An Evaluation of Indoor Environmental Quality and Occupant Well-Being in Three Southern Rural Manitoba School Buildings

by

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ABSTRACT

There is little empirical evidence in the literature to support industry claims about how green schools tend to have better indoor environmental quality (IEQ) than conventional ones and how teachers in green schools tend to feel better about their schools' IEQ than those in conventional ones. There is also little empirical evidence in the literature about the impact of improved IEQ in schools on teachers' well-being and their levels of satisfaction with their indoor environments. This research is based on a collaborative partnership with the Government of Manitoba Public Schools Finance Board, and three different public school divisions in Manitoba. It aims to develop and validate a comprehensive methodology to evaluate schools' IEQ, teachers' well-being and satisfaction with it, and the relationship between these two aspects. The research evaluated these specific aspects within a sample of three rural schools in Southern Manitoba, Canada: one middle-aged, conventional school; one new, non-green school; and one new, green school certified using the Leadership in Energy and Environmental Design (LEED) Rating System.

The methodology developed in this thesis employs three main data collection techniques: 1) field measurements using an existing mobile instrument cart to capture environmental indicators of thermal comfort, indoor air quality, lighting quality and acoustics quality in classrooms, 2) a field observation form to record the physical conditions of the evaluated classrooms, and 3) an occupant survey to evaluate teachers' satisfaction with their classrooms' IEQ. The analysis of the data collected showed how the new, LEED school tended to have better IEQ with respect to thermal comfort, indoor

air quality, and lighting quality than the other two schools. Acoustics quality in the new, LEED school was found to be on par with that in the other two schools. The results also showed how teachers in the new, LEED school tended to feel more comfortable with their indoor environment than teachers in the other two schools. It also demonstrated a strong and statistically significant positive correlation between air velocity measurements and occupants' perception of thermal comfort. There was also a statistically significant negative correlation between Volatile Organic Compound levels and teachers' perception of Indoor Air Quality.

The developed methodology also demonstrated internal consistency between the results stemming from the on-site physical measurements and those from survey responses. It also demonstrated external consistency between this research's results and the literature's results, thus validating its accuracy and reliability. This methodology, adapted in part from existing workplace evaluation methods, offers a reliable and comprehensive methodology for evaluating IEQ performance of schools that other researchers can use to better understand IEQ in relation to occupant well-being in schools and that owners and operators can use to evaluate the performance of their school buildings and systems. It also provides researchers and owners and operators with a dataset they can use and build upon to identify common trends for IEQ and occupant well-being in schools across the country. The methodology can be used to evaluate the performance of these and other similar schools, thereby helping improve the operation, maintenance and overall performance of existing schools.

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LIST OF SYMBOLS, NOMENCLATURE AND ABBREVIATIONS

ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
BEPAC	Building Environmental Performance Assessment Criteria
BOMA	Building Owners and Managers Association
BREEAM	Building Research Establishment Environmental Assessment Method
BUS	Building Use Studies
CaGBC	Canada Green Building Council
CBE	Centre of Built Environment
CO	Carbon Monoxide
CO_2	Carbon Dioxide
GBTool	Green Building Tool
HVAC	Heating, Ventilation, and Air-Conditioning
IAQ	Indoor Air Quality
IEQ	Indoor Environmental Quality
IP	Internet Protocol
ISO	International Organization for Standardization
K-12	Kindergarten to twelfth grade
LEED	Leadership in Energy and Environmental Design
NRC	National Research Council Canada
O_3	Ozone
PM	Particulate Matter
PMV	Predicted Mean Vote
POE	Post Occupancy Evaluation
PPD	Predicted Percentage Dissatisfied
RH	Relative Humidity
SBS	Sick Building Syndrome
T	Temperature
TVOCs	Total Volatile Organic Compounds
USGBC	US Green Building Council
v	Air Velocity

VOCs	Volatile Organic Compounds
IEQC	Indoor Environmental Quality Cart

1.0 Chapter 1: Introduction

This chapter provides background information about this research, describes its significance and originality, and presents the specific problem addressed by it; as well as its goal, objectives scope and hypotheses. The chapter ends with a listing of the definitions adopted for the key terms used throughout the research.

1.1. Background Information

People spend more than 90% of their time indoors (Hoppe, 2002). In their survey of more than 10,000 participants from the United States and Canada, Leech et al. (2000) found that people spent on average about 10% of their time outdoors in the summer and only 2% to 4% in the winter. This is typical of industrial countries, especially ones with extreme weather conditions. This makes researching indoor environmental quality (IEQ) and more specifically aspects related to thermal comfort, indoor air quality, lighting quality and acoustics quality and its impact on occupant well-being a necessity.

IEQ has become an important public health issue. Concerns about the adverse effects of poor IEQ began in the 1970s when occupants of residential, commercial, and institutional buildings reported health problems associated with their buildings (Kreiss, 1988). Such problems were later characterized as sick building syndrome (SBS) and buildings' related illness. IEQ problems are estimated to affect more than 10 million occupants in 30% of the buildings in North America alone, resulting in losses of billions of dollars because of decreased health and productivity (Hoppe, 2002).

Buildings are expected to provide an indoor environment that is acceptable to their occupants and does not affect their health and productivity negatively. While IEQ issues have come to the forefront and have become a contentious topic of debate in recent years, this was not always the case (Catalina & Iordache, 2012). The focus since the 1960s has been on making buildings as energy-efficient as possible (Leslie, 2014). About two hundred and fifty reports have been published since then, with the Division of Building Research at the National Research Council - Institute for Research in Construction publishing a series of reports (e.g. Canadian Building Digest) on buildings' moisture, air leakage, thermal loss, and durability.

Even though the movement to make buildings more energy-efficient has led to the emergence of air-tight buildings that consume a lot less energy, it has also led to buildings with poorer IEQ that now require mechanical ventilation to meet minimum air ventilation rates (Leslie, 2014). These IEQ concerns in addition to other environmental concerns have led to the development of the first environmental rating system of its kind in North America: the Building Environmental Performance Assessment Criteria (BEPAC). BEPAC has progressively given way to a host of other rating systems such as the Building Research Establishment Environmental Assessment Method (BREEAM), the Green Building tool (GBTool), C-2000, Green Globes, the Building Owners and Managers Association (BOMA) Building Environment Standards, and the Leadership in Energy and Environmental Design (LEED) (CaGBC, 2013). These systems emphasize the need for sustainable and green buildings that conserve resources and improve indoor environments (i.e. environmental benefit), save on long-term costs (i.e. economic benefit) and provide health and productivity benefits to building occupants and the community (i.e. social benefit). They have driven the demand for green buildings, as evidenced by the number of projects that have registered for green building certification using these systems. Since the foundation of the Canada Green Building Council (CaGBC) in 2002, more than 4400 buildings have registered for Leadership in Energy and Environmental Design (LEED) certification, with more than 1200 projects already certified (CaGBC, 2013).

While the literature seems to have focused on evaluating green office buildings, not enough attention seems to have been paid to school buildings (Lee & Guerin, 2009). This is despite the time children spend in schools and the impact of school buildings' indoor environments on their developing bodies, their overall health and their school performance. It is also in spite of strong public support and demand for better indoor school conditions to improve children's learning abilities and their overall educational experience. This makes the need for more research on the impact of IEQ on students and teachers' performance of primary importance (Catalina & Iordache, 2012).

The need for more research on the impact of IEQ on occupants is compounded by a need to investigate occupants' perception of IEQ. While many studies seem to have focused on the qualitative evaluation of occupants' perception of IEQ and their well-being, this research investigates the relationship between quantitatively measured IEQ parameters and qualitative aspects of occupant well-being.

1.2. Definitions

This subsection includes the definitions adopted for a number of key terms used throughout this research. These definitions are essential to understanding this research given how these terms can be interpreted in a number of different ways.

Indoor Environmental Quality (IEQ): IEQ refers to the quality of a building's environment in relation to the health and wellbeing of its occupants, and includes aspects of design, analysis, and operation that lead to energy efficient, healthy, and comfortable buildings (NIOSH, 2013). In this research, it specifically refers to the measured parameters of four main aspects: thermal comfort, indoor air quality, lighting quality and acoustical quality.

Occupant Well-Being: In the broadest sense, wellbeing is defined as the balance point between an individual's physical, social and psychological resources and the physical, social and psychological challenges he or she faces (Dodge et al. 2012). The well-being of people is commonly defined in terms of their health, comfort and happiness (Steemers & Manchanda, 2010). In this research, its use is strictly limited to occupants' satisfaction with their indoor environment. While many aspects of the indoor environment can contribute to occupants' satisfaction with it (Frontczak et al., 2012), this research focuses specifically on occupants' satisfaction with four main aspects: thermal comfort, indoor air quality, lighting quality and acoustics quality.

Thermal Comfort: Thermal comfort relates to the thermal environment and to the condition of the mind that expresses satisfaction with that environment and can be assessed using objective and subjective methods (ASHRAE 55, 2004). It is an aspect, among many others with direct impact on IEQ and occupant well-being. In this research, the term refers specifically to the parameters of air temperature, air velocity and relative humidity.

Indoor Air Quality (IAQ): IAQ refers to thermal conditions that can affect the health, comfort and performance of occupants such as the concentration of pollutants and that can be mitigated through the use of ventilation, source control and filtration (Health Canada, 2013). Pollutants can include contaminants such as mould, radon, carbon monoxide and formaldehyde. In this research, IAQ parameters include carbon dioxide levels, carbon monoxide levels and volatile organic compound levels.

Lighting Quality: Lighting quality is more than just providing an appropriate quantity of light. Several aspects contribute to lighting quality such as illuminance, luminance distributions, light colour characteristics and glare (Veitch and Newsham 1998). Lighting quality can be judged based on the level of visual comfort and performance required for different activities. In this research, lighting quality is restricted solely to ambient and task illuminance levels.

Acoustics Quality: Acoustic quality is the quality of sound within building spaces. It is based on a number of parameters such as reverberation time, sound insulation and background noise (Zannin and Marcon, 2007). In this research, acoustics quality focuses specifically on ambient noise levels in indoor spaces.

