AN EVALUATION OF INDOOR ENVIRONMENTAL QUALITY AND OCCUPANT WELL-BEING IN MANITOBA SCHOOL BUILDINGS

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ABSTRACT

This exploratory research aims to evaluate indoor environmental quality in the classrooms of three school buildings in Southern Manitoba, Canada, and to evaluate the well-being of these schools' teachers as it pertains to their perception of their classrooms' indoor environment. The schools include a middle-aged, conventional school; a new, non-green school; and a new, green school certified using the Leadership in Energy and Environmental Design rating system. The methodology involved using a mobile instrument cart to conduct snapshot measurements of thermal comfort, indoor air quality, lighting and acoustics in classrooms and an occupant survey to evaluate teachers' long-term satisfaction with their classrooms' indoor environmental quality. The results showed that the new, green and new, non-green schools' classrooms performed better than the conventional, middle-aged school's classrooms with respect to some aspects of thermal comfort and indoor air quality only. Teachers in the new, green school and in the new, non-green school were more satisfied than teachers in the conventional, middle-aged school with their classrooms' overall indoor environmental quality, lighting quality and indoor air quality. Surprisingly, the new, green and new-non green school classrooms' performance were very comparable with the new, green school's classrooms performing statistically significantly better with respect to relative humidity. Similarly, none of the differences in teachers' satisfaction ratings between the new, green and new, non-green school were statistically significant.

KEYWORDS:

building performance evaluation, post occupancy evaluation, indoor environment, building energy use

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1. INTRODUCTION

People spend 90% of their time indoors (Hoppe, 2002), making the need to provide energy-efficient buildings with satisfactory indoor environmental quality (IEQ) a priority. Even though the traditional focus on energy-efficiency has led to the emergence of airtight buildings that consume less energy, it has also led to buildings with poorer IEQ that require mechanical ventilation to meet minimum air ventilation rates (Leslie, 2014). These environmental concerns have led to the development of a number of environmental rating systems, the most prominent of which is the Leadership in Energy and Environmental Design (LEED) (CaGBC, 2013). These systems emphasize the need for green buildings that conserve resources, save on long-term costs and provide healthful and productive environments to building occupants and the community.

While the literature has focused on evaluating office buildings, not enough attention has been paid to school buildings (Lee & Guerin, 2009). There is in particular little empirical evidence about their IEQ performance and school teachers' well-being in relation to their indoor environment in Canadian school buildings in particular. This exploratory research aims to address this limitation by evaluating IEQ in the classrooms of three conventional and green school buildings in Southern Manitoba, Canada, focusing on the aspects of thermal comfort, indoor air quality (IAQ), lighting and acoustics. It also aims to evaluate the well-being of these schools' teachers as it pertains to their perception of their classrooms' indoor environment.

A review of the literature on IEQ in green buildings shows a focus on investigating thermal comfort in particular, most probably due to the relationship between thermal comfort, heating, ventilation, and air-conditioning and energy consumption (Huang et al., 2012). One important aspect of thermal comfort is the level of control occupants have over it. A number of studies (e.g. Baker, 2011; Lackney, 2001) found that the higher the level of occupant control of thermal comfort, the more satisfied occupants were with it.

IAQ is another important determinant of IEQ, prompting a number of studies (e.g. Myhrvold et al., 1996; Wargocki and Wyon, 2013) to investigate its impact on students. These studies (e.g. Zuraimi et al., 2007) found naturally ventilated buildings to be healthier for students suffering from respiratory illnesses than mechanically ventilated ones.

Studies on lighting quality in schools (e.g. Heschong 2003b; Mardaljevic et al. 2009) generally showed that students in classrooms with sufficient daylight performed better on tests than students in classrooms with little daylight. Those studies on lighting quality in office buildings such as Heschong Mahone Group (2003a) noticed productivity improvements in office workers following increases in natural daylighting, and when workers were subjected to a pleasant view.

Acoustics quality is the aspect that is the least investigated in the literature. Existing research showed that proper acoustical design that focuses on reducing background noise and reverberation time can have a direct effect on acoustical performance and student learning (Acoustical Society of America, 2010; Lilly, 2000). Nevertheless, there is a need for more guidance on acoustics that can be incorporated into existing green building rating systems (Prakash, 2005).

Research on school buildings' IEQ, in particular green school buildings remains limited (Elzeyadi, 2012), despite high performance schools being the fastest growing sector of the construction industry (McGraw Hill, 2011). Schools in Canada account for 11% of the total energy used by commercial and institutional buildings and are the second largest consumers of energy in this sector (Office of Energy Efficiency, 2013).

A review of the literature shows no standardized method for assessing school buildings' IEQ. Most studies (e.g. Brager & Baker, 2009; Catalina & Iordache, 2012) used occupant surveys to do so. Only a few (e.g. Turunen et al., 2014) used physical measurements and occupant surveys combined. Sanoff et al. (2001) developed their own set of questionnaires that are now broadly used in the literature (e.g. Higgins et al., 2005). Moreover, most studies (Katafygiotou & Serghides, 2014; De Giuli et al., 2015) investigated very small samples of schools. Only a few (e.g. Haverinen-Shaughnessy et al., 2015; Al-Hubail and Al-Temeemi, 2015) used larger samples.

