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VALIDATION OF A METHODOLOGY TO EVALUATE INDOOR ENVIRONMENTAL QUALITY IN GREEN RESIDENTIAL BUILDINGS

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Abstract: Despite the abundance of literature on buildings' indoor environmental quality (IEQ) in general and their impact on occupants given the time people spend indoors, there is limited empirical evidence on residential buildings' IEQ in particular and their effects on occupants. This paper reports on a preliminary analysis of an ongoing research study aiming to evaluate IEQ in 19 green homes built to the Leadership in Energy and Environmental Design (LEED) rating system in the city of Brandon, Manitoba. Specifically, this study is devoted to validating a methodology to evaluate these homes, relying on a preliminary analysis of four of the 19 homes. Despite the inherent weaknesses of the preliminary data, specifically in terms of size, the instruments demonstrate robustness in their application in a larger study. Four main data collection instruments are proposed in alignment with the fact that IEQ is a holistic concept from design stage to occupancy: 1) a comprehensive physical measurement protocol, 2) a questionnaire survey 3) interviews with these homes' architects and facility managers and 4) a field observation form to record the physical conditions of these homes. When complete, the results should help designers and facility managers identify IEQ aspects and parameters in need of improvement, physical conditions that can help improve these aspects and parameters, and the effects of improving them on home occupants. More research should be conducted to improve the robustness and the efficacy of the proposed tools. Further, this study could spur future research in the limited area of green residential homes.

Keywords: - Indoor environmental quality, Green buildings, Residential buildings, Methodology

1 INTRODUCTION

Since the insurgence of the 'green wave', the research suggest that green buildings generally outperform non-green buildings. However, the empirical evidence for green residential buildings is limited considering that the majority of studies have explored the performance of green commercial buildings. The rapid growth in the number of registered and certified green residential buildings (see Bonde and Ramirez 2015) necessitates a better understanding of their performance. At the same time, it is important to develop a methodology to evaluate IEQ in green residential buildings. For instance, to evaluate the performance of IEQ in green residential buildings, many studies have focused on the operational phase and building occupants only. Although this is informative, it fails to capture the perspectives of other key stakeholders such as designers and facility managers (Akom et al. 2016) who play essential roles in providing suitable indoor environment for occupants. Also, the majority of IEQ studies in homes (Xiong et al. 2015, Zalejska-

Jonsson 2014, Langer et al. 2015) were limited in scope given that they employed either objective or subjective assessment only, and also investigated a limited number of indoor environmental parameters. For instance, Xiong et al. (2015) investigated only indoor air quality utilising only physical measurements; whilst Zalejska-Jonsson (2014) evaluated IEQ through only subjective assessments. In the former study occupants' satisfaction were neglected, whereas in the latter study physical environmental parameters were not investigated. Both methods are invaluable to identifying performance gaps; however, using them in isolation – although informative – is inadequate to capture the whole picture of IEQ performance. This paper presents preliminary results of an ongoing study conducted in green and non-green certified residential homes in Brandon, Manitoba, to validate a comprehensive methodology developed and reported in Akom et al. (2016) for assessing the IEQ of homes. When completed, the study seeks to evaluate the IEQ performance of LEED and non-LEED certified residential homes. The remaining sections of this paper focus on the literature review, methodology and results and discussion.