Research Consistency: Research consistency is a measure based on correlations between different items of the same aspect (Barchard, 2010). In this research internal and external consistency refer respectively to the level of agreement between the results of the physical measurements and the occupant well-being survey results and between the results of the research and those found in the literature.

1.3. Research Significance and Originality

The significance and originality of this research stem from it being one of the first studies in Canada to scientifically evaluate school buildings. The research also proposes a new comprehensive methodology to evaluate indoor environmental quality (IEQ) and occupant well-being in school buildings based, in part, on adaptations of existing workplace post-occupancy evaluation methods. One significant aspect of this methodology is its reliance on on-site physical quantitative evidence of IEQ performance as well as qualitative evidence to evaluate occupant well-being. Another significant aspect of this methodology is its focus on evaluating all aspects of IEQ rather than just one aspect (e.g. Indoor Air Quality).

The research also provides a dataset for evaluating IEQ aspects in Manitoba school buildings. This is a dataset that can grow significantly through the contributions of other researchers and industry practitioners and thus help identify common trends for IEQ and occupant well-being in other schools across the country. This dataset and the research's methodology can be used to benchmark the performance of new and existing schools throughout the country. They can be used to enhance the actual operation and maintenance of existing and new schools in order to enhance their actual and future performance, through reporting existing problems with those schools, thereby helping offer improved conditions to students, teachers and other school occupants. They can also be used for the design of new schools that offer improved IEQ to their occupants and higher levels of occupant satisfaction.

1.4. Problem Statement, Research Goal and Objectives

As introduced in subsection 1.1, researchers such as (Lee & Guerin, 2009) find that not enough attention has been paid to the evaluation if IEQ in school buildings. While some studies have been done in the USA and Europe, a review of current literature (Chapter 2) suggests there is little empirical evidence about the impact of the full range of IEQ parameters on occupants' well-being in Canadian school buildings. There is also little empirical evidence in the literature about the indoor environmental quality (IEQ) of green school buildings and occupants' well-being in them in comparison to conventional ones in Canada. Therefore, the main goal of this research is to develop and validate a comprehensive methodology to evaluate IEQ in connection to occupant well-being in school buildings.

The objectives of this research are to:

1) Develop a comprehensive methodology to evaluate IEQ in relation to teachers' well-being in school buildings.
2) Test the methodology by evaluating IEQ in relation to teachers' well-being in a sample of conventional and green school buildings.
3) Validate the methodology using internal and external evidence of consistency.

1.5. Research Scope

The research focused on Canadian schools and more specifically on schools in the Province of Manitoba in Canada. A collaborative partnership was established with the Government of Manitoba Department of Education Public Schools Finance Board, and three different public school divisions that shall remain anonymous for confidentiality purposes. The research focused on evaluating three rural schools in Southern Manitoba: one from each school division. The sample included a middle-aged, conventional school; a new, non-LEED school; and a new, LEED Certified school. Middle-aged schools represent the ones constructed between 1960 and 1989, and new schools represent the ones built in or after 1990. The sample included the only green school to have been built and certified to LEED standards in the province. This research focused on evaluating four main IEQ aspects: Indoor Air Quality (IAQ), thermal comfort, lighting quality, and acoustics quality. It focused on assessing IEQ using on-site physical measurements in classrooms specifically. IEQ was assessed in six classrooms in each of the three schools. The research also entailed inviting all of the 32 teachers (N = 32) working in those three schools to participate in an online survey to investigate their level of satisfaction with their schools' indoor environments.

1.6. Research Hypotheses

The research aims to test a number of hypotheses, namely that:

1) A comprehensive methodology for evaluating IEQ in relation to occupant well-being should involve on-site physical measurements of different IEQ aspects (i.e. thermal comfort, IAQ, lighting quality, and acoustics quality), a qualitative occupant well-being survey focusing on similar aspects, and field observations.
2) IEQ is highest in the classrooms of the new, LEED school and lowest in the classrooms of the middle-aged, conventional one.
3) Teachers' satisfaction with IEQ is highest in the classrooms of the new, LEED

school and lowest in the classrooms of the middle-aged, conventional one.

4) There is a relationship between schools' measured IEQ and teachers' satisfaction with IEQ, such that teachers in schools with higher levels of measured IEQ are more satisfied with their schools' IEQ than teachers in schools with lower levels of measured IEQ.
5) The methodology developed to evaluate IEQ and occupants' well-being in school buildings is a valid methodology that is internally and externally consistent.

2.0 Chapter 2: Literature Review

This section presents a review of the literature on IEQ and occupant well-being. Four main databases were used to identify this literature: Scopus, Science Direct, Google Scholar and Compendex Web; using the keywords "Indoor Environmental Quality", "Green Buildings", "School Buildings", "Occupant Satisfaction" and "Occupant Well-Being". Given the large number of journal and conference papers found as a result of this search, the search was limited by combining keywords together (e.g. "Indoor Environmental Quality" & "School Buildings"), and skimming through the papers' abstracts to determine the relevancy and suitability of each. This resulted in the use of a total of 65 journal and conference papers and four books for the literature review.

2.1. Importance of Indoor Environmental Quality and Occupant Well-Being

The strongest driver for building green is that of reducing buildings' energy consumption (Hoppe, 2002). All green building rating systems provide credits for reducing energy consumption, and in most systems these credits are weighted the heaviest. Indoor Environmental Quality (IEQ) is usually less emphasized in green building rating systems despite the intricate relationship between IEQ and energy consumption and its direct impact on occupants' satisfaction or dissatisfaction indoors (Abbaszadeh et al., 2006). This is also despite the fact that people spend approximately 90 percent of their time indoors (U.S. Environmental Protection Agency & the U. S. Consumer Product Safety Commission 2004), making them more prone to health risks due to exposure from indoor air pollutants (Hoppe, 2002). Indoor Environmental Quality

(IEQ) problems are not limited to one type of buildings (e.g. homes, office buildings, school buildings) as poor IEQ can negatively affect the health, productivity, and well-being of occupants in any of these buildings. Wargocki et al. (2000) found a relationship between poor IEQ conditions and SBS, and between good IEQ and improved health and productivity. Sullivan et al. (2013) showed how improving buildings' IEQ increased occupant satisfaction and performance. Hancock and Vasmatzidis (2003) found that poor indoor environments could cause dizziness, throat irritations, and other health problems which could in turn lead to decreased occupant satisfaction, performance, and productivity. Even though these studies seem to establish a relationship between IEQ and occupant well-being, there is a need for a more in-depth investigation of these issues (Singh et al., 2010). The investigation of these issues is complicated by how difficult it can be to quantify the value of improved occupant health and productivity and resulting costs or cost savings (Birkenfeld et al., 2011).

One of the most popular green rating systems developed to date is the LEED system, established by the U.S. Green building Council (USGBC) in 1998 as a voluntarily US national standard for developing high-performance, sustainable commercial buildings (USGBC, 2009). Since its foundation, the system has proven to be a popular choice for certifying new and existing green buildings (Issa et al., 2010). Although there are claims to the improved indoor environmental quality (IEQ) of green buildings certified using this and other systems, there is little empirical evidence in the literature to substantiate such claims. This is because most research and industry practices seem to have focused on energy as the main driver to building green; and thus on improving the energy effectiveness of green buildings with little consideration of other aspects such as IEQ.

IEQ in school buildings is a matter of particular concern. Like other buildings, school buildings are likely to have indoor environmental problems caused by inadequate funding and the inadequate operation and maintenance of these buildings. Children are also more prone to indoor environmental problems than adults given how they breathe higher volumes of air relative to their body weights than adults and how their tissues and organs are still actively growing (Faustman et al., 2000). Also, children spend more time in schools than any other indoor environment, their homes excepted. Poor indoor environmental conditions can have adverse effects on their learning and their school performance in general: effects that could go all the way to their adult lives (Mendell & Heath, 2005). Few studies have focused on evaluating the effects of schools' IEQ on students' learning and performance (e.g. Gilliland et al., 2001; Issa et al., 2011; Swail, 2013; Heschong Mahone Group, 2003b and Park et al., 2002). This is because of the problems that can arise in schools ranging from overcrowding to air quality to lighting, leading to the deterioration of school facilities.

2.2. Indoor Environmental Quality Parameters

IEQ includes many parameters that may have an impact on occupants such as thermal comfort, IAQ, ventilation rates, background noise, ergonomics, and lighting quality (Heinzerling et al., 2013 and Lee et al., 2012). These parameters combined make the study of IEQ more complex. A review of the literature on IEQ in green buildings showed how the literature has focused on investigating four main IEQ parameters in general: thermal comfort, air quality, lighting, and acoustics (Radwan et al., 2013). A review of every aspect separately and in relation to one another is crucial to understanding the intricate relationships between them. Thermal comfort appeared to be the IEQ aspect the most investigated in the literature, most probably due to the tight relationship between thermal comfort; heating, ventilation, and air-conditioning and by extension energy consumption: the main driver to building green.

The research involved investigating four main IEQ aspects: thermal comfort, indoor air quality, lighting, and acoustics. The subsections below include a detailed review of the literature focusing on these aspects.

2.2.1. *Thermal Comfort*

Thermal comfort is one of the key determinants of occupants' satisfaction with IEQ (Huang et al., 2012). Prior to mechanical ventilation, heating and air conditioning; thermal comfort was dependent on natural conditioning methods like cross ventilation, passive heating, and simple operable windows (Baker, 2011). Studies in the 1970s (e.g. Fanger, 1973) found that buildings' indoor temperatures needed to be within a small range of values to ensure thermal comfort: a finding that informed many building codes eventually (Brager & de Dear, 1998). A new method currently used is mixed-mode Heating, Ventilation, and Air Conditioning (HVAC). This mixed-mode method encourages the use of both natural ventilation through operable windows and other controlling devices, as well as mechanical ventilation. This method has helped develop guidance on the effective use of mechanical and natural HVAC systems simultaneously

(Brager & Baker, 2009). Another important aspect of thermal comfort is the level of control that occupants have over it. Huizenga et al. (2006) found that occupants' dissatisfaction with thermal comfort was due to the absence of thermostats and operable windows. A number of other studies (e.g. Baker, 2011 and Lackney, 2001) found similar results, such that the higher the level of occupant control of thermal comfort; the more satisfied occupants were with it.

2.2.2. *Indoor Air Quality*

Indoor air quality (IAQ) is another important determinant of IEQ. Its impact on occupants cannot be underestimated (Prakash, 2005). Building systems and materials can improve overall IAQ through the use for example of HVAC systems that filter out pollutants, or deteriorate it through using systems and materials that increase particulate matter, volatile organic compounds or moisture that leads to mold problems (Baker, 2011). High concentrations of pollutants such as carbon dioxide (CO_2) indoors have been associated with SBS symptoms, such as headache and thinking difficulty (Wargocki et al., 2000. Furthermore, a study by Fisk and Rosenfeld (1998) estimated the annual costs of IAQ-related problems at $100 billion. These costs are due to problems such as SBS, building-related illness, increased absenteeism, and the need for more extensive building operation and maintenance.

A few studies investigated the relationship between IAQ and students (e.g. Myhrvold et al., 1996 and Wargocki & Wyon, 2013). Mendell and Heath (2005) found a relationship between IAQ indicators and students' respiratory illnesses such as asthma.

They also found naturally ventilated buildings to be healthier for students suffering from respiratory illnesses than mechanically ventilated ones. Another study by Zuraimi et al. (2007) assessing 104 childcare buildings in Singapore, reported very similar results with respect to naturally ventilated childcare centers and the relationship between IAQ and children's health.

2.2.3. *Lighting Quality*

School buildings were traditionally built to receive sufficient natural lighting (Baker, 2011). Even though the evolution of lighting technologies has helped offer more sophisticated lighting systems that improve indoor lighting conditions tremendously, it has made newer school buildings more reliant on artificial lighting and less reliant on natural lighting. Studies (e.g. Heschong Mahone Group, 1999) analyzing the relationship between daylight and student performance showed how students in classrooms with sufficient daylight performed better on tests than students in classrooms with little daylight. A study by Patricia et al. (2000) comparing students' performance before and after moving to a new classroom with sufficient daylight exposure, found that students' test scores were higher in the new classroom. Even though such research emphasized the importance of natural lighting in schools, there's a lack of research on the effectiveness and specific impact of more sophisticated lighting systems. A study by Mardaljevic et al. (2009) noted how green buildings rating system (e.g. LEED and BREEAM) did not have metrics to evaluate glare and visual comfort, leading to the design of spaces that were not necessarily comfortable to occupants. In the face of such discomfort, occupants either chose to do nothing, or close the blinds and turn on indoor lights, thereby missing on intended energy savings, and the potential performance benefits stemming from the use of natural lighting (Baker, 2011). Another study (Heschong 2003a) noticed productivity improvements of 13% in workers in office buildings following increases in natural daylighting, and 10% to 25% improvements in tests of mental function and memory recall when workers were subjected to a pleasant view. Another study (Heschong 2003b) found that good views enhanced student learning while glare, direct sun penetration, poor ventilation, and poor indoor air quality worsened it.

Some studies (e.g. Cajochen, 2007 and VanBommel, 2006) reported on the non-visual biological importance of light to occupants. Natural and artificial light synchronize the biological clock of people regulating their daily routine, so that people are awake during the day and sleep at night (Cajochen, 2007). Bright light leads to alertness during daytime and quality sleep at night, reinforcing the notion that bright light can have a positive impact on students' health and well-being, and by extension their performance (Van Bommel, 2006).

2.2.4. *Acoustics Quality*

Acoustics quality is the aspect that is the least investigated in the literature. Recent research on classroom acoustics showed how children need quieter, less reverberant spaces than adults (California Energy Commission, 2003). Children are immature listeners and have a difficult time mentally separating verbal signals from background noise. Research on classroom acoustics in particular is fairly well-developed, and has led to the development of standards such as those of the American National Standards

Institute (ANSI) for classroom acoustics. The research is carefully described in Annex A of the ANSI Standard 12.60 and shows how proper acoustical design can have a direct effect on acoustical performance, which can by extension have a positive impact on students' learning (Acoustical Society of America, 2010).

The design of schools' acoustics usually focuses on two main objectives: 1) reducing background noise levels (e.g. from HVAC systems), and 2) reducing reverberation time (i.e. echo) (Lilly, 2000). Strategies used to achieve these objectives range from using materials that reduce sound transmission through walls, to providing specific interior finishes that help reduce echoes in classrooms (YeeChoi & McPherson, 2005). Sound privacy can also be an issue if voices can be heard through walls. Even though acoustical design metrics and strategies have been elaborated on in the literature; there has been less focus on acoustics in practice and in some green building rating systems (Prakash, 2005). This is despite the potential impact of sound acoustical design on students' classroom performance, reinforcing the need to better study this relationship, and translate the results to guidance that can be incorporated into existing green building rating systems.

2.3. Methods to Evaluate Indoor Environmental Quality and Occupant Well-Being

This section includes a review of the various qualitative and quantitative methods used to evaluate IEQ and occupant well-being in the literature, focusing on on-site physical measurements, occupant surveys, and field observations in particular.

2.3.1. *Quantitative Methods*

Objective methods involve using electronic instruments and sensors to conduct physical measurements of specific IEQ parameters such as air temperature, volatile organic compounds (VOCs), carbon dioxide (CO_2) and background noise. These instruments are usually manufactured to reference standards such as ISO 7720 (i.e. Ergonomics of the Thermal Environment-Instruments for Measuring Physical Quantities) and ASHRAE Standard 70 (i.e. Method of Testing for Rating the Performance of Air Outlets and Inlets) (ASHRAE 55, 2004). The measured values for each parameter are compared to the recommended values found in reference standards such as ASHRAE 55 (i.e. Thermal Environmental Conditions for Human Occupancy) to assess IEQ. Nevertheless, it is often difficult to find accurate, easy-to-use, and inexpensive instruments and sensors to conduct these evaluations (Heinzerling et al., 2013). Some sensors are difficult to use, require regular calibration to ensure their accuracy and are expensive to buy and calibrate (Heinzerling et al., 2013). There are also issues pertaining to the time, cost and labour required to deploy these sensors across a large building, conduct these physical measurements and then analyze the vast amount of data that is available as a result (Reynolds et al., 2001). Table 2-1 presents a brief review of the most important equipment used in the literature to evaluate IEQ.

Table 2-1 Equipment Used to Evaluate IEQ in Literature

Equipment Name and Developer	IEQ Aspects Investigated			
	Thermal Comfort	IAQ	Lighting	Acoustics
Instrumented chair-like cart (Heinzerling et al., 2013) Developed by CBE Berkeley	Air temperature, air velocity, and globe temperature at 0.1, 0.6, 1.1m; dew-point temperature and chair surface temperature at 0.6m; radiant asymmetry at 1.1m	N/A	Illuminance	N/A
Indoor climate monitor desktop device (Heinzerling et al., 2013) Developed by CBE Berkeley	Air temperature, globe temperature, RH, air velocity	CO_2	Illuminance	N/A
Pyramid desktop device (Newsham et al., 2012) Developed by NRC Canada	Air temperature, radiant temperature, RH, air velocity	CO_2	Illuminance	Sound pressure level
Portable UFAD Commissioning Cart (PUCC) – Advanced thermal comfort (Heinzerling et al., 2013) Developed by CBE Berkeley	Air temperature at 0.1 m, 0.25 m, 0.6 m, 1.2 m, 1.7 m, and 0.1 m from the ceiling as well as floor and ceiling surface temperatures using infrared temperature sensors (IRTs); Underfloor plenum temperature, pressure	N/A	N/A	N/A
NRC Indoor climate evaluator (NICE) (Newsham et al., 2012) Developed by NRC Canada	Air temperature; air velocity at 0.1 m, 0.7, and 1.1m; globe temperature, RH	CO_2, HCHO, CO, VOCs, PM	Illuminance, luminance	Sound pressure level

IEQ Cart (Mallory-Hill, 2012) Developed by Faculty of Architecture U of MB and EH Price Winnipeg	Air temperature; air velocity at adjustable levels; globe temperature, RH	CO_2, O_3, CO, VOCs, PM, Formaldehyde	Ambient & task illuminance	Sound pressure level

2.3.2. *Qualitative Methods*

Physical measurements alone are inadequate at evaluating IEQ and its impact on building comfort, satisfaction, well-being and building performance as they do not capture more qualitative, occupant-related aspects. Building occupants are a valuable source of information that can provide feedback to architects, designers, and building owners about the performance of existing buildings given their presence in the building year round, thus the importance of Post-Occupancy Evaluations (POE) (Heinzerling et al., 2013). POE involves assessing a building's performance once occupied using not only quantitative methods but also qualitative ones such as surveys, questionnaires, cohort studies, observations, or task performance tests (Arens, 2007). Although several POE processes have been developed and validated over the years, there is no established standardized process for conducting POEs (Newsham et al., 2012).

Surveying is often the simplest and least-expensive method for evaluating IEQ due to its low cost in comparison with that of using measurement instruments (ASHRAE Journal, 2012). Surveying also provides information about occupants' perceptions of IEQ which can be very different from the actual, physical IEQ conditions of a building, yet valuable to buildings' owners and operators (Muhič & Butala, 2004). It is usually complimentary to quantitative methods and can be used to validate them. A number of survey tools have been developed to study, among other things, occupants' perceptions of buildings' IEQ. Mallory-Hill and Westland (2012) and Peretti and Schiavon (2011) conducted a thorough review of these tools. Sample tools include the Building Use Studies (BUS) Occupant Survey (Leaman, 2010), the Building Assessment Survey and

Evaluation Study (USEPA, 2003), the Centre for the Built Environment (CBE) Survey (Baker, 2011), the Cost-effective Open-Plan Environments (Veitch et al., 2002), and the Health Optimization Protocol for Energy efficient Buildings Project (Bluyssen et al., 2003). Despite the availability of all of these tools, there is no standard tool that is used to survey all building occupants (Peretti & Schiavon, 2011).

The two most widely used survey tools in the literature are the Building Use Studies (BUS) survey and the Center for the Built Environment (CBE) survey (Peretti & Schiavon, 2011). BUS was founded in London in 1981, resulting in the development of a full methodology with the same name four years later and that is still in use today. The BUS survey has been used in a variety of contexts, in residential and office buildings specifically (Leaman, 2010). The CBE survey is the most used survey tool today, having been used in over 600 buildings, mostly office buildings and on more than 60,000 respondents globally (Peretti & Schiavon, 2011). Most recently, a survey was developed by Newsham et al. (2012) at the National Research Council in Canada (NRC) to investigate the differences in occupants' perception of IEQ between green and conventional buildings in North America.

2.3.3. *Use in the Literature*

Recent literature reviews suggest that very few studies (e.g. Mallory-Hill & Westland, 2012; Deuble & de Dear, 2012; Konis, 2013 and Newsham et al., 2012 seemed to rely on on-site physical measurements. This is most probably because of the time, effort and equipment required to conduct these measurements (Radwan et al., 2013). In contrast, most studies appeared to rely on occupant surveys, most probably due to the relative ease of conducting them in comparison with other research methods. Studies using both methods seemed to focus on office buildings in particular (e.g. Newsham et al., 2012; Reynolds et al., 2001 and Sadick et al., 2014a and 2014b). This could be due to the potential significant implications of improving these buildings' IEQ, in terms of improved employees' health and productivity, and thus decreased long-term business costs (Newsham et al., 2012). The second most evaluated type of buildings in the literature included institutional buildings, such as schools and universities (e.g. Baker, 2011 and Issa et al., 2011). This could be due to the need to improve students and teachers' learning and teaching respectively, and improve their overall performance, health and well-being (Issa et al., 2011).

2.4. Indoor Environmental Quality and Occupant Well-Being in the Literature

Despite the lack of empirical evidence on the precise impact of improved IEQ on occupants' health and productivity, there is growing evidence in the literature pointing to that impact (e.g. Newsham et al., 2009 and Thayer et al., 2010). A recent industry survey by PRNewswire (2010) showed how 10% of building tenants saw improvements in productivity in green buildings; 83% found the indoor environment of these buildings to be healthier, and 94% were more satisfied with it than in conventional buildings. Despite these results, there remains little formal investigation of whether new, green buildings once built and occupied, offer indoor environments that are significantly better than conventional ones (Newsham et al., 2012). There is also little formal investigation of the specific impact of poor IEQ on occupants' health and productivity, reinforcing the need for more research in this area (Heinzerling et al., 2013). This section includes a review of the state of the literature focusing on IEQ and occupant well-being, in school buildings first and then in other types of buildings.

2.4.1. *School Buildings*

A review of the literature shows how most building performance studies seemed to focus on commercial buildings (e.g. Newsham et al., 2012; Reynolds et al., 2001 and Sadick et al., 2014a and 2014b). This being said, research into school building performance has grown rapidly in the past decade. Building high performance schools is reported to be the fastest growing sector of the construction industry, with a projected 65% increase in that sector over the next five years and a projected 29% share of the whole construction market (McGraw Hill, 2011). In North America, schools can consume up to 25% more energy than is necessary (Straka & Aleksic, 2009). Commercial and institutional buildings in Canada use 12% of the country's secondary energy use and 11% of its national greenhouse gas emissions (Office of Energy Efficiency, 2013). In addition, schools in Canada account alone for 11% of the total energy used by institutional and commercial buildings in the country and are thus the second largest consumers of energy in this sector (Natural Resources Canada, 2011). Nevertheless, research into green schools remains limited despite the potential range of benefits of these schools (Elzeyadi, 2012). This is a problem given how school buildings differ from other types of buildings with respect to aspects such as daily routine, occupants, and management systems (Baker, 2011).

A review of the literature shows how no formal standardized method currently exists for assessing school buildings' performance. Most studies (e.g. Brager & Baker, 2009 and Catalina & Iordache, 2012) used occupant surveys to do so. Only a few used physical measurements and occupant surveys combined (e.g. Prakash, 2005 and Swail, 2013). Sanoff et al. (2001) developed their own method that is broadly used in the literature (e.g. Baker, 2011; Higgins et al., 2005 and Lackney, 2001). The method included a lengthy set of questionnaires and aimed to improve the design of new facilities by setting specific educational goals for them. It did not involve any objective measurements that could be compared against established standards. The study also made suggestions about the application of the method, highlighting the importance of planning, cultural appropriateness, and conceiving different designs for different learning styles. Other studies also relied on surveys to assess existing school building facilities. Earthman and Lemasters (2009) surveyed schools principals about their schools' building systems and design features. Uline and Tschannen-Moran (2008) surveyed teachers about their school buildings' quality and how their buildings affected their teaching. However, most studies investigated very small samples of schools. Only a few studies (Issa et al., 2011, Swail 2013) used larger samples with the aim of delivering statistically significant results.

The results of these studies showed common results. A study by Kelting and Montoya (2012) interviewing educational leaders (e.g. school principals, education policy makers) showed how many found energy efficiency to be more important than IEQ and how many did not see the potential correlation between daylighting and student performance. Dascalaki and Sermpetzoglou (2011) collected second-hand energy performance data, monitored various indoor environmental conditions and surveyed students and teachers about IEQ in Hellenic schools. Seven percent of the students reported thermal discomfort in the summer due to overheating; 20% reported visual and acoustical discomfort and 58% of the teachers preferred brighter visual conditions. Even though some classroom windows and doors were kept open to enhance fresh air penetration, 25% of the students found IAQ and air ventilation to be problematic. Two-third of the schools evaluated failed to meet thermal envelope standards due to problems associated with the use of insufficient insulation and single glazing windows. A third did not meet their relative humidity (RH) and CO_2 standards. Another study of 39 schools by Smedje and Norback (2000) in Sweden found similar results. Approximately, 77% of the schools were found to not meet building code regulations. Another study by Wargocki and Wyon (2013) found the environmental conditions in elementary schools to be inadequate and much worse than those in office buildings, even in developed countries.

In Canada, a study by Issa et al. (2011) using a combination of second-hand absenteeism and student performance data and occupant surveys, found that green schools offered a more comfortable indoor environment with respect to ventilation, IAQ, lighting, and thermal comfort than other schools. The study focusing on 33 Toronto schools found acoustics to be worse in the green schools investigated, but absenteeism to be lower and student performance to be higher in them. A recent study by Swail (2013) focused on IAQ specifically and used a combination of physical measurements, an occupant survey, and second-hand data (i.e. absenteeism data) from 24 schools in

Winnipeg, Manitoba. The study found IAQ to be problematic (e.g. low RH values, high CO_2 concentrations) in nearly all schools. No relationship was found between staff absenteeism and IAQ parameters. However, 96% of the respondents complained about IAQ in their workplace, and 79% reported experiencing SBS-like symptoms. Another study by Straka and Aleksic (2009) using on-site physical measurements and occupant surveys and focusing on three Toronto schools showed how satisfied teachers were with thermal comfort in their classrooms. These results were in line with indoor temperatures which fell within the recommended range. A relationship was also found between classroom temperatures and occupants' ranking of their classrooms' IEQ. Nevertheless, no clear relationship could be established between CO_2 levels and occupants' ranking of their rooms' IEQ, demonstrating therefore how thermal comfort, rather than IAQ tend to have a more significant impact on occupants' perception of IEQ.

2.4.2. ***Other Buildings***

Studies on office buildings using both methods include the one by Nicol and McCartney (2000), investigating 26 buildings in Europe and aiming to develop an adaptive control system for Europe. The study correlated physical measurements of several IEQ aspects (i.e. CO_2 concentration, globe temperature, air temperature, relative humidity, illuminance, air velocity, and noise level) to the results of an occupant survey. Another study by U.S. EPA (2003) used physical measurements to evaluate the indoor environmental conditions (i.e. CO_2, CO, temperature, RH, VOCs, $PM_{2.5}$, PM_{10}) of 100 office buildings in the US, as well as an occupant survey to evaluate employees' health and well-being in these buildings. A more recent study by Newsham et al. (2012)

investigating 24 green and conventional office buildings across Canada and the Northern US correlated their IEQ conditions (e.g. thermal conditions, air quality, acoustics and lighting) to the satisfaction and well-being of these buildings' occupants. Visual observations of the physical conditions of these offices (i.e. workstation size, ceiling height, window access and shading, electric lighting system, and surface finishes) were also used to validate the physical measurements and occupant survey used in the study.

3.0 Chapter 3: Methodology

This chapter presents the complete methodology used in the research. The first section presents the methods used to collect and analyze IEQ and occupant well-being data in schools as part of achieving objective 1. The second section describes how the methodology was applied on the specific sample of schools studied in line with objective 2, whereas the third section describes how the methodology was validated as part of achieving objective 3.

3.1. Methodology Development

On-site physical measurements, an occupant survey and field observations represent the different components making up the methodology used in this research. These components are described below.

3.1.1. *On-Site Physical Measurements*

This research involved using 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). The cart aimed to evaluate the IEQ parameters shown in Table 3-1. The IEQC shown in Figure 3-1 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 cart was adjusted to meet the IEQ standards and performance criteria of school buildings, focusing on evaluating the IEQ aspects of Thermal Comfort, Indoor Air Quality (IAQ), Lighting Quality and Acoustics Quality.

Table 3-1 IEQ Variables, Parameters and Methods Used in Research

IEQ Aspects	Parameters	Instruments	Recommended Values	Mounting Heights
Thermal Comfort	Air temperature	RTD	20 to 24.5°C[1]	0.10m 0.59m 0.97m
	Air velocity	Thermo Air 64	0.1 to 0.2 m/s[1]	
	Relative humidity	Gray Wolf IQ610	30 to 65% [2]	0.80m
IAQ	Carbon dioxide	Gray Wolf IQ610	< 1,100 ppm [2]	0.80m
	Carbon monoxide		< 5 ppm [3]	
	TVOCs		< 300 µg/m^3 [4]	
	Ozone		0.075 ppm (8 h)[5]	
Lighting Quality	Illuminance	Li Cor LI 210	300 to 750 lux [6]	0.80m
Acoustics Quality	Sound pressure level	Scantek Sound Level Meter	35 to 55dB [7]	1.17m

[1] ASHRAE 55-2004. (2004). ASHRAE 55-2004 Thermal environmental conditions for human occupancy: American society of heating, refrigerating and air-conditioning engineers.
[2] ASHRAE 62.1-2013. (2013). ASHRAE 62.1-2013 Ventilation for Acceptable Indoor Air Quality: American society of heating, refrigerating and air-conditioning engineers.
[3] Health Canada. (2003). Indoor air quality: Tools for schools action kit for Canadian schools. Environmental and Workplace from http://www.hc-sc.gc.ca/ewh-semt/pubs/air/tools_school-outils_ecoles/index-eng.php.
[4] ECA (European Concerted Action "Indoor Air Quality and its Impact on Man"). Guidelines for Ventilation Requirements in Buildings, Report No. 11, EUR 14449 EN. Luxembourg, Office for Official Publications of the European Communities, 1992.
[5] US Environmental Protection Agency. (2008). National Ambient Air Quality Standards. http://www.epa.gov./air/criteria.html
[6] Rea, M. S. (2000). The IESNA lighting handbook: reference & application..
[7] Acoustical Society of America. (2010). Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools.

Figure 3-1 Indoor Environmental Quality Cart used in Research

The methodology involved identifying the specific parameters to be measured for every IEQ aspect and the specific sensor that will be used to measure each parameter, as shown in Table 3-1. The methodology also entailed identifying the specific methods that will be used to measure each parameter as well as recommended values or ranges of values for each parameter. These values were found in various standards such as the ones produced by ASHRAE (2004, 2013), the Acoustical Society of America (2010), and Health Canada (2003). The methods involved determining the units for each parameter, the mounting heights of the sensor that will be used to measure each parameter, as well as the measurement period or cycle for each parameter. Many of the methods and standards used as part of this methodology were based on office buildings' standards. This is because of the lack of standards and other forms of guidance for school buildings in general. Should specific standards be developed for schools in the future, these standards are not expected to differ much from the ones for office buildings, except for mounting heights which would need to be adjusted to accommodate students' seating heights.

Air temperature and air velocity were measured at three levels in accordance with the ASHRAE 55 (2004) standard for thermal comfort. Nevertheless, the mounting heights of the sensors used to measure these parameters were slightly adjusted to accommodate children's seating heights, as the standard was intended for adults. Measurements were taken at feet, chest, and seated head levels at 0.10m, 0.59m, and 0.97m respectively. With respect to carbon dioxide (CO_2), ASHRAE 62.1 (2013) standard recommended that CO_2 concentrations indoors do not exceed outdoor concentrations by more than 700 ppm. As outdoor levels typically ranged between 350 and 400 ppm, this amounted to a maximum indoor limit of about 1,050 to 1,100 ppm. With respect to carbon monoxide (CO) (Health Canada, 2003) warned against indoor levels above 5 ppm as these indicate the presence of combustion pollutants. The ASHRAE 62.1 (2013) standard set the eight hour average exposure limit for CO at 9 ppm. As it wasn't feasible to use the cart for that long in every classroom, the Health Canada (2003) standard was used instead to evaluate this parameter. With respect to Total Volatile Organic Compounds (TVOCs), no specific standards were found for non-industrial settings. There was also disagreement within the science and medical fields about the degree of risk posed by various amounts of VOCs (Batterman & Peng, 1995). Reynolds et al. (2001) found TVOC levels between 160 - 300 $\mu g/m^3$ to be associated with SBS symptoms.

The research involved measuring all parameters over ten minutes in each classroom. However, only the last five minutes of measurements was used for the analysis to avoid the high and low values commonly found at the start of measurements and associated with the lagging response of sensors. For example, the TVOCs channel of the sensor was found to have a lag response time of about 2 minutes.

3.1.2. *Occupant Survey*

An occupant survey was used to evaluate teachers' 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 building and classroom environments and teachers' unique needs. It was accompanied by a cover page and a cover letter to provide more information about it.

The survey encompassed a total of 40 questions over five different modules: a Core module and four separate modules for thermal comfort, air quality, lighting quality, and acoustics quality respectively. Only six questions were open-ended optional questions; the remaining ones were closed-ended of different types (e.g. Likert scale, multiple choice) to make them quicker to answer and simpler to deal with. Where appropriate, multiple choices questions included an "Other: please specify" option to give respondents the opportunity to add to the choices available. Table 3-2 summarizes the design and content of the questionnaire.

Table 3-2 Design and Content of Survey

Questions Numbers	Question Types	Issues Investigated
Questions 1-7	Multiple choice	School name, age, years of experience in school, number of students in classroom, location/ orientation of classroom.
Questions 8-12	Likert	Satisfaction with overall physical condition
Questions 13, 15-19	Multiple choice	Thermal comfort issues, level of personal control, impact on work performance
Question 14	Likert question	Satisfaction with thermal comfort
Question 20	Open-ended	Other thermal comfort issues
Question 21	Likert	Satisfaction with IAQ
Questions 22-24	Multiple choice	IAQ issues, impact on work performance
Question 25	Open-ended	Other IAQ issues
Question 27	Likert	Satisfaction with lighting quality
Questions 26, 28,29, 31-33	Multiple choice	IAQ issues, level of personal control, daylighting quality and visual comfort
Questions 30, 34	Open-ended	Other lighting and daylighting quality issues
Question 35	Likert	Satisfaction with acoustics quality
Questions 36-38	Multiple choice	Sources of noise, impact on work performance
Question 39	Open-ended	Other acoustics quality issues
Question 40	Likert	Satisfaction with overall IEQ

The Core module enquired about respondents' demographics, their general satisfaction with their school building's conditions and layout, its location, as well as various other operation and maintenance aspects. The other four modules enquired about respondents' satisfaction with temperature and thermal comfort, IAQ, lighting quality, and acoustics quality. Satisfaction questions used a seven point Likert scale, ranging from "Not at all Satisfied" to "Very Satisfied" as shown in the sample question in Figure 3-2. Dissatisfied respondents answering any of these questions with a score below four (i.e. "Neutral") were asked to explain their answers further.

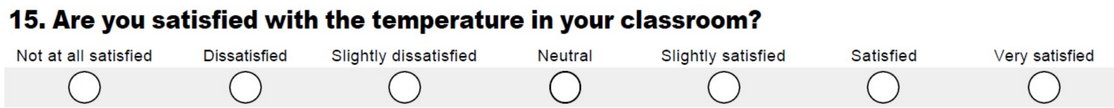

Figure 3-2 Typical Seven-Point Scale used to Answer Satisfaction Rating Questions in Survey

With respect to the scope of this survey, this survey did not focus on the teaching, learning and administrative aspects that are not under the control of building designers. In addition, the survey did not focus on financial issues that my affect school buildings' operation and maintenance or health aspects such as respiratory illnesses, and absenteeism connected to IEQ and building issues. These questions were avoided to encourage participation and dissemination of the survey without fear of retribution or liability. Questions were also kept subjective for that same purpose, asking occupants to report on their satisfaction with various aspects and the impact of any of these aspects on their work performance.

3.1.3. *Field Observations*

The observation form, based on Sadick et al. (2014a and 2014b) in APPENDIX II was used to record other information not captured in the survey or by the IEQC 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, the number and types of lamps used in each, and other physical characteristics of the classrooms evaluated. It also included a space for drawing classrooms and noting any unique features in them. This information was collected to validate on-site physical measurements and occupant survey responses. Also photographs were taken on the days of measurements to depict any of these issues visually.

3.2. Methodology Application

This section describes how the methodology described in Section 3.1 was applied to the sample of schools evaluated, as well as the methods used to analyze the collected data.

3.2.1. *Data Collection*

This subsection describes the methods used to collect the study data. It focuses in particular on how the schools evaluated as part of this research were selected, how IEQ was physically measured in these schools and how the perceptions of the teachers in these schools were also investigated.

3.2.1.1. Schools Recruitment

The research involved contacting six school divisions by email. Initial meetings were set with each of the four that responded, with presentations made during these meetings explaining the goal and objectives of the research, the methods used to achieve them, as well as its expected benefits and contributions. One school division declined to participate following the meetings, resulting in the participation of three school divisions in total.

The research involved requesting preliminary data from each school division about each of their schools using the form in Appendix III. Preliminary information was collected for approximately a total of 50 schools, resulting in the division of these schools into three main categories: old and middle-aged, new non-green and new green schools. Older schools were built before 1960, middle-aged ones were built between 1960 and 1989 and the new schools were built on or after 1989. These cut-off years were based on the ones used by the Commercial Buildings Energy Consumption Survey (CBECS, 2012). Only one LEED certified school was available and was therefore selected as the new, LEED school. The research involved using a stratified random sampling process and Newman proportional allocation to select the middle-aged conventional school, and new non-LEED school to be included in the sample. This was to ensure the inclusion of schools with various occupant capacities and floor areas as the floor areas of the schools in the population varied between 1,000 and 10,000 m^2. This form was usually filled out by every school division's superintendents. Information collected included the location of every school building, its size, classroom layout, occupancy capacity, and school grades served by every school.

Table 3-3 summarizes the main features of the three rural Southern Manitoban schools selected. The names of the schools and their school divisions were omitted for confidentiality purposes. The data collection phase involved requesting floor plans for each school and conducting an initial visual inspection of every school to select the classrooms, the IEQ of which will be assessed. The selection was based on classrooms' orientation, their use and the availability of students in those classrooms on the days of measurement. Six classrooms from within every school were eventually selected for the IEQ physical measurements using the procedure outlined below.

Table 3-3 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
Available Automatic controls	Lighting, temperature	Temperature	Temperature
Ventilation Type	Mechanical Ventilation	Mechanical ventilation	Mechanical Ventilation

3.2.1.2. Indoor Environmental Quality

The physical assessment of IEQ was conducted in June 2014. The assessment involved a visual inspection of every classroom and a full physical evaluation of the different IEQ parameters measured using the cart on the days of the visit. Prior to visiting every school, an email was sent to the schools' principals to confirm the dates and times of the school visit and of the visit of every classroom. The procedures followed during every visit are outlined below:

1) Once on site, the teachers and students in every classroom to be evaluated were notified by the school principal of the time of the IEQ physical measurements.
2) The IEQC was set up in the centre of every classroom and was kept running for approximately 10 minutes to capture the IEQ parameters to be measured. This was done in the presence of students and teachers, without interrupting regular classroom activities to capture the actual working environment as much as possible.
3) Field observations were captured on the observation form in Appendix II, with photographs taken at the same time as well.
4) Once the measurements were complete, the data was saved and the cart removed from every classroom, with the full process repeated again in the next classroom to be evaluated.

3.2.1.3. Occupant Well-Being

The teacher survey was administered online in September 2014 via the software:

"SurveyMonkey", approximately three months following the days of the physical measurements. Teachers were invited to take the survey by their school principals or the divisions' superintendents. Participants received an email invitation, with a link to the online survey, and a cover page and consent letter as mandated by the University of Manitoba Research Ethics Board. Participants were required to provide their full and informed consent prior to participating in the survey by clicking on the "Agree" button at the end of the consent letter page. The survey was made available to them for a period of two weeks as suggested by Baker (2011), with email reminders sent to them by the end of the first week, and one day before its closing as recommended by the CBE survey (Baker, 2011). Prior to deployment, the survey received human ethics approval by the University of Manitoba Education/Nursing Research Ethics Board as shown in APPENDIX I.

The research ensured the confidentiality and security of survey responses. Survey responses were returned online to secured "SurveyMonkey" servers. Only members of the research team had access to them. Given the anonymity of survey responses, the research team could neither identify the teachers who had participated in the survey, nor their email and internet protocol (IP) addresses. An anonymous link was created in "SurveyMonkey" and incorporated into the email invitation sent to survey participants. Although the invitation was emailed to the school principals who forwarded the email invitation to participants themselves, the principals did not receive any of the survey responses and could not identify any of the teachers who had participated in it. The security of the "Survey Monkey" software was such that only one response could be submitted from any single computer and IP address.

3.2.2. *Data Analysis*

This subsection describes the methods used to analyze the data collected. It provides the specific research questions answered through the research as well as the statistical tests used to answer them. It also describes the specific methods used to analyze the physical parameters of IEQ, teachers' perceptions of IEQ as well as the relationship between the two aspects.

3.2.2.1. Research Questions and Statistics

Several statistical tests were conducted using the software IBM SPSS version 22 to evaluate the statistical significance of the results at $p = 0.05$ and a 95% level of confidence. All variables were tested for continuity and homogeneity to ensure that non-parametric tests could be used on them. For the purpose of this research, the non-parametric Kruskal-Wallis H test was used to test the statistical significance of the differences in:

1) The on-site physical measurements of every IEQ aspect (i.e. indoor temperature, air velocity, RH values, CO_2 concentration, TVOCs, desktop illuminance, and background noise) across the three schools
2) Teachers' satisfaction with every IEQ aspect (i.e. thermal comfort, indoor air quality, lighting, and acoustics) across the three schools

If statistically significant differences were found, a Dunn's Bonferroni post hoc pairwise comparisons test was used to identify the specific statistically significant differences between every pair of schools.

The Spearman's Rank Correlation Coefficient test was also used to assess the strength and statistical significance of the relationship between:

1) The on-site physical measurements of different IEQ aspects (e.g. temperature and RH, TVOCs and CO_2)
2) Occupants' satisfaction with various IEQ aspects
3) The on-site physical measurements of every IEQ aspect and occupants' satisfaction with that same aspect

Table 3-4 summarizes the specific research questions answered through the research, the statistical tests used to answer these questions, and the location of these answers in the thesis.

Table 3-4 Research Questions, Statistical Tests Used to Answer them and Answers' Location in Thesis

Research Questions	Statistical Tests	Answers' location
How do the schools' thermal comfort, IAQ, lighting quality, and acoustics quality measurements compare with recommended values?	Maximum, minimum, and mean values	Section 4.1
Are there statistically significant differences in thermal comfort, IAQ, lighting quality, and acoustics quality measurements across the schools?	Kruskal-Wallis H test, Dunn's Bonferroni post hoc test	Section 4.1
Are there statistically significant correlations between various thermal comfort and IAQ parameters?	Spearman's Rho Correlation	Section 4.2

Are there statistically significant differences in teachers' satisfaction with thermal comfort, IAQ, lighting quality, and acoustics quality across the schools?	Kruskal-Wallis H test, Dunn's Bonferroni post hoc test	Section 4.2
Are there statistically significant correlations between teachers' satisfaction with various IEQ aspects?	Spearman's Rho Correlation	Section 4.2
Are there statistically significant correlations between thermal comfort, IAQ, lighting quality, and acoustics quality measurements; and teachers' satisfaction with these aspects?	Spearman's Rho Correlation	Section 4.3

3.2.2.2. Indoor Environmental Quality

Thermal comfort was measured using three parameters: temperature and air velocity at three different heights (i.e. feet, chest, and head) as well as relative humidity (RH). The average temperature and air velocity for every school was compared to the ASHRAE 55 standard. A Kruskal Wallis H test was also used to test the statistical significance of the difference between these values across the three schools. These values in addition to the ones related to teachers' satisfaction with thermal comfort were used to estimate the predicted percentage of dissatisfied respondents (PPD) as well as the predicted mean vote (PMV) based on physical conditions. The Spearman's Rho correlation test was also used to assess the relationship between temperature and RH values.

IAQ was evaluated through the measurement of Carbon Dioxide (CO_2), Carbon Monoxide (CO), Total Volatile Organic Compounds (TVOCs), and Ozone Concentration (O_3) levels. The average values for CO_2 levels were compared to the ASHRAE standard 62.1. The average values of every other parameter in every school were compared to their industry standards, with the differences between the average values for every parameter across the three schools tested for statistical significance. The Spearman's Rho correlation test was also used to assess the relationship between CO_2 and TVOC levels, and between TVOCs and RH values.

The average values for desktop illuminance on both sides of students' desks at a desk height of 0.8 m were compared to the standard value by Reynolds et al. (2001). The difference between the average values for every school was also tested for statistical significance.

The average values for background noise at the seated height of a student's ear (i.e. 1.17 m) were also compared to the industry standard by the Acoustical Society of America (2010).

3.2.2.3. Occupant Well-Being

The survey was sent out to the 32 teachers working in the three schools. All responses received for every single question were considered in the analysis. The Kruskal-Wallis H test was used to determine the statistical significance of the differences in teachers' responses across the three schools, with the Dunn's Bonferroni post hoc pairwise comparisons test used if statistically significant differences were found to evaluate the differences between every pair of schools. The Spearman's Rho correlation was also used whenever possible to test the strength and statistical significance of the correlation between teachers' dissatisfaction with specific IEQ aspects and issues that may explain this dissatisfaction where applicable. Appendix V shows a preliminary analysis of all survey responses.

The analysis considered the statistical significance of the differences in teachers' overall satisfaction with their school buildings, their school buildings' maintenance, space availability, usage, aesthetics and general cleanliness across the three schools. The differences in teachers' satisfaction with IEQ in general and with every IEQ aspect (i.e.

thermal comfort, IAQ, lighting quality and acoustics quality) in particular was also tested for statistical significance. The analysis also involved correlating teachers' satisfaction with IEQ in general with their satisfaction with every IEQ aspect to identify the aspect(s) with the most impact on their satisfaction with overall IEQ.

With respect to thermal comfort, the statistical significance of the differences in teachers' satisfaction with thermal comfort in general and with specific aspects of thermal comfort (e.g. controllability, air movement, temperature) in particular across the three schools was also determined. The PPD and PMV valued derived from the physical measurements were compared to the ASHRAE 55 standard. The analysis also involved evaluating the relationship between teachers' satisfaction with thermal comfort and their perception of the impact of thermal comfort on their work performance.

The differences in teachers' satisfaction with IAQ in general and with every specific IAQ aspect across the three schools were also tested for statistical significance. The analysis involved comparing the percentage of satisfied teachers and their mean satisfaction levels with the ASHRAE 62.1 standards for ventilation. The analysis also entailed correlating teachers' satisfaction with IAQ to their perception of the impact of IAQ on their work performance.

The statistical significance of the differences in teachers' satisfaction with natural and artificial lighting and with various other aspects of lighting across the three schools was also investigated. The relationship between these various aspects was also investigated, including the relationship between their satisfaction with lighting and their perception of the impact of lighting quality on their work performance.

The analysis also involved evaluating the statistical significance of the differences in teachers' satisfaction with acoustics quality and its various aspects over the three schools. The analysis also involved determining the school with the highest percentage of satisfied teachers with acoustics quality. The relationship between teachers' satisfaction with acoustics quality and with various sources of noise in their schools was investigated. The relationship between teachers' satisfaction with acoustics quality and their perception of the impact of acoustics on their work performance was also investigated.

3.2.2.4. Indoor Environmental Quality in Relation to Occupant Well-Being

The analysis extended to evaluating the relationship between the physical measurements of IEQ and teachers' perception of IEQ as evidenced by the survey results. The analysis focused specifically on the relationship between the physical measurements of thermal comfort (i.e. temperature, air velocity, and RH) and teachers' perception of their schools' thermal comfort. Similar relationships were investigated between measured IAQ (i.e. CO_2 and TVOCs) and teachers' perception of IAQ, between measured lighting quality (desktop illuminance) and teachers' perception of lighting quality, and between measured acoustics quality (i.e. background noise) and teachers' perception of acoustics quality.

3.3. Methodology Validation

This section describes the two methods used to validate the methodology.

3.3.1. *Internal*

The internal validation involved comparing the physical measurements of IEQ to the occupant survey results to evaluate the consistency of the evidence produced using these different methods and thus validate them. That being said, inconsistent results do not automatically call into question the validity of the methods making up the methodology. This is because the way occupants feel about the IEQ, as evidenced by survey results could be very different from the actual physical conditions of the indoor environment as evidenced by the on-site physical measurements. This could be the case despite the use of a valid and reliable research methodology.

3.3.2. *External*

The external validation entailed comparing the most important key findings of this research to findings in the literature to evaluate the consistency of these findings. Just like for the internal validation, inconsistent results do not automatically invalidate the methodology given how every research has its own unique set of factors and variables that make lead to very different results, despite the use of reliable and valid research methodologies for each (Sadick et al. 2014a and 2014b). It is therefore unreasonable to expect different research studies to produce the same results even if both share a number of similar factors and variables.

4.0 Chapter 4: Results and Discussion

This chapter presents the results of the data analysis. The first section focuses on the results of the analysis of the physical measurements of IEQ. The second focuses on the results of the occupant well-being survey whereas the third presents the results of the correlation between measured IEQ and occupants' perception of IEQ. The final section presents the results of the analysis of the external and internal consistency of the research methodology with the aim of validating it.

4.1. Indoor Environmental Quality

This section presents the results of the analysis of the on-site physical measurements of IEQ, focusing on thermal comfort, IAQ, lighting quality and acoustics quality specifically.

4.1.1. *Thermal Comfort*

Table 4-1 presents the average, minimum and maximum values of the key thermal comfort parameters of temperature (t), air velocity (v) and relative humidity (RH) in every school as measured by the IEQC in comparison with the values recommended by ASHRAE standard 55-2010. Appendix VI presents more detailed results. Table 4-1 shows how average temperatures were acceptable, except surprisingly for the LEED school where some classrooms' average temperatures exceeded recommended levels. The highest temperature of 25.8°C was recorded in the new, LEED school and was 1.3°C higher than the recommended level. This could be due to the high number of students (i.e.

32 students) in the classroom where this temperature was recorded because of the merging of the students in two classes at the time the measurements were taken. The Kruskal Wallis H test showed a statistically significance difference in the average temperatures recorded across all schools ($p = 0.013$). The post hoc analysis revealed a statistically significant difference in the average temperatures between the new, LEED school ($t = 23.9°C$) and the middle-aged, conventional one ($t = 22.3°C$; $p = 0.012$). Figure 4-1 shows the distribution of the average temperatures recorded across all schools, with the centre line inside each box representing the median value for the range of temperatures in each school.

Table 4-1 Key Measurements of Thermal Comfort Parameters

Schools	Parameters	Temperature (°C)	Air Velocity (m/s)	RH (%)
New, LEED	Minimum	23.2	0.23	42.6
	Average	23.9	0.46	44.0
	Maximum	25.8	0.70	47.0
New, Non-LEED	Minimum	21.2	0.34	48.0
	Average	22.9	0.81	52.6
	Maximum	23.8	1.14	58.1
Middle-Aged, Conventional	Minimum	21.0	0.32	51.0
	Average	22.3	0.44	53.3
	Maximum	23.2	0.70	56.5
Recommended Values		20 to 24.5	0.10 to 0.20	30 to 65

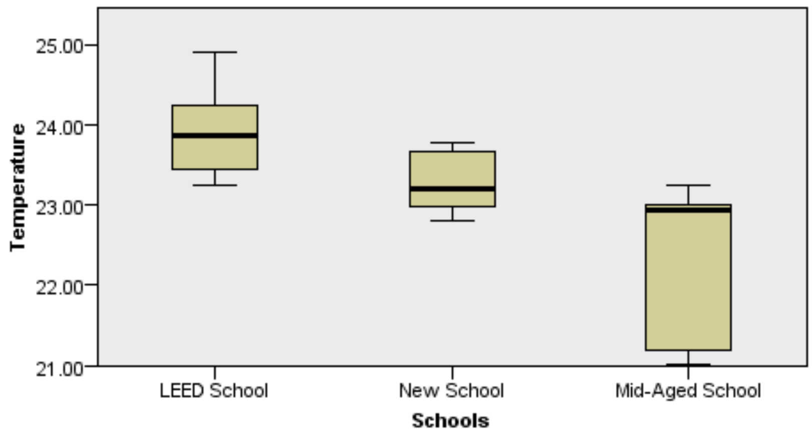

Figure 4-1 Distribution of Temperature Measurements

On the other hand, air velocities measured at the three heights were all above the recommended 0.2 m/s. The results of the Kruskal-Wallis H test showed that the difference in average air velocities across the three schools was not statistically significant. None of the schools exceeded or went below the RH recommended range. The Kruskal Wallis test showed a statistically significance difference in the average RH values across all schools ($p = 0.003$). The post hoc analysis revealed a statistically significant difference in RH values between the LEED school (RH = 44%) and the new one (RH = 52.6%; $p = 0.015$) and between the LEED school and the middle-aged one (RH = 53.3%; $p = 0.007$). Figure 4-2 shows the distribution of RH values, with the centre line inside each box representing the median value for the range of RH values in each school. The relative dryness of the air observed in the LEED school could be due to it having the highest average temperature among the three schools. The Spearman's rank correlation coefficient test showed a strong negative correlation between average temperatures and RH values ($r = -0.695$; $p = 0.001$). This would have been expected if the study was conducted in winter, given how difficult it can be to maintain RH values during the winter months in Manitoba (Hutcheon, 1968).

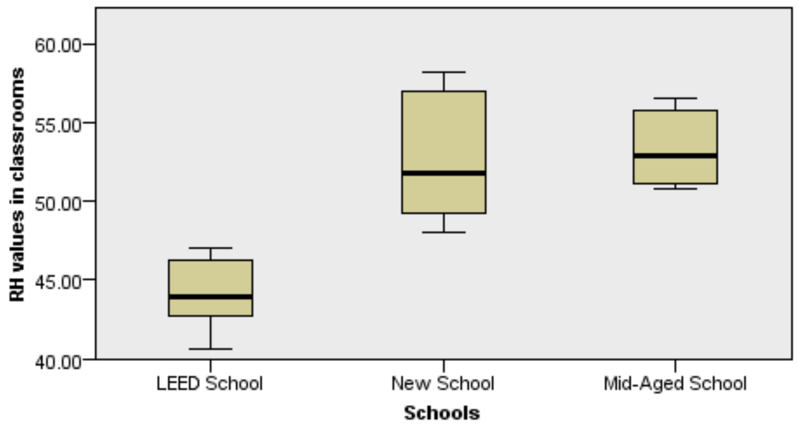

Figure 4-2 Distribution of Relative Humidity Measurements

4.1.2. *Indoor Air Quality*

Table 4-2 shows the maximum, minimum and average values of key IAQ parameters recorded using the IEQC in comparison with recommended values, with Appendix VI showing the full results. The table shows how the average CO_2 levels in all schools ranged between 709 and 971 ppm and were all below the recommended ASHRAE level of 1,100 ppm. However, higher than recommended CO_2 levels were recorded in some classrooms in the new, non-LEED school and in the middle-aged, conventional one. The new, non-LEED school recorded a maximum value of 1225 ppm whereas the middle-aged, conventional one recorded a slightly lower maximum value of 1115 ppm. This could be due to the higher number of students and thus higher occupancy of some of these classrooms and to their prolonged use in comparison with other ones, with some classrooms holding two periods back to back as noted in the observation sheet.

The two classrooms with the highest CO_2 levels were portable classrooms in the new, non-LEED school. These had their own HVAC system that was separate from the rest of the school and managed by teachers themselves, and which may have therefore contributed to these much higher CO_2 values. The Kruskal-Wallis H test showed how the distribution of CO_2 values, with their median values depicted in Figure 4-3 was not similar for all schools. A statistically significant difference in average CO_2 levels was noted across the three schools ($p = 0.02$), with pairwise comparisons using the post hoc test revealing statistically significant differences in average CO_2 values between the new, LEED school and the middle-aged, conventional one only ($p = 0.021$).

Table 4-2 Key Measurements of IAQ Parameters

Schools	Parameters	CO_2 concentrations (ppm)	TVOCs ($\mu g/m^3$)
New, LEED	Minimum	629.17	272.21
	Average	709.90	344.60
	Maximum	767.40	457.09
New, Non-LEED	Minimum	743.50	206.18
	Average	906.20	408.69
	Maximum	1225.20	561.77
Middle-Aged, Conventional	Minimum	862.70	627.53
	Average	971.10	732.12
	Maximum	1114.50	988.56
Recommended Values		<1,100	<300

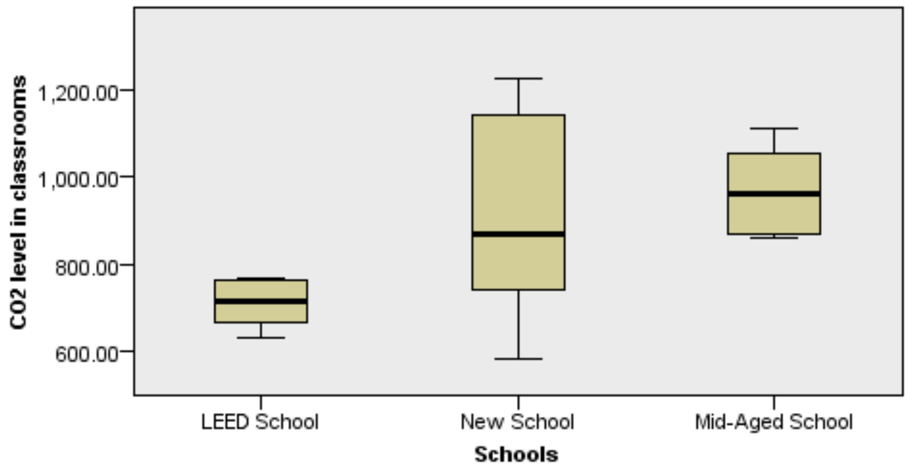

Figure 4-3 Distribution of CO_2 Measurements

The average TVOC values for the new, LEED school and new, non-LEED one (344 µg/m^3 and 408 µg/m^3 respectively) were slightly above the recommended value of 300 µg/m^3. The middle-aged, conventional school recorded an average value of 732 µg/m^3 that was much higher than the recommended value of 300 µg/m^3. Even though the reason behind this high level of TVOCs in the middle-aged, conventional school was not investigated, some classrooms in this school seemed to have cleaning and disinfecting chemicals that may have contributed to the higher value (Minnesota Department of Health, 2010). Other classrooms had new furniture and more teaching materials (e.g. colouring pens, paper, glues) as shown in Figures 4-4 and 4-5 that may have still been off-gassing. To better explain these higher values, further research should focus on breaking down TVOCs to their different compounds (e.g. heptane, limonene, toluene, or xylene) and measuring the concentration of each separately. A statistically significant difference was also found in average TVOC levels across the three schools ($p = 0.006$). Pairwise comparisons using the post hoc test revealed statistically significant differences in the average values between the new, LEED school and the middle-aged, conventional one ($p = 0.009$), and between the new, non-LEED school and the middle-aged, conventional one ($p = 0.033$).

Figure 4-4 Teaching Materials in Classroom in Middle-Aged, Conventional School

The analysis of the relationship between classrooms' thermal comfort (i.e. temperature and RH values) and their IAQ (i.e. CO_2 and VOCs) confirmed the literature's finding that a building's carbon dioxide concentration can be an indicator of the concentration of TVOCs concentration and IAQ in general (Reynolds et al., 2001). The analysis showed that CO_2 levels was positively correlated with TVOC levels ($r = 0.552$, $p = 0.18$). TVOC levels were also strongly positively correlated with RH ($r = 0.711$, $p = 0.001$). No correlation was found between TVOC levels and temperature. Table 4-3 summarizes these results.

Figure 4-5 New Lockers in Classroom in Middle-Aged, Conventional School

Table 4-3 Correlations between Key Thermal Comfort and IAQ Parameters: Statistical Analysis Results

Aspects Correlated	R	P
CO_2 – TVOCs	0.552	0.180 $^{N.S}$
TVOCs – RH	0.711	0.001*
RH – Temperature	-0.695	0.001*

*Correlation is significant at the 0.05 level

4.1.3. *Lighting Quality*

Table 4-4 shows the maximum, minimum, and average values of desktop illuminance in each of the three schools with Appendix VI detailing the full recordings for every classroom in every school. The average illuminance level in each of the three schools was within the recommended range of 300 to 700 lux even though the minimum and maximum values were out of it. The lowest illuminance level of 141.84 lux was recorded in one classroom in the new, LEED school. The field observation form and photographs of Figures 4-6 and 4-7 show how 50% of the lights were off and the window shades were all closed in that particular classroom at the time of measurements, which may explain the low illuminance level. The shades were also found to be approximately 60% open, with half of the lights turned off in the classroom with the lowest illuminance level (202 lux) in the new, non-LEED school.

Table 4-4 Key Measurements of Lighting Quality Parameters

Schools	Parameters	Desktop illuminance (lux)
New, LEED	Minimum	141.84
	Average	528.95
	Maximum	874.75
New, Non-LEED	Minimum	202.04
	Average	536.04
	Maximum	743.05
Middle-Aged, Conventional	Minimum	546.40
	Average	671.34
	Maximum	824.88
Recommended Values		300 – 700

Figure 4-6 Shades in Classroom in New, LEED School

Figure 4-7 Lights and Shades in Classroom in New, LEED School

On the other hand, the highest illuminance levels of 800.41 lux and 874.75 lux in the new LEED school were recorded in two adjacent classrooms with the same orientation. These classrooms had windows that were larger and thus received more daylight than the classrooms in the new, non-LEED and middle-aged, conventional schools. Fifty percent of the shades were open in the first classroom with the lower illuminance level whereas all of them were open in the second classroom with the higher level, as shown respectively in Figures 4-8 & 4-9. The highest illuminance levels of 743.05 lux in the new, non-LEED school and 824.88 lux in the middle-aged, conventional one were also associated with two classrooms where all of the blinds were open and all of the lights turned on at the time of measurement.

Figure 4-8 Partially Open Shades in Classroom in New, LEED School

The results of the Kruskal-Wallis H test showed that the distribution of average desktop illuminance values was similar for all schools as depicted in Figure 4-10, and that the difference in these average values across the three schools was not statistically significant.

Figure 4-9 Fully Open Shades in Classroom in New, LEED School

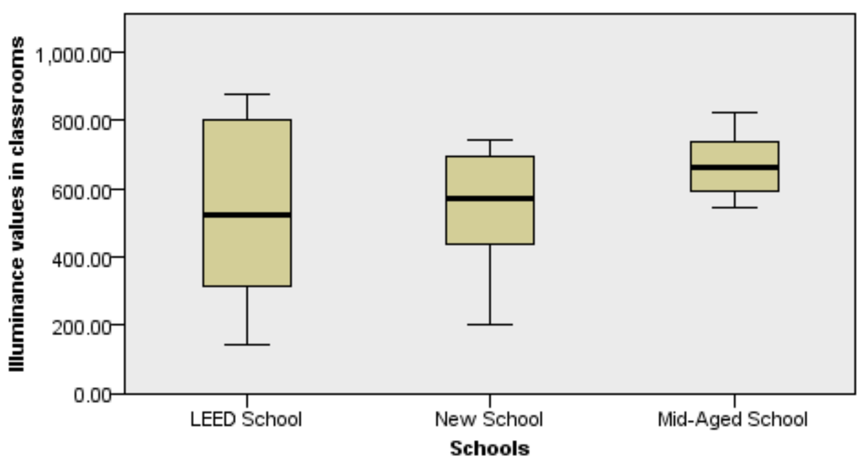

Figure 4-10 Distribution of Illuminance Measurements

4.1.4. *Acoustics Quality*

Table 4-5 shows the maximum, minimum and average values for background noise levels in each school in comparison with recommended values whereas Appendix VI details all values recorded in all classrooms for all schools. The results of the Kruskal-Wallis H test also showed a similar distribution of average background noise levels in all three schools as in Figure 4-11. The background noise levels recorded in each classroom in the three schools were quite uniform, ranging from 54 to 60 dB, with only a few values outside of this range. The highest recorded value of 70.29 dB was found in a classroom in the new, non-LEED school. This could have due to HVAC unit in this classroom that was causing unusual noise. The lowest recorded value of 47.35 dB was found in a classroom in the new, LEED school. Only five students were present in that classroom at the time and were writing an exam which could explain this low value. Future research needs to investigate these potential reasons further. The results of the Kruskal-Wallis test also showed how none of the differences in average background noise levels between any two schools were statistically significant.

Table 4-5 Key Measurements of Acoustics Quality Parameters

Schools	Parameters	Background Noise (dB)
New, LEED	Minimum	47.35
	Average	57.49
	Maximum	64.80
New, Non-LEED	Minimum	55.33
	Average	60.15
	Maximum	70.29
Middle-Aged, Conventional	Minimum	49.04
	Average	54.24
	Maximum	63.51
Recommended Values		35 – 55

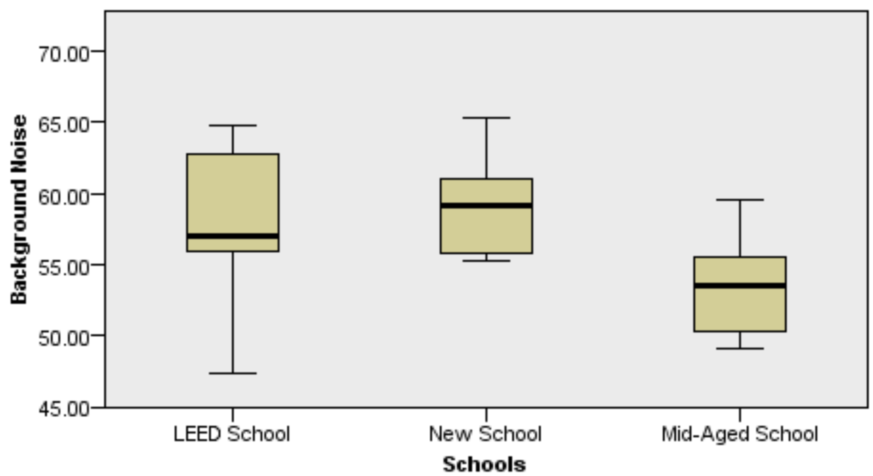

Figure 4-11 Distribution of Background Noise Measurements

4.2. Occupant Well-Being

Of the entire population of 32 teachers in all three schools, 27 completed the survey successfully and only one failed to complete it, resulting in a total response rate of approximately 84%. The new, LEED school had the lowest response rate at 50%, whereas the response rates in the new, non-LEED and middle-aged, conventional schools were 100% and 92% respectively. This gap in response rates could be due to happier, more satisfied teachers in the new, LEED school. This is because occupants who are less satisfied with their environment and want to complain are usually the ones that are more likely to fill such surveys (Leaman & Bordass, 2007).

4.2.1. *Overall Physical Condition*

The statistical analysis of the data using the Kruskal-Wallis H test revealed a statistically significant difference ($p = 0.001$) in teachers' satisfaction with their school buildings' overall physical condition across the three schools. The post hoc pairwise comparisons revealed statistically significant differences in teachers' satisfaction levels between the new, LEED school and the middle-aged, conventional one ($p = 0.001$) and between the new, non-LEED school and middle-aged, conventional one ($p = 0.005$). As depicted in Figure 4-12, teachers in the new, LEED school were also more satisfied with their school buildings' general maintenance and cleanliness than teachers in the new, non-LEED and middle-aged, conventional ones. The Kruskal-Wallis h test revealed a statistically significant difference in teachers' satisfaction with their school buildings' general maintenance ($p = 0.001$) and cleanliness ($p = 0.022$) across the three schools. However, the post hoc pairwise comparisons revealed that only the difference between the new, LEED school and the middle-aged, conