aspects. To facilitate a meaningful analysis of survey results, the most important aspects of the buildings were divided into six broad categories, consisting of:

1. Overall satisfaction with the building
2. Noise,
3. Indoor environment quality (IEQ) in the winter,
4. IEQ in the summer,
5. Lighting, and
6. Overall comfort.

Figure 1 summarizes survey results according to these categories. The response rates achieved are summarized in Table 3. The analysis of student surveys showed that the student answer distribution was independent of age. This means that the students in Grade 4 and older could be successfully surveyed for the purposes of a Post-Occupancy Study. Since none of the POE conducted to date included elementary or high school buildings, there is no suitable comparison benchmark for occupant surveys in elementary schools. Therefore, the average occupant responses from both buildings were compared to the midpoint "4" of the survey's scale, which also represents a neutral score. As evident from Figure 1, all schools scored above the midpoint in all of the categories, with LEED certified schools results being marginally better. All buildings were rated the highest in overall satisfaction, while lighting, noise and overall comfort received medium scores. In all three schools, indoor environment quality (IEQ) in the winter and spring/ fall (which includes thermal comfort and air quality) was rated the lowest. Most classrooms which achieved high scores for IEQ in the winter, also achieved high scores for the overall comfort. Good ratings for lighting and noise did not necessarily indicate high overall comfort scores. For all of the categories, data followed a normal distribution, slightly skewed towards the high satisfaction. In School 1 most of the respondents gave a score of 7 for overall satisfaction.

Field Measurements The results of the survey were used to identify areas of concern and areas where high levels of comfort were achieved. The spaces which achieved the lowest, average and highest scores in the category of winter indoor environment quality were selected for further investigation through field testing. In order to assess thermal comfort, temperature and relative humidity have been monitored for a period of one year with measurements recorded every two minutes. To evaluate indoor air quality, carbon dioxide levels were monitored for one day periods in various classrooms logging every 10 seconds.

Analysis showed that average and maximum temperatures and respective relative humidity fall under what is considered to be thermal comfort range in the winter [8]. This comfort range is shown in grey on the psychometric chart in Figure 2.

The results confirmed that the average temperature in the classrooms which achieved low scores for winter thermal comfort and air quality, was between 0.5°C and 1.3°C lower than the measured temperature in classrooms with high ratings. Lower relative humidity (by up to 10%) in low rated spaces was also observed.

Most of the minimum winter temperatures and humidity observed during occupancy hours fall outside of the comfort range. However, the low temperatures were usually recorded early in the morning on very cold days before the schools were fully occupied. For example, two of the lowest temperatures were recorded February 27 and 28, when outdoor temperatures at 8am were -15°C and -18°C respectively, which is well below seasonal norms. Generally, smaller temperature variations were recorded in rooms which achieved higher scores in occupant survey. Slight temperature drops usually occur when the classroom is temporarily unoccupied, for example during recess. Larger temperature variations were recorded in the areas with a lot glazing resulting in large heat loss in the morning and large heat gain from solar radiation. This resulted in slight thermal discomfort in these spaces. Thermostats in the classrooms allow occupants to adjust indoor temperature by +/-1°C. This adjustment in combination with large glazed areas may not have resulted in the improvement of comfort level.

Indoor Air Quality Measured average carbon dioxide levels in both schools ranged from 691 – 1019 ppm, which is below 1200 ppm, a general limit recommended by ASHRAE [9]. It has been noted that occasionally higher levels of CO_2 than 1200 ppm were observed (maximum of 1764 ppm). This could be the direct result of prolong occupancy (e.g., 2 period class) and could be regarded as an exception. There was also no clear correlation between CO_2 levels and room rankings for indoor environment quality (IEQ), unlike the strong correlation between temperature and room rankings. This means that the results for IEQ reflect occupant sentiment towards thermal comfort, more so than air quality. This could also suggest that generally, occupants in TLW and CWS find thermal quality more important (or a bigger problem) than air quality.

Overall Comfort Occupancy survey results and field measurements both indicate that occupancy comfort levels are quite high in all schools. Over 80% of respondents rated overall satisfaction with the indoor environment over four. It is also considered that comfortable environment is achieved when over 80% of the people are comfortable [9]. In addition, thermal comfort and air quality measurements also fall under what is commonly believed to be a comfort range in the winter.

Energy use Predicted energy was available for LEED certified projects only. Study of energy simulation results and LEED certification submission resulted in determination of predicted performance. It was found that generally simulation underestimated the energy use, especially the use of the gas which may be associated with the efficiency of the equipment. Figure 3 summarizes actual performance of each school, predicted performance for schools 1 and 3 and other average energy consumption for Ontario, Canada and new schools.

CONCLUSIONS

New mechanical systems are both energy efficient and capable of delivering very good in-door environment. In combination with building automated system the quality of interior spaces and energy efficiency improved. This applies to all new schools. Therefore there is no significant difference between LEED school and new school. It has been noticed that the wall systems have only moderate thermal resistance and large amounts of glazing will result in significant heat losses.

The operation practices can have a significant impact on energy use. All corridors had 50% of lights on at all times, although the illumination levels were high enough that lighting was not required.

Occupancy lighting sensors in the classrooms were designed to reduce electricity use, but in reality, these systems were being circumvented by users who have opted to manually control the lighting conditions or motion activated sensor resulted in lighting coming while it was not required.

The LEED submission documents illustrated that significant savings on heating in TLW were expected to be achieved mostly through the use of efficient mechanical systems. However, gas consumption in TLW was much higher than expected indicating that the strategy of reliance on mechanical systems was unable to materialize expected savings on gas consumption.

The design which focuses on daylighting must be accompanied by a detailed study investigating impact of daylight. It has been observed that upper level of windows introduced to bring in the light caused significant glare in south facing classrooms. The glare is strong and very disturbing to children sitting at a work table. As a result of this problems interior window blinds were introduced. These are manually operated for each of many windows in each classroom. It was uncommon to find blinds down all the time and interior lighting on even when glare is not a problem.

On the other hand, the use of passive cooling strategies, such as natural ventilation, may not be the best solution for the schools as manually operated windows are often found without manual winders. These were probably removed because of difficulty in controlling their operations as they conflict with the computerized operation of the mechanical system.

Evaluation of occupant comfort and satisfaction through both field measurement and survey results indicated high comfort levels. Comfortable environment during heating season was achieved in all schools as over 80% of occupants [9] rated it 4 or higher.

All buildings received high scores in all surveyed categories (above midpoint on a survey’s scale). Lighting was rated exceptionally high, which could have a positive impact on students' ability to learn [4]. Survey results have also shown satisfaction with indoor air quality and thermal comfort. This was especially true in School1, where several respondents have also indicated that their health (in particular respiratory) problems reduced dramatically when they began attending (or working in) the school. This shows that the design strategies for improving indoor air quality, such as careful choice of building material and use of radiant floor heating, were successfully implemented. According to the results of the occupant survey, one aspect that needs closer attention during the design phase is building acoustics, since satisfaction with noise levels was rated the poorest.

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REFERENCES

1. U.S. Department of Energy DOE. Building technologies program: schools. (May 2007), [Online], Available: http://www.eere.energy.gov/buildings/info/schools/ [17 November 2007].
2. Natural Resources Canada. Commercial and institutional consumption of energy survey. (CIBEUS Tables). (May, 2005). [Online], Available: http://www.oee.nrcan.gc.ca/corporate/statistics/neud/dpa/data_e/cibeus_description.cfm?attr=0 [15 November 2007].
3. Turner, C. (Oct 2006). A Post-Occupancy look at LEED building performance. *Heating/Piping/Air Conditioning Engineering: HPAC*, p. 26-33.
4. Kats, G. (Dec 2005). National Review of Green Schools. A Report for the Massachusetts Technology Collaborative, p. 32, 45.
5. Building Performance Evaluation Protocol. (2006). EcoSmart Foundation. Available: http://www.sbtc.ca/index.cfm?pk=3 [October 21, 2007]
6. Baird, G et al. (2004). Probe-Style Questionnaire Surveys of Building Users – An International Comparison of their Application to Large-Scale Passive and Mixed-Mode Teaching and Research Facilities. *Closing the Loop Conference.*
7. Canadian Climate Normals 1971-2000. (2006). Environment Canada.http://www.climate.weatheroffice.ec.gc.ca/prods_servs/cdn_climate_summary_e.html [15 January 2009]
8. ANSI/ASHRAE Standard 55-2004, Thermal Environmental Conditions for Human Occupancy. (2004).
9. ANSI/ASHRAE Standard 62-2001, Ventilation for Acceptable Indoor Air Quality. (2001).

Table 2: Heating, cooling, building envelope, features

Facility	Energy Use		Building Envelope Summary	Features
	Electricity	Gas		
School 1	AC, VAV, Lighting	Condensing boiler w. VAV diffusers, radiant floor heating, HR	R_{walls}= 15-20 R_{window} = 3	Daylighting – light shelves, natural ventilation, indoor air environment, CO_2 monitoring, BAS
School 2	AC, lighting	Forced air w. radiant floor heating	R_{walls}= 18 R_{window} = 2	Daylighting/ shading Acoustic separation, CO_2 monitoring
School 3	AC, lighting	Condensing boiler, forced w. hydronic heating	R_{walls}= 15.5-17.6 R_{window} = 1.8	Daylighting/ shading, CO_2 monitoring

Abbreviations: AC – air conditioning; VAV – variable air volume; HR – heat recovery; BAS – building automation system