2 LITERATURE REVIEW

IEQ studies have increased significantly over the years because of the growing recognition of the impact of indoor environment on the health of occupants (Hui, Li, and Zheng 2006). These studies are important in evaluating performance of buildings and also in identifying any gaps between actual and predicted performance (Alborz and Berardi 2015). Zalejska-Jonsson (2012), in particular, identified problems with indoor temperature and what stage of the design process they could be addressed. Patton et al. (2016) also identified the contribution of occupants' behaviour to performance gap. However, the accuracy and applicability of IEQ research findings and results will depend on the quality of data, both subjective and objective (Heinzerling et al. 2013). Therefore, the attention in recent years has been toward standardization of IEQ measurement and performance indicators (Heinzerling et al. 2013). In this regard, various documents abound that provide guidance on IEQ measurement, e.g. ASHRAE/CIBSE/USGBC Performance Measurement Protocol for Commercial Buildings: Performance Measurement Protocols Best Practices Guide. However, these standards are focused on energy simulations and performance with limited guidelines on how to measure and evaluate IEQ (Heinzerling et al. 2013). Several studies (Lai et al. 2009, Heinzerling et al. 2013) have attempted to fill this gap through the development of IEQ assessment models. Lai et al. (2009) proposed empirical expressions to determine occupants' satisfaction via a multiple logistic regression using four selected IEQ parameters. Different methodologies for evaluating IEQ involve the use of subjective and objective evaluations (Xue, Mak, and Ai 2016, Heinzerling et al. 2013). However, as argued by Heinzerling et al. (2013), there is no consensus on the measuring protocols. Within this body of studies, focus on green residential buildings has been limited. Furthermore, in green residential studies, IEQ is typically evaluated subjectively using occupants' satisfaction (e.g. Zalejska-Jonsson 2014). Where objective measurement is used, it is often limited to only thermal comfort and indoor air quality (e.g. Xiong et al. 2015, Langer et al. 2015), thus oversimplifying the importance of light and acoustic comfort. As aforementioned, the importance of both objective and subjective measurements, and also a holistic evaluation of all IEQ parameters cannot be overemphasised. The methodology developed in this study overcomes these inherent weaknesses by combining both objective and subjective measurements. At the same time, the main four IEQ factors are adequately evaluated.

3 METHODOLOGY

The developed methodology comprised of physical measurement protocol to evaluate the physical indoor environmental parameters of houses, observation sheets to collect building information and outdoor conditions, occupant survey to evaluate satisfaction with indoor environment and interviews with designers and facility managers. Elaborate information on the developed methodology is reported in Akom et al. (2016). The questionnaire survey was in three parts as follows: 1) Demography, 2) Occupancy and 3) IEQ. The physical measurement protocol included monitoring of thermal comfort, air quality, acoustics, and lighting parameters with calibrated electronic sensors. Furthermore, the designers interview survey was in two main parts as follows: 1) Demography and 2) IEQ design considerations, goals and challenges faced. The interview survey of the facility managers was similar to that of the designers; however, the Part two focused on IEQ goals and challenges upon first occupancy of buildings and at least one year after occupancy. The observation sheet was used to record other essential IEQ related information not captured by either the physical measurement or the questionnaire survey. Examples of observations recorded include but not limited to potential sources of pollution, physical condition of houses, weather data.

The methodology was applied to four green single family residential homes in Brandon, Manitoba built to Leadership in Energy and Environmental Design (LEED) rating system administered by the Canada Green Building Council (CaGBC). The buildings were occupied in 2011 and received LEED Canada for Homes 2009 gold-certification in 2014. The houses are all two storeys high wood framed with three bedrooms, living room, kitchen, and basement. Each house has a footprint of 1520 ft^2. All locations in each house, except the bathroom, was furnished with hardwood base floor and finished with linoleum. The bathrooms and storage/laundry floors were finished with sheet vinyl. The wood framed walls were covered with gypsum wall boards and finished with paint. ft3 architecture, landscape and interior design, were the designers of the houses, while the houses were under the management of Manitoba Housing. Physical monitoring of the IEQ parameters was conducted from September to October of 2016. Measurements took place in three spaces per house i.e. bedroom one, bedroom two and living room. The average of these measurements was considered representative for evaluation of house level (see Lai et al. 2009). The paper-based questionnaire survey was administered during the physical measurement of IEQ in each house. The total number of responses were six (6), representing 100 per cent response rate of occupants above the age of 18 years. Additionally, the interviews of designers and facility manager lasted approximately 45 minutes each and were conducted during the study period. The observation observations were conducted during the IEQ monitoring period for each house. Subsequently, the various tools were validated by either of the two ways or both i.e. external or internal validity of results. The internal validity involved comparing the results generated by the various tools, whereas the external validity involved the comparison of the results, particularly from the questionnaire survey and physical measurements, to available standards and publications in literature.