The results of these studies showed common results. Dascalaki and Sermpetzoglou (2011) evaluated IEQ in Hellenic schools and found that a third of all schools did not meet their relative humidity (RH) and carbon dioxide (CO_2) standards. Another study by Smedje and Norback (2000) in Sweden found that 77% of the schools did not meet building code regulations. In Canada, a study of 33 Toronto schools by Issa et al. (2011) using a combination of second-hand absenteeism and student performance data and occupant surveys, found teachers in green schools to be more satisfied with all aspects of IEQ except for acoustics than teachers in other schools. The study found absenteeism to be lower and student performance higher in green schools. A study by Swail (2013) focused on evaluating IAQ in 24 Winnipeg schools using a combination of physical measurements, an occupant survey, and second-hand absenteeism data found IAQ to be problematic in nearly all schools, with 79% of respondents experiencing sick building syndrome-like symptoms. Another study by Straka and Aleksic (2009) using on-site physical measurements and occupant surveys and focusing on three Toronto schools found a relationship between classroom temperatures and occupants' ranking of their classrooms' IEQ.

2. METHODOLOGY

This section presents the methodology used to recruit the schools participating in this research and to collect and analyze school classrooms' IEQ and teachers' well-being. It describes the three main components making up the methodology: the on-site physical measurements, the occupant survey and the field observations.

2.1. Schools' Recruitment

The research involved collaborating with three school divisions from the rural southern region of Manitoba, Canada. Preliminary data from the 50 schools in those divisions was collected in order to select a conventional, middle-aged school; a new, non-LEED school and a new, LEED school to evaluate. The only LEED school available within this population was selected as the new, LEED school. A stratified random sampling process and Newman proportional allocation were used to select the two other schools. Table 1 summarizes the main features of the three schools selected.

The new, LEED school was a Silver one certified to the LEED Canada for New Construction and Major Renovation 1.0 rating system. It had achieved 34 points out of 70, scoring in its IEQ category 6 out of 15 points. These points show that the school had developed and implemented an IAQ management plan for its construction but not the pre-occupancy phase.

TABLE 1. Features of Schools Selected for Research

Features	New, LEED School	New, Non-LEED School	Middle-Aged, Conventional School
School Type	K-12	Elementary	Elementary
Total Building Floor Area (m^2)	2660	2760	3400
Number of Floors	1	1	1
Number of Classrooms	7	8	8
Number of Teachers	8	11	13
Number of Occupants	80	230	210
School Open for Community Use?	Yes	Yes	Yes
Opening Year	2009	1991	1968
Ventilation Type	Mechanical	Mechanical	Mechanical

It used low-emitting adhesives, sealants and sealant primers; low-emitting paints and coatings; and low-emitting carpets and rugs. Nevertheless, it did not use low-emitting composite woods and laminate adhesives. It offered high levels of occupant control of lighting, thermal and ventilation systems by providing at least an average of one operable window and one lighting control zone per 18.5 m^2 for all regularly occupied areas. However, it did not use a CO_2 monitoring system to provide feedback on space ventilation performance. It did not install a ventilation system that resulted in an air change effectiveness greater than or equal to 0.9. Although it complied with ASHRAE (2004) for thermal comfort conditions for human occupancy, it did not provide a permanent monitoring system to ensure continued building thermal performance. The school did not achieve at least 250 lux of daylight illuminance levels for 75% of occupied spaces, nor did it provide a direct line of sight to vision glazing for building occupants in 90% of all regularly occupied areas.

2.2. On-Site Physical Measurements

The research involved conducting snapshot measurements of school classrooms' IEQ, focusing on the IEQ aspects and parameters shown in Table 2 using the sensors shown in the same table. The research also entailed determining recommended values for each parameter as found in standards such as ASHRAE (2004, 2013) and determining the units for each parameter, the mounting heights of the sensor used to measure each, as well as the measurement period or cycle. Many of the methods and standards used were based on office buildings because of the lack of similar standards for school buildings.

The research team used the Indoor Environmental Quality Cart (IEQC) developed by the University of Manitoba Faculty of Architecture in collaboration with E H Price Winnipeg (Mallory-Hill, 2012) to evaluate these IEQ parameters. The IEQC shown in Figure 1 is a mobile, state of the art piece of equipment that combines several sensors, each aiming to measure one or more IEQ parameters, with an onboard computer remotely controlled by a laptop computer. This cart represents an improvement of an older model developed by Newsham et al. (2012) to study the IEQ of office buildings.

The evaluation started with an initial inspection of every school and of its floor plans to select the classrooms to be assessed. Six classrooms of similar sizes (60 to 70 m^2) and occupancy loads (15 to 25 students present in each) were selected from every school. All six classrooms in every school were evaluated in one day, with one sampling location used per classroom. The IEQC was set up in the centre of every classroom and kept running for ten minutes to capture the IEQ parameters to be measured. Only the last five minutes of measurements were used

TABLE 2. IEQ Aspects and Parameters Evaluated in Research

IEQ Aspects	Parameters	Sensors	Recommended Values		Mounting Heights (m)
Thermal Comfort	Air temperature	RTD	20 to 24.5°C	ASHRAE 55-2004 (2004)	0.10, 0.59, 0.97
	Air velocity	Thermo Air 64	0.1 to 0.2 m/s	ASHRAE 55-2004 (2004)	
	Relative humidity	Gray Wolf IQ610	30 to 65%	ASHRAE 62.1-2013 (2013)	0.80
IAQ	Carbon dioxide	Gray Wolf IQ610	< 1,100 ppm	ASHRAE 62.1-2013 (2013)	0.80
	Total Volatile Organic Compounds (TVOCs)		< 300 μg/m^3	Bienfait et al. (1992)	
Lighting Quality	Illuminance level	Li Cor LI 210	300 to 750 lux	Rea (2000)	0.80
Acoustics Quality	Sound pressure level	Scantek Sound Level Meter	45 to 60 dB	Acoustical Society of America (2010)	1.17

FIGURE 1. Indoor Environmental Quality Cart Used in Research

for the analysis to avoid the initial high and low values associated with the lagging response of sensors. The measurements were done in the presence of students and teachers, without interrupting regular classroom activities. The schools were visited on days where outside weather conditions were similar. The weather was sunny and clear on those days with the range of temperatures at midday varying between 15°C and 18°C. The research team visited all selected classrooms on the day of measurements in the early morning to close any open windows. Students and teachers were instructed not to open them until the measurements were completed in their respective classrooms.

2.3. Occupant Survey

An occupant survey was also administered online to the 32 teachers in these three schools to evaluate their long-term satisfaction with their classrooms' IEQ. The survey was based on Newsham et al. (2012) and Sadick et al. (2014a and 2014b) surveys for office buildings, but adjusted to match school buildings and teachers' unique needs. It encompassed a total of 40 questions, the majority of which were closed-ended over five different modules: a Core module and four separate modules for thermal comfort, IAQ, lighting quality, and acoustics quality respectively.

2.4. Field Observations

An observation form, based on Sadick et al. (2014a and 2014b) was used to record other information such as outside weather conditions on the days of measurement, as well as the number of students and the equipment available (e.g. monitors, projectors, printers) in each classroom. Other information captured included classrooms' floor and wall finishes and the number and types of lamps used in each. This information was collected at the same time as the on-site physical measurements, with photographs of indoor conditions taken at that time as well.

2.5. Data Analysis

Several statistical tests were conducted using the software IBM SPSS version 24 and Laerd Statistics (2015) to evaluate the statistical significance of the results at p = 0.05 and a 95% level of confidence. The research focused on analyzing the physical measurements of IEQ, and teacher survey responses separately.

2.5.1. Physical Measurements of IEQ

An analysis of the different classrooms evaluated showed that two of them were portable classrooms in the new, non-LEED school. Given that those classrooms had their own HVAC systems and were not connected to the main building and its systems, they were not taken into account in the statistical analysis of the physical measurements of IEQ. Every IEQ parameter measured was considered a continuous variable with every classroom the unit of analysis for statistical analysis purposes. A Multiple Analysis of Covariance (MANCOVA) test was used to evaluate the effect of classroom group (i.e. the independent variable) on the combined thermal comfort parameters of classroom temperature, air velocity and RH (i.e. the dependant variables) after controlling for the effect of classroom occupant density (i.e. the covariate). Classroom group referred to whether the classroom was in the conventional, middle-aged school; the new, non-LEED school; or the new, LEED one. Classroom occupant density referred to the ratio of the number of occupants in the classroom at the time of measurements to classroom floor area. Another MANCOVA test was used to evaluate the effect of classroom group on the combined IAQ parameters of classroom CO_2 and TVOC levels after controlling for the effect of classroom occupant density. Preliminary assumption checking revealed that there was multivariate normality for the different thermal comfort and IAQ dependant variables, as assessed by the Shapiro-Wilks test ($p > 0.05$). There were also no univariate or multivariate outliers, as assessed by boxplot inspection and Mahalanobis distance ($p > 0.001$), and no multicollinearity between the different dependant variables for thermal comfort and IAQ, as assessed by Pearson's correlation. There was a linear relationship between the covariate and each dependant variable for each classroom group, as assessed by visual inspection of scatterplots. There was also homogeneity of regression slopes as the interaction term (classroom group * classroom occupant density) was not statistically significant for each dependant variable ($p > 0.05$). There was homogeneity of variance-covariances matrices, as assessed by Box's test of equality of covariance matrices ($p > 0.01$). If a statistically significant effect was found, individual Analysis of Covariance (ANCOVA) tests were conducted to evaluate the effect of classroom group on each individual parameter. If this effect was statistically significant, Bonferroni post hoc tests were used to investigate the statistical significance of the differences between every two groups of classrooms. Data related to these tests are reported as unadjusted mean ± standard deviation unless otherwise noted.

Two ANCOVA tests were used to evaluate the effect of classroom group (i.e. the independent variable) on the single parameter of classroom desktop illuminance level for lighting and on the parameter of classroom background noise level for acoustics (i.e. the dependant variable) after controlling for the effect of classroom occupant density (i.e. the covariate). Preliminary assumption checking showed a linear relationship between the covariate and each dependant variable for each classroom group, as assessed by visual inspection of scatterplots. There was also homogeneity of regression slopes as the interaction term (classroom group * classroom occupant density) was not statistically significant for each dependant variable ($p > 0.05$). Standardized residuals for classroom groups were normally distributed, as assessed by Shapiro-Wilk's test ($p > 0.05$). There was homoscedasticity, as assessed by visual inspection of the standardized residuals plotted against the predicted values and homogeneity of variances, as assessed by Levene's test of homogeneity of variance ($p > 0.05$). No outliers in the data were found, as assessed by no cases with standardized residuals greater than ±3 standard deviations. Data related to these tests are reported as unadjusted mean ± standard deviation unless otherwise noted.

2.5.2. Occupant Well-Being

Teachers' responses to the survey questions were in general considered nominal or ordinal variables, with every single teacher considered the unit of analysis for statistical analysis purposes. There were six questions within the survey where teachers were asked to rate using a Likert scale ranging from "Not at all satisfied" (i.e. 1) to "Very satisfied" (i.e. 7) their level of satisfaction or dissatisfaction with each IEQ aspect in their schools' classrooms. These ratings were considered ordinal variables. The aspects rated included: overall classroom IEQ, thermal comfort, IAQ, overall lighting quality, daylighting quality and acoustics quality. Kruskal-Wallis tests were used to determine whether there were statistically significant differences in teachers' ratings of each aspect (i.e. the dependant variable) between teachers in the three schools (i.e. the independent variable). Distributions of teachers' satisfaction ratings for all of these aspects were not similar for the three teacher groups, as assessed by visual inspection of a boxplot. Therefore, the Kruskal-Wallis test could not be used to determine the statistical significance of the differences in the medians of these groups and was used instead to determine the statistical significance of the differences in these groups' distributions or mean ranks. If a statistically significant effect was found, pairwise comparisons were performed using Dunn's (1964) procedure with a Bonferroni correction for multiple comparisons. Statistically significant values related to the test are reported as mean ranks with the adjusted p-values unless otherwise noted.

Cumulative odds ordinal logistic regression with proportional odds tests were used to evaluate the effect of school teachers' age, length of employment, gender and school (i.e. the independent variables) on their satisfaction with each of the following aspects: overall classroom IEQ, thermal comfort, IAQ, overall lighting quality, daylighting quality and acoustics quality (i.e. the dependant variable). Survey questions enquiring about school teachers' age, employment, gender and school were multiple choice questions. Teacher gender was considered a nominal variable with teachers having to select between "male" and "female". School was considered an ordinal variable with teachers having to select the name of the school they worked in from the three schools available. Teachers' age and years of experience were also ordinal variables. Teachers had to select between "30 or under", "between 31 and 50" and "over 50" for their age and between "less than 1 year", "between 1 and 2 years", "between 3 and 5 years" and "over 5 years" for the length of their employment in their respective schools. Nevertheless, all ordinal variables were treated as nominal as per the requirements of the test. Preliminary assumption checking showed no multicollinearity between the independent variables as tolerance values were greater than 0.1 and variance inflation factor (VIF) values less than 10. The assumption of proportional odds was met for each test focusing on each IEQ aspect except for lighting, as assessed by a full likelihood ratio test comparing the fit of the proportional odds model to a model with varying location parameters ($p > 0.05$). Therefore, a multinomial logistic regression was used to evaluate the effect of the same independent variables on the dependant variable: teachers' satisfaction with their classrooms' lighting quality. Nevertheless, as per the requirements of the test, it assumed that the dependant variable was nominal. Preliminary assumption checking found no outliers, high leverage values or highly influential points.

Spearman's rank-order correlation test was used to determine the relationship between teachers' satisfaction with their ability to control their classrooms' daylighting on one side and their satisfaction with each of the following aspects on the other: classroom daylighting quality, overall lighting quality and visual comfort. Teachers were asked to rate their satisfaction with all of these aspects using a Likert scale ranging from "Not at all satisfied" (i.e. 1) to "Very satisfied" (i.e. 7) with the ratings considered ordinal variables. Visual inspection of the relationships between every pair of variables showed they were monotonic.

3. RESULTS AND DISCUSSION

This section presents the results of the data analysis. The first subsection focuses on the results of the physical measurements of IEQ and the second on the occupant well-being survey results.

3.1. Indoor Environmental Quality

This subsection presents the results of the analysis of the on-site physical measurements of thermal comfort, IAQ, lighting and acoustics in the schools' classrooms. Table 3 shows the descriptive statistics for all of these measurements.

3.1.1. Thermal Comfort

The MANCOVA test results showed a statistically significant difference between the different classroom groups on the combined classroom temperature, air velocity and RH after controlling for classroom occupant density, $F\,(6, 20) = 6.672$, $p = 0.001$; Wilks' $\Lambda = 0.111$; partial $\eta^2 = 0.667$. The individual ANCOVAs revealed a statistically significant difference in classroom temperature between the different classroom groups after controlling for classroom occupant density, $F\,(2, 12) = 5.455$, $p = 0.021$; partial $\eta^2 = 0.476$. There was also a statistically significant difference in classroom relative humidity between classroom groups after controlling for classroom occupant density, $F\,(2, 12) = 25.575$, $p < 0.0005$; partial $\eta^2 = 0.810$. No statistically significant difference in classroom air velocity was found between the different classroom groups.

The Bonferroni post-hoc tests showed that classrooms in the conventional, middle-aged school had a statistically significant lower mean classroom temperature (22.39 ± 1.01°C) than classrooms in the new, LEED school (23.92 ± 0.60°C, $p = 0.019$). Table 3 shows that the

TABLE 3. Descriptive Statistics for Thermal Comfort, IAQ, Lighting, and Acoustics Physical Measurements.

Classrooms	IEQ Aspect	Thermal Comfort			Indoor Air Quality		Lighting	Acoustics
	Parameters	Temperature (°C)	Air Velocity (m/s)	RH (%)	CO_2 concentrations (ppm)	TVOCs (μg/m^3)	Illuminance Level (lux)	Background Noise (dB)
New, LEED	Minimum	23.23	0.30	40.61	629.17	272.21	141.84	47.35
	Maximum	24.90	0.69	47.00	767.50	457.09	874.75	64.80
	Mean	23.92	0.47	44.05	709.90	344.60	528.95	57.49
	Standard Deviation	0.60	0.14	2.34	57.02	76.08	288.47	6.12
Classrooms within recommended values (%)		84	0	100	100	33	67	67
New, Non-LEED	Minimum	22.81	0.35	48.02	580.31	206.18	434.89	55.85
	Maximum	23.78	1.15	52.48	910.31	561.77	693.13	70.29
	Mean	23.36	0.82	50.17	766.78	325.46	567.78	61.15
	Standard Deviation	0.45	0.35	1.96	114.74	166.48	122.49	6.32
Classrooms within recommended values (%)		100	0	100	100	50	100	75
Middle-Aged, Conventional	Minimum	21.02	0.33	50.81	862.77	627.53	546.29	49.04
	Maximum	23.24	0.70	56.52	1114.50	988.56	824.88	63.51
	Mean	22.39	0.44	53.33	971.18	732.12	671.35	54.24
	Standard Deviation	1.01	0.14	2.46	99.40	134.61	100.30	5.18
Classrooms within recommended values (%)		100	0	100	84	0	67	84
Recommended Values		20 to 24.5	0.10 - 0.20	30 - 65	<1,100	<300	300 – 700	45 - 60

temperature of every single classroom in the three schools fell within the recommended range of 20 to 24.5°C, except for one classroom in the new, LEED school, indicating a high degree of thermal comfort within them.

The post-hoc tests also showed that classrooms in the new, LEED school had a statistically significant lower mean RH (44.05 ± 2.34%) than classrooms in the new, non-LEED school (50.17 ± 1.96%, $p = 0.026$) and in the conventional, middle-aged one (53.33 ± 2.46%, $p < 0.0005$). This was in line with the low RH levels reported in Swail (2013) in Winnipeg schools. This could be due to the lower mean occupant density of the new, LEED school's classrooms (20 people/100 m^2), and lower mean humidity ratio (8.4 g moisture/kg dry air) derived from using the psychrometric chart (Venmar CES, 2016) in comparison with the mean occupant density and humidity ratio of the conventional, middle-aged school (28 people/100 m^2 and 9.2 g moisture/kg dry air respectively) and new, non-LEED school's classrooms (36 people/100 m^2 and 9.4 g moisture/kg dry air respectively). Table 3 shows that all relative humidity (RH) measurements in the classrooms of the three schools were within the recommended range of 30 to 65%, indicating satisfactory thermal comfort within them.

However, all classroom air velocities measured when windows were closed were above the recommended 0.2 m/s in all schools. The new, non-LEED school's classrooms had the highest mean air velocity of the three schools (v = 0.82 ± 0.35 m/s) whereas the new, LEED school and middle-aged conventional school's classrooms had lower mean values of 0.47 ± 0.14 m/s and 0.44 ± 0.14 m/s respectively.

3.1.2. Indoor Air Quality

The MANCOVA test results showed a statistically significant difference between classroom groups on the combined classroom CO_2 and TVOC levels after controlling for classroom occupant density, $F(4, 22) = 11.640$, $p < 0.0005$; Wilks' $\Lambda = 0.103$; partial $\eta^2 = 0.679$. There was a statistically significant difference in CO_2 levels between classroom groups after controlling for classroom occupant density, $F(2, 12) = 10.872$, $p = 0.002$; partial $\eta^2 = 0.644$. There was also a statistically significant difference in TVOC levels between classroom groups after controlling for classroom occupant density, $F(2, 12) = 18.780$, $p < 0.0005$; partial $\eta^2 = 0.758$.

The Bonferroni post-hoc tests showed that classrooms in the conventional, middle-aged school had a statistically significant higher CO_2 mean levels (971.18 ± 99.40 ppm) than classrooms in the new, non-LEED school (766.78 ± 141.74 ppm, $p = 0.034$) and in the new, LEED school (709.90 ± 57.02 ppm, $p = 0.002$). This could also be due in part to the lower mean occupant density of the new, LEED school's classrooms in comparison with the new, non-LEED and conventional, middle-aged school's classrooms. Table 3 shows that CO_2 levels were below recommended levels in all classrooms in the new, LEED school and in the new, non-LEED one but above it in 16% of the classrooms in the conventional, middle-aged one. Swail (2013) also reported high CO_2 levels in nearly all Winnipeg schools in Manitoba.

The post-hoc tests also showed that classrooms in the conventional, middle-aged school had a statistically significant higher TVOC mean level (732.12 ± 134.61 μg/m^3) than classrooms in the new, non-LEED school (325.46 ± 166.48 μg/m^3, p = 0.001) and in the new, LEED school (344.60 ± 76.08 μg/m^3, $p < 0.0005$). The lower TVOC levels in the new, LEED school may have been related to the low-emitting adhesives, sealants and paints used in this school's classrooms whereas the higher TVOC levels in the middle-aged, conventional school may have been related to the cleaning and disinfecting chemicals found in some of this school's classrooms and to the new furniture found in others that may have still been off-gassing.

While 50% of the classrooms in the new, non-LEED school had TVOC levels below the recommended 300 μg/m^3, only 33% of the classrooms in the new, LEED school and none of the classrooms in the conventional, middle-aged one had TVOC levels below this level.

3.1.3. Lighting

The ANCOVA test results showed that after adjusting for classroom occupant density, there wasn't a statistically significant difference in classroom illuminance level between the different classroom groups, F (2, 12) = 0.657, p = 0.536, partial η^2 = 0.099.

As shown in Table 3, the new, LEED school's classrooms had the lowest mean illuminance level of all schools (528.95 ± 288.47 lux). The lowest illuminance level was recorded in one classroom in the new, LEED school (141.84 lux), where 50% of the lights were off and the window shades closed at the time of measurement. By contrast, the highest illuminance levels in the new LEED school (800.41 lux and 874.75 lux) were recorded in two adjacent classrooms with the same orientation. These classrooms had windows that were larger than average, with 50% of the shades open in the first classroom and all shades open in the second, as shown in Figure 2. The highest illuminance levels in the new, non-LEED school (743.05 lux) and in the middle-aged, conventional one (824.88 lux) were also associated with two classrooms where all of the shades were open and all lights turned on at the time of measurement. All of the classrooms in the new, non-LEED school had illuminance levels within the recommended range of 300 to 700 lux versus 67% in the new, LEED school and the conventional, middle-aged one.

3.1.4. Acoustics

The ANCOVA test results showed that classroom group had no statistically significant effect on classroom background noise level after controlling for classroom occupant density, F (2, 12) = 0.691, p = 0.520, partial η^2 = 0.103.

FIGURE 2. Fully Open Shades in Classroom in New, LEED School.

Table 3 shows that only 67% of the classrooms in the new, LEED school had background noise levels within the recommended range of 45 to 60 dB for occupied spaces, versus 75% and 84% in the new, non-LEED and conventional, middle-aged schools respectively. The middle-aged, conventional school's classrooms had the lowest mean background noise level (54.24 ± 5.18 dB) whereas the new, non-LEED school's classrooms had the highest mean background noise level (61.15 ± 6.32 dB). The highest value was recorded in a classroom in the new, non-LEED school (70.29 dB) and could have been due to the uncharacteristically loud HVAC noise in this classroom.

3.2. Occupant Well-Being

Of the entire population of 32 teachers in all three schools, 27 completed the survey, resulting in a total response rate of approximately 84%. This section presents the results of the analysis of those responses, with Table 4 providing more descriptive statistics about them.

3.2.1. Overall Indoor Environmental Quality

The Kruskal-Wallis test results showed that the mean ranks or distributions of the ratings for teachers' satisfaction with overall classroom IEQ were statistically significantly different between teacher groups, $\chi^2(2) = 12.409$, $p = 0.002$. The post hoc analysis revealed statistically significant differences in classroom IEQ satisfaction ratings between teachers in the middle-aged, conventional school (7.00) and new, non-LEED school (15.86) ($p = 0.006$) and between teachers in the middle-aged conventional school (7.00) and in the new, LEED school (18.50) ($p = 0.023$). All teachers were satisfied with overall classroom IEQ in the new, LEED school and in the new, non-LEED one, versus 50% only in the conventional, middle-aged one. These results were expected given the superior environment offered by the new, LEED school in comparison with the other two schools. It is in line with the results of other Canadian school studies (e.g. Issa et al., 2011), thereby reinforcing LEED school occupants' improved perception of IEQ in comparison with other school occupants.

The ordinal logistic regression test also showed that the school surveyed had a statistically significant effect on teachers' satisfaction with overall classroom IEQ, Wald $\chi^2(2) = 10.589$, $p = 0.005$. The odds that teachers in the new, non-LEED school would consider overall classroom IEQ satisfactory was 159.215 (95% CI, 7.551 to 3374.802) times that of teachers in the middle-aged conventional school, a statistically significant effect, Wald $\chi^2(1) = 10.589$, $p = 0.001$.

The ordinal logistic regression test showed that teachers' length of employment also had a statistically significant effect on their satisfaction with overall classroom IEQ, Wald $\chi^2(1) = 4.459$, $p = 0.035$. The odds that teachers who worked for "more than 5 years" in the same school would find overall classroom IEQ satisfactory was only 0.192 (95% CI, 1.126 to 23.809) times that of teachers who worked "between 3 and 5 years" in the same school, a statistically significant effect Wald $\chi^2(1) = 3.527$, $p = 0.022$. This effectively means that teachers who worked "between 3 and 5 years" in the same school were 5.208 times more likely to find overall classroom IEQ satisfactory than teachers who worked for "more than 5 years" in the same school.

3.2.2. Thermal Comfort

The Kruskal-Wallis test results revealed that the mean ranks or distributions of the ratings for teachers' satisfaction with classroom thermal comfort were statistically significantly different

TABLE 4. Descriptive Statistics for Teachers' Satisfaction Ratings with Overall IEQ, Thermal Comfort, Indoor Air Quality, Overall Lighting Quality.

	Satisfaction Ratings	Overall IEQ	Thermal Comfort	IAQ	Lighting	Daylighting	Acoustics
New, LEED	Minimum	6.00	3.00	4.00	6.00	6.00	4.00
	Maximum	6.00	6.00	6.00	7.00	7.00	6.00
	Mean	6.00	5.25	5.50	6.25	6.25	5.25
	Standard Deviation	0.00	1.50	1.00	0.50	0.50	0.96
Teachers Satisfied (%)		100	75	100	100	100	100
New, Non-LEED	Minimum	4.00	2.00	3.00	2.00	1.00	2.00
	Maximum	6.00	7.00	7.00	6.00	7.00	6.00
	Mean	5.64	4.64	5.00	4.27	5.30	4.27
	Standard Deviation	0.67	1.69	1.27	1.49	2.06	1.42
Teachers Satisfied (%)		100	65	90	65	80	65
Middle-Aged, Conventional	Minimum	2.00	1.00	1.00	2.00	1.00	3.00
	Maximum	6.00	6.00	6.00	7.00	7.00	6.00
	Mean	3.90	3.00	3.27	3.60	4.40	4.67
	Standard Deviation	1.29	1.86	1.62	1.78	2.32	1.12
Teachers Satisfied (%)		50	40	42	50	66	90

between the three teacher groups, $\chi^2(2) = 6.459$, $p = 0.040$. Nevertheless, the post hoc analysis revealed no statistically significant differences in classroom thermal comfort satisfaction ratings between any two teacher groups. The ordinal logistic regression model investigated also found that the school surveyed did not have any statistically significant effects on teachers' satisfaction with classroom thermal comfort.

Nevertheless, Table 4 shows that teachers in the new, LEED school were more satisfied with classroom thermal comfort (mean rating (MR) = 5.25) than teachers in the new, non-LEED school (MR = 4.64) and in the conventional, middle-aged one (MR = 3.00). The percentage of teachers satisfied with classroom thermal comfort was lowest as expected in the middle-aged, conventional school (40%) and highest in the new, LEED school (75%), confirming Issa et al.'s (2011) results about LEED schools. Nevertheless, the percentage of dissatisfied teachers in all three schools exceeded the 20% limit recommended by the ASHRAE (2004), raising concerns about teachers' perception of classroom thermal comfort in general. This could be due to the issues experienced by them in all three schools. Approximately, 75% of all teachers complained about their inability to control their classrooms' temperature, reinforcing the need to provide them with personal controls such as thermostats to address these issues, as stipulated by Baker (2011) and Lackney (2001). Sixty-nine percent found their classrooms to be cold most of the time. These issues were very similar to the ones reported in studies such as Katafygiotou and Serghides (2014).

3.2.3. Indoor Air Quality

The Kruskal-Wallis test results showed that the mean ranks or distributions of the ratings for teachers' satisfaction with classroom IAQ were statistically significantly different between teacher groups, $\chi^2(2) = 8.386$, $p = 0.015$. The post hoc analysis revealed statistically significant differences in classroom IAQ satisfaction ratings between teachers in the middle-aged conventional school (8.68) and in the new, non-LEED school (16.41) ($p = 0.043$) only.

The ordinal logistic regression test also showed that the school surveyed had a statistically significant effect on teachers' classroom IAQ satisfaction, Wald $\chi^2(2) = 8.879$, $p = 0.012$. The odds that teachers in the new, LEED school would find classroom IAQ satisfactory was 23.739 (95% CI, 1.078 to 522.692) times that of teachers in the middle-aged conventional school, a statistically significant effect, Wald $\chi^2(1) = 4.031$, $p = 0.045$. The odds that teachers in the new, non-LEED school would find classroom IAQ satisfactory was also 11.337 (95% CI, 1.640 to 78.385) times that of teachers in the middle-aged conventional school, a statistically significant effect, Wald $\chi^2(1) = 6.057$, $p = 0.014$.

Table 4 also shows that all teachers in the new, LEED school were satisfied with classroom IAQ versus 90% and 42% of the teachers in the new, non-LEED school, and the middle-aged, conventional one respectively. These results are in line with the results by Swail (2013) and Issa et al. (2011) in Canada, and Turunen et al. (2014) elsewhere. Teachers' overwhelming satisfaction with IAQ in the new, LEED school could be related to its improved ventilation system, its IAQ management plan, and its use of environmentally-friendly materials and products. Teachers rated odours as the most problematic classroom IAQ issue (MR = 4.93), followed by stuffy and stale air (MR = 3.65): results that were in line with the ones reported in the literature (e.g. Baker, 2011; Mendell & Heath, 2005). Approximately, 50% of respondents attributed this odour problem to outside sources such car exhaust and sewer smell.

3.2.4. Lighting Quality

The Kruskal-Wallis test results demonstrated that the mean ranks or distributions of the ratings for teachers' satisfaction with overall classroom lighting were statistically significantly different between teacher groups, $\chi^2(2) = 6.362$, $p = 0.042$. The post hoc analysis found statistically significant differences in overall classroom lighting satisfaction ratings between teachers in the middle-aged, conventional school (10.10) and in the new, LEED school (20.75) ($p = 0.035$). Table 4 shows that all teachers in the new, LEED school were satisfied with overall classroom lighting quality, whereas only 65% and 50% of teachers were satisfied with it in the new, non-LEED school and the conventional, middle-aged one respectively. Approximately, 33% of teachers attributed their dissatisfaction with lighting quality to not enough daylight, with 44% reporting technical issues such as flickering. Some commented on how fluorescent lighting affected their eyesight and gave them headaches, leading many to turn them off during the day.

No statistically significant difference was detected in the mean ranks or distributions of the ratings for teachers' satisfaction with classroom daylighting between teacher groups. This is despite all teachers in the new, LEED school being satisfied with daylighting quality versus 80% and 66% in the new, non-LEED and conventional, middle-aged schools respectively.

All teachers in the new, LEED school were satisfied with the level of controllability of their lighting systems versus 80% and 60% of the teachers in the new, non-LEED school and conventional, middle-aged school. Spearman's correlation test results showed a strong statistically significant positive correlation between teachers' satisfaction with their ability to control classroom daylighting and their satisfaction with classroom daylighting quality, r_s (22) = 0.703, $p < 0.0005$). There was also a strong positive correlation between teachers' satisfaction with their ability to control classroom daylighting and their satisfaction with visual comfort, r_s (22) = 0.875, $p < 0.0005$). These results were expected and in line with existing literature results (e.g. Abbaszadeh et al., 2006; Patricia et al., 2000; Wang et al., 2015).

3.2.5. Acoustics Quality

The Kruskal-Wallis test results showed that the mean ranks or distributions of the ratings for teachers' satisfaction with classroom acoustics were not statistically significantly different between teacher groups, $\chi^2(2) = 1.750$, $p = 0.417$. This is despite Table 4 showing that teachers in the new, LEED school were on average more satisfied with classroom acoustics (MR = 5.25) than teachers in the new, non-LEED school (MR = 4.27) and teachers in the conventional, middle-aged one (MR = 4.67). All teachers in the new, LEED school were satisfied with classroom acoustics quality versus 65% and 90% in the new, non-LEED school and middle-aged school respectively.

Teachers in general rated HVAC noise to be the most problematic (MR = 3.18). They found it most problematic in the new, non-LEED school in particular (MR = 4.43) which may explain why they rated their satisfaction with classroom acoustics quality the lowest (MR = 4.27). Teachers in the new, LEED school found noise coming from other classrooms and corridors to be most problematic (MR = 2.5), which is in line with the results by Baker (2011). These results raise concerns that have been raised in the past (e.g. Issa et al., 2011; Lee & Guerin, 2009) about acoustical insulation in LEED schools and the need to further emphasize acoustics in future versions of LEED.

The ordinal logistic regression test showed that teachers' age had a statistically significant effect on teachers' satisfaction with classroom acoustics, Wald $\chi^2(1) = 6.756$, $p = 0.009$.

Teachers who were "over 50 years old" were 9.007 (95% CI, 1.717 to 47.251) times more likely to find classroom acoustics satisfactory than teachers who were "between 30 and 50 years old", a statistically significant effect Wald $\chi^2(1) = 4.549$, $p = 0.024$.

4. CONCLUSION

This research showed that the new, LEED school's classrooms performed better than the conventional, middle-aged school's classrooms with respect to some aspects of thermal comfort and IAQ. The new, LEED school's classrooms had a statistically significant slightly higher mean temperature but lower mean relative humidity than the conventional, middle-aged school's classrooms. They also had statistically significant lower mean CO_2 and TVOC levels than classrooms in the conventional, middle-aged school. None of the other differences in lighting and acoustics between the two groups of classrooms were statistically significant.

The research also showed that the new, non-LEED school's classrooms performed better than the conventional, middle-aged school's classrooms with respect to IAQ alone. Just like the new, LEED school's classrooms, the new, non-LEED school's classrooms had a statistically significant slightly higher mean temperature but lower mean relative humidity than the conventional, middle-aged school's classrooms. None of the other differences in performance were statistically significant.

The research showed that the new, LEED and new-non LEED school classrooms' performance were very comparable with the new, LEED school's classrooms performing statistically significantly better only with respect to RH. None of the other differences in performance between the two groups of classrooms were statistically significant, which calls into questions some of the claims about the superior performance of LEED school buildings and green school buildings and indoor environments.

With respect to teachers' well-being, the research demonstrated that teachers' satisfaction ratings were statistically significantly higher in the new, LEED school than in the conventional, middle-aged school for overall classroom IEQ and lighting quality. Despite teachers in the new, LEED school being more satisfied with all other classroom aspects than teachers in the middle-aged, conventional one, none of these differences were statistically significant. Similarly, teachers' satisfaction ratings were statistically significantly higher in the new, non-LEED school than in the conventional, middle-aged school for overall classroom IEQ and for IAQ only. Surprisingly, none of the differences in teachers' satisfaction ratings between the new, LEED and new, non-LEED school were statistically significant, thus calling into question claims about LEED and green buildings' occupants' improved perception of their indoor environment.

Future research should focus on evaluating a larger representative sample of schools and classrooms and surveying a larger sample of teachers. It should also focus on considering the impact of a number of other financial, technical and behavioural variables on the results. Future research and future versions of the survey should also focus on investigating teachers' instantaneous rather than long-term satisfaction with IEQ so that those can be correlated to the snapshot physical measurements of IEQ. To enable this correlation, future research should also focus on linking the teachers surveyed to the classrooms evaluated physically so that the unit of analysis is the classroom for the IEQ physical measurements and the survey data. Despite its shortcomings, this research is one of the first to evaluate IEQ and occupant well-being based on quantitative empirical evidence of IEQ and qualitative evidence of well-being in Canadian schools. It should contribute together with other research studies to developing a body of knowledge that can be translated to evidence-based guidance to inform the design, construction, operation and maintenance of schools with better indoor environmental conditions and improved well-being to its occupants.

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