4 RESULTS AND DISCUSSION

4.1 Demographics and background information

The questionnaire respondents were three females and three males. Also, majority (i.e. 83.3%) of the respondents were at most 30 years of age. Most importantly, a significant portion (i.e. 83.3%) of the respondents have stayed 3-5 years and also spent within 10 to 20 hours per day in their houses, thus, they are most likely to provide reliable judgement of homes' IEQ. The average number of households was six people, which is higher tan the LEED design assumption of 4 people per 3-bedroom unit. In terms of activity, the dominant activities included sedentary (i.e. playing games, watching television) and also low-intensity (such as cooking).

Two members of the design team were interviewed, after a review of design documents (plans and specification) and LEED documentation, to provide a detail understanding of design intent, design assumptions and included sustainable features particularly for IEQ. The Designers indicated that they have worked on more than 40 green building projects with variable occupancy types. Conversely, the facility manager (FM) indicated limited experience in managing green houses. However, the FM has been managing the houses investigated in this study for the past three years and remarked that there was no difference between managing LEED homes and non-LEED ones.

4.2 Indoor environmental Quality

4.2.1 Objective environmental measurement

Table 1 shows the results of the objective measurements of the thermal environment in the studied houses. Average levels of air and radiant temperatures of each house were between 22ºC and 26ºC, with outdoor temperatures between 15 ºC and 20 ºC. Similarly, the corresponding relative humidity in the studied houses was between 33% and 43%. In terms of air velocity, the average measured values ranged from 0.00-0.01 m/s. From table 1, the standard deviations of the respective averages are shown in parentheses. Variations within different spaces of the same house was not substantial, likewise variations between houses.

However, relative humidity differed substantially within different spaces in house No. 3 (standard deviation = 5.53). The probable explanation may be occupant activities such as cooking in the non-partitioned kitchen adjacent to the living room thus increasing the amount of moisture in the atmosphere and subsequently the relative humidity. One unanticipated finding was that the air velocities were extremely low i.e. almost zero. Notwithstanding, the distribution of the air velocity was uniform within spaces of the same house and even among different houses.

Table 1. Thermal comfort parameters measured in houses

Parameters	House			
	No. 1	No. 2	No. 3	No. 4
Air temperature (^oC)	22.54 (0.28)	22.34 (0.64)	25.34 (0.25)	22.28 (0.21)
Radiant temperature(^oC)	23.08 (0.42)	22.61 (0.54)	25.70 (0.22)	22.48 (0.37)
Relative humidity (%)	42.46 (0.66)	40.46 (0.93)	34.67 (5.53)	39.78 (1.12)
Air velocity (m/s)	0.00 (0.00)	0.00 (0.00)	0.00 (0.01)	0.00 (0.00)

Table 2 shows the results of objective measurements of carbon dioxide, Total volatile organic compound (TVOC), carbon monoxide, $PM_{2.5}$ and PM_{10} successively. The average TVOC, carbon dioxide, carbon monoxide, $PM_{2.5}$ and PM_{10} concentration of each house was between 632 ppm and 830 ppm; 545 µg/m^3 and 908 µg/m^3; 0.78 ppm and 0.95 ppm; 2.0 µg/m^3 and 5.50 µg/m^3; and 11.0 µg/m^3 and 22.83 µg/m^3 respectively. Although six channels of particulate matter measured (i.e. $PM_{0.3}$, $PM_{0.5}$, $PM_{1.0}$, $PM_{2.5}$, PM_5 and PM_{10}), only two channels were reported as showed in the Table 2 and is consistent with IEQ research practice (Escobedo et al. 2014, Patton et al. 2016, Russo et al. 2015). Table 2 also shows considerable differences in carbon dioxide concentration between spaces in houses, particularly in houses No. 1 and No. 2. These observed differences can partially be explained by the occupancy density and also window opening behavior. In the living room where relatively low levels were recorded, occupants indicated they frequently opened their windows to introduce fresh air in the cases of stuffy or stale air. It is also interesting to note the level of variability among the houses in terms of PM_{10} and also $PM_{2.5}$. At the same time, significant differences in PM_{10} among spaces are observed in houses No. 1 and No.3. The differences among houses can be ascribed to occupant characteristics such as population density, ethnicity, etc., while the differences within different spaces of the same house are explained by the activities carried out within each space.

Table 2. Indoor air quality parameters measured in houses

Parameters	House			
	No. 1	No. 2	No. 3	No. 4
Carbon dioxide (ppm)	719.69 (151.81)	632.21 (146.47)	828.29 (92.58)	663.15 (95.13)
TVOC (µg/m^3)	883.96 (225.44)	546.66 (44.64)	907.21 (91.05)	655.61 (60.20)
Carbon monoxide (µg/m^3)	0.80 (0.16)	0.79 (0.06)	0.88 (0.18)	0.94 (0.08)
$PM_{2.5}$ (µg/m^3)	5.46 (1.02)	5.43 (2.96)	2.02 (0.57)	4.34 (0.21)
PM_{10} (µg/m^3)	11.34 (5.59)	22.83 (0.59)	17.81 (14.17)	15.56 (0.50)

Average values of artificial light and daylight illuminance are presented in Table 3. Artificial lighting differs substantially within different space of the same house and among different houses. For example, artificial lighting in house No.1 varied from 4590 lx to 379.2 lx, while other houses varied from 4590 lx to 704.9 lx. It seems more probable to ascribe the observed differences to the number and type of lighting fixtures within the different spaces of the same house. The amount of light intensity emitted from the different fixtures equally varied based on the functionality of space; thus, the intensity appeared higher in the living room than the bedrooms. Among the different houses the most probable explanation may be as a result of individual preferences which influence intensity adjustment, since the fixtures were similar across all houses. Another possible reason for variation in lighting intensity is the type of room surfaces and furniture. The differences observed in daylight illuminance among different houses may be related to different time of the day. For example, measurement in houses No. 2 and No. 4 occurred during cloudy time. The differences in illuminance level within different spaces of the same house is probably because of the number and sizes of windows and other openings. The living rooms have at least one more window than the bedrooms and the sizes are about four times the sizes of the bedrooms' windows, thus allowing more daylight into the living rooms.

Table 3. Illuminance levels measured in houses

Parameter (lux)	House			
	No. 1	No. 2	No. 3	No. 4
Electric light	250.91 (248.46)	222.04 (87.27)	266.25 (304.55)	149.02 (1.03)
Daylight	254.59 (282.30)	171.46 (67.38)	284.09 (334.77)	108.15 (66.91)

In terms of acoustic quality, background noise levels were between 34 dB (A) to 52 dB (A) (refer to Table 4). The difference in levels between bedrooms and living rooms can be ascribed to noise from refrigerators in the living room and also their proximity to road traffic. The sound transmission classes (STC) of the measured houses are 36, 36, 32 and 34 for No. 1, No. 2, No. 3 and No. 4, respectively. Sound transmission loss was measured between walls of bedrooms. Figure 1 shows the sound transmission loss (STL) of the various houses. What is surprising about the STL is that in houses No. 1 and No. 2, although they had the same STC (i.e. 36), there was marginal differences in the transmission loss at lower frequencies. However, within frequencies 800 to 4500 hertz, both houses attenuated the same amount of noise. The marginal differences at the lower frequencies in these two homes (No. 1 and No. 2) would perhaps reflect in occupants' acoustic satisfaction.

Table 4 Background noise measured in houses

Parameter (dBA)	House			
	No. 1	No. 2	No. 3	No. 4
Background noise	40.85 (0.92)	41.85 (0.49)	47.15 (1.63)	43 (12.16)

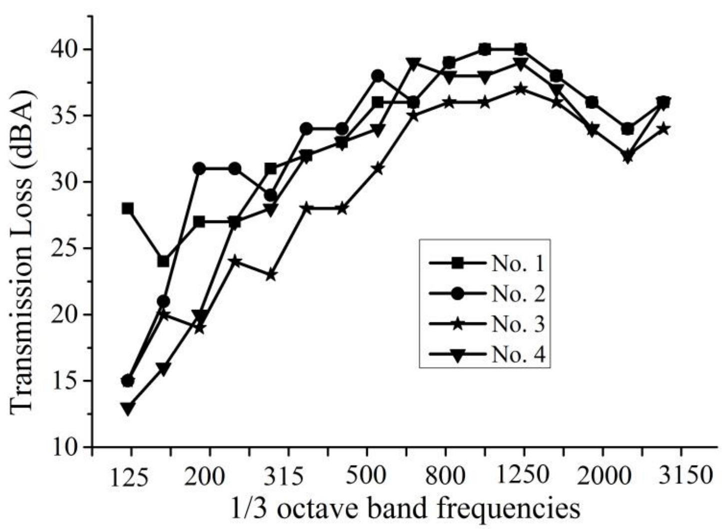

Fig. 1. Sound Transmission Loss in the measured houses

4.2.2 Subjective questionnaire survey

Figure 2 shows the mean satisfaction levels of the four main IEQ factors in the different houses. The mean satisfaction levels differ for different IEQ factors of the same house and among different houses. Generally, occupants in house No. 4 reported the highest mean satisfaction levels for all four factors, whereas occupants in house No. 1 reported lowest mean satisfaction levels. Thermal comfort was rated significantly higher in three (i.e. houses No. 2, No. 3 and No. 4) out of the four houses. Satisfaction with certain IEQ factors were similar resulting in overlaying curves as shown in figure 2. However, overall subjective response showed that majority of the occupants were satisfied with general IEQ (see Fig. 2). It is significant to note that the overall IEQ satisfaction follows the individual factors' satisfaction.

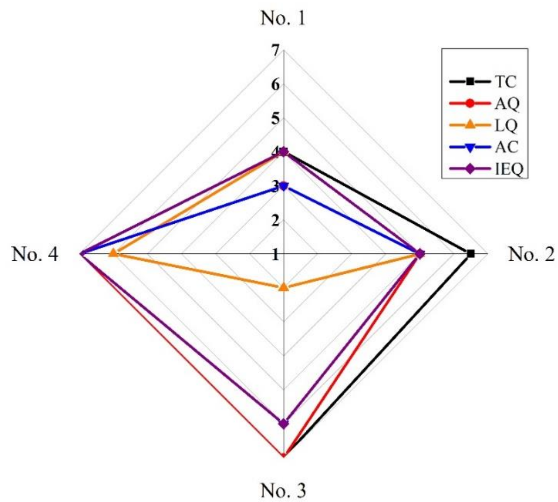

Fig. 2. Relationship with satisfaction with general IEQ and IEQ factors

4.2.3 Comparison between objective and subjective measurements

Either subjective measurement only or objective measurement only fails to paint adequately the true picture of IEQ performance. In view of this, an attempt was made to draw relationships between the subjective satisfaction with IEQ main factors and objective environmental measurements. The small number of responses did not permit a more rigorous comparative analysis between the objective and subjective assessments. Hence, direct matching of the survey responses to the objective measurements was undertaken. Figure 3 shows the matching between the mean satisfaction levels and the objective measurements (operative temperature, TVOC, background noise level and illuminance intensity). TVOC was selected as an indicator of indoor air quality as opposed to the long-standing convention of CO2 given that building materials such as vinyl floors used for the studied buildings were not low VOC as is conventionally expected for green buildings; although paints and adhesives and sealants were low VOC. From Figure 3, there appears to be no obvious direct relationship between the subjective (qualitative) responses and objective physical measurements.

4.2.4 Interviews

According to the designers, the major deciding design factors were durability, energy efficiency, water efficiency and quality control. However, because of the interrelatedness of IEQ and energy efficiency it was important to pursue goals also in that direction. The major construction strategy adopted in improving thermal comfort, according to the designers, was "*third party inspection / testing of systems helped to ensure [that] design and [installation] is performing as intended".* A similar technique was adopted during the construction stage to help address potential air quality issues. One of the members on the team, for instance, mentioned "*third party inspection / testing of ventilation system performance"* as the dominant strategy. Although the LEED rating system available at the time of design and construction did not place much emphasis on acoustics, the designers mentioned that "*interior partitions between units were of higher STC to minimize sound transmission between units".*

Interestingly, the FM indicated no specific goals with respect to IEQ in these houses. Majority of the problems reported by the occupants bothered on issues with thermal comfort, predominantly during the early stages of occupancy. For instance, the FM indicated that occupants complained about the long hours it takes to condition air (heating and cooling) partly because of the sophistication of controls. According to the FM, "*the thermostats that were originally installed in the unit where not easy to operate. We were called several times to unit to repair heat and A/C once the thermostats were replaced the calls stopped".* It is important to mention that air supply and exhausts ducts were cleaned only when houses are vacated and new tenants move in.

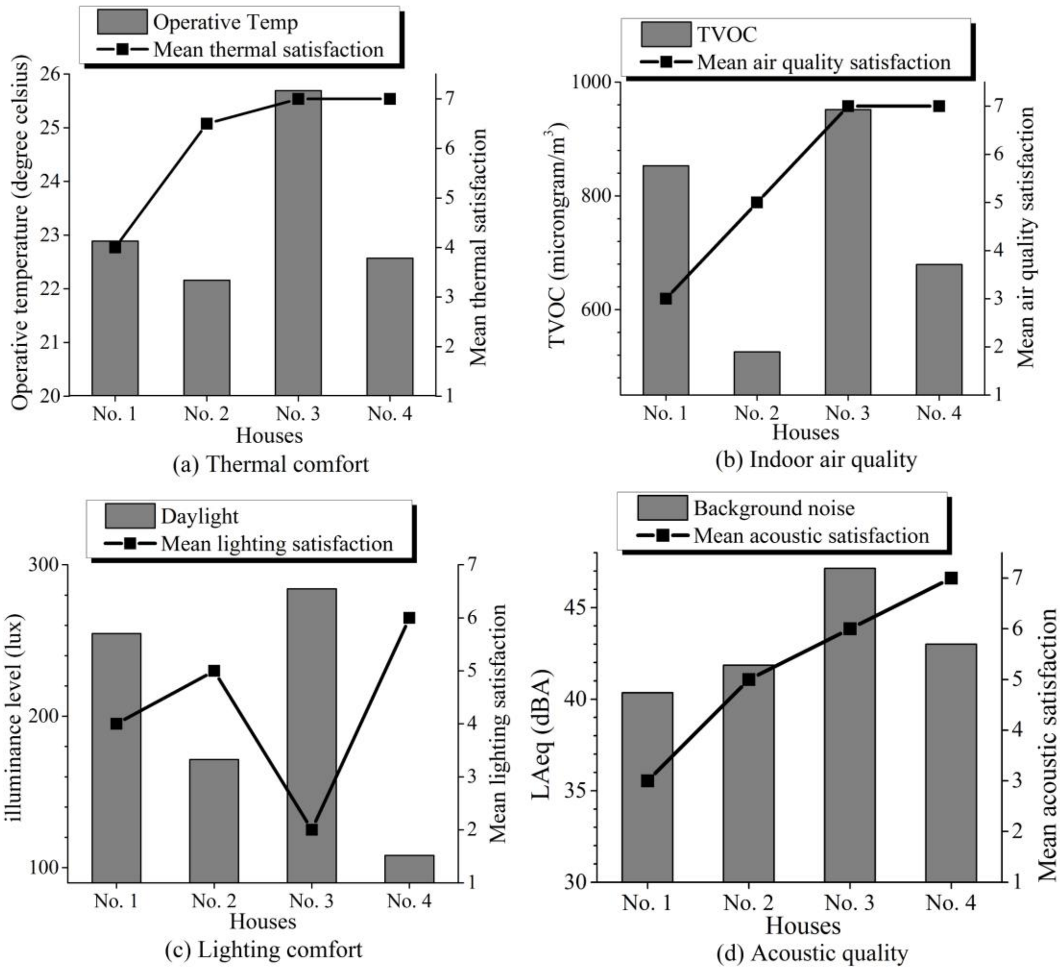

Fig. 3. Comparison between IEQ subjective responses and objective measurements

5 VALIDATION OF METHODOLOGY

In this section, the methodology is validated by relying on both external and internal consistency of the findings. With respect to external validity, the results of this study were compared to recommended thresholds published in literature by similar studies and also by recognised standards. In contrast, the internal validation relied on the internal consistency of the results, i.e. the results of the objective measurements, field observations, subjective questionnaire and interviews were compared.

5.1 Comparison with reference exposure levels (RELs) in literature and standards

Reference exposure levels (RELs) have been published by organisations, and also reported in literature by numerous studies. In this subsection, the results reported in this study are compared with these RELs. Table 5 illustrates the compliance with the recommended RELs. As can be seen in the Table, majority of the measured air temperature were well within the recommended range for comfort (i.e. 18-24 ^{o}C) for the studied season by various standards and also reported studies in literature (McGill, Oyedele, and McAllister 2015). Only 1 out of the 4 houses measured, exceeded the recommended levels for comfort. A closer examination pointed to personal preference for relatively warm atmosphere as opposed to poor performance. However, another probable explanation may be occupants' inadequate knowledge of thermostat controls as the record on the observation sheet showed a temperature set-point of 25^{o}C which is 1^{o}C above the upper limit of the recommended threshold. In contrast, all the measured environmental parameters of indoor air quality were well below the REL. In particular, fine particulate matter ($PM_{2.5}$) was below the threshold recommended by the Canadian guidelines on residential indoor air quality. Background noise levels exceeded the recommended threshold by about 12.5%. It is also significant to mention that the recorded levels were similar to results published in literature on indoor air quality in residential green buildings (Xiong et al. 2015, Langer et al. 2015). Xiong et al. (2015) reported a maximum carbon dioxide level of 895 ppm in multi-family houses built to LEED rating system. Also, Langer et al. (2015) found maximum levels exceeding 2000 ppm in single family houses constructed to passive concept. The maximum carbon dioxide level (830 ppm) obtained in this study was less than these two studies. Similar result is seen in the levels of TVOC. Unfortunately, these studies did not report on occupant satisfaction. In another study (Zalejska-Jonsson 2014) that reported on occupants' satisfaction, satisfaction with perceived air quality was similar to the results obtained in this current study.

Results of acoustic comfort and sound insulation of home are limited in literature. Previous studies (e.g. Zalejska-Jonsson 2014, 2012) found higher occupants' satisfaction with acoustic quality in passive houses in Sweden. This is somewhat marginally different from the results in this current study; a similar trend is also seen in lighting quality. Lighting satisfaction reported by Zalejska-Jonsson (2014) were marginally higher than the levels reported in the current study. Studies on objective measurements of acoustics in green residential houses are simply non-existing.

Table 5 Recommended levels of environmental parameters

Parameter	Reported values	Studies in literature	Canadian guideline/ ASHRAE	WHO guideline	Percentage exceeding REL
Air temperature	22-26 ^{o}C	18-24 ^{o}C (McGill, Oyedele, and McAllister 2015)	-	-	25%
Radiant temperature	22-26 ^{o}C	-	-	-	
Relative Humidity	33-43%	≤60% or 65-70% (Hui, Li, and Zheng 2006, McGill, Oyedele, and McAllister 2015)	30-60%	-	0
Air velocity	0-0.01 m/s		-	-	
Carbon dioxide	478-924 ppm	650-1000 ppm (Lai et al. 2009)	-	-	0
TVOC	498-1072 µg/m^3	300 – 25,000 µg/m^3	-	-	
Carbon monoxide	0.6-1.1 ppm		25 ppm (1 hr)	25 ppm (1 hr)	0
$PM_{2.5}$	2.02 – 5.46 µg/m^3		-	10- 25 µg/m^3 (24 hr)	0
PM_{10}	11.34 µg/m^3 - 22.83 µg/m^3		-	20-50 µg/m^3	0
Background noise	34 – 52 dB(A)	50 dB (A)	-	-	12.5%
Illuminance level	47.47– 520.80 lx	100-2000 lux (Cheong, Kim, and Leigh 2014)	-	-	0

5.2 Internal consistency of results

Internal evidence obtained in this study are compared to assess the validity of the instruments developed. Table 6 compares the consistency of the results from the various research instruments. In terms of thermal comfort and acoustic, there appears to be consistency in the results among the occupants' survey, objective measurements and the interviews.

Table 6 Internal consistency of data collection tools

Occupant Survey	Objective measurements	Interviews
Occupants were generally satisfied with thermal comfort than the other environmental parameters	Measured thermal comfort parameters (air temperature, radiant temperature, relative humidity) were within recommended levels.	***Designers:*** *Energy performance was the main driver of LEED certification and as such influenced thermal comfort. The goals were not that innovative, but we wanted to make sure they were just good*
Acoustic quality appeared less satisfied after lighting quality. The disturbing sources largely were from noise outside and even with inside sources, speech dominated. Noise from HVAC was rated low.	STC measured in the studied houses were below 40, within which loud speech and traffic noise, music systems are still a potential problem	***Facilities Manager:*** *The major complaint is family house normal noise* ***Designers:*** *No special noise attenuation strategies were used except that contained in the building codes*
	Artificial illuminance levels were high enough for the intended functionality	***Designers:*** *Advanced lighting package was pursued*

6 CONCLUSION

In this study, a mixed-methodology developed to evaluate IEQ performance of green residential building, was validated based on the preliminary results of an on-going study. Based on the weaknesses of the data, specifically the limited number of houses (only four houses) and participants (only six occupants), no significant and rigorous analyses were carried out. Hence, the results are simplified and deemed preliminary. However, the positive results justify a larger scale application of the methodology, which will involve a more rigorous and scientific analysis of the data. The preliminary results showed that IEQ is a holistic concept that is not limited to only occupancy. It followed that designers' and facilities manager's perspectives are equally important in situating the overall IEQ performance in residential buildings. It is significant to note that objective measurements or subjective measurements alone did not fully capture IEQ performance. Compared to RELs, the results indicate that the developed instruments exhibit great potential for use in evaluating IEQ of green residential buildings for increasing occupants' satisfaction, in addition to, helping facility managers to optimize operational strategies of green residential buildings. Designers will be able to rely on the identified problems and as such identify the stage where they can be mitigated. A major significance of the questionnaire survey was the ability to ask occupants' temporary satisfaction during the time of actual monitoring period, which makes it possible to realistically compare subjective and objective measurements. Conventional IEQ questionnaire surveys typically elicit general satisfaction, which may not be a representation of the conditions existing at the monitoring period. A larger scale application of the methodology would be carried out in all the 19 homes in an attempt to evaluate the IEQ performance of both LEED and non-LEED certified homes. The evaluation would be done over two seasons – fall 2016 and winter 2017. At the same time, long term measurements using non-sophisticated sensors would also be carried out in two selected homes to analyse trends in the performance of the LEED and non-LEED certified home. This will aid to identify also overlaps in the assessment methods which are not evident in this preliminary result.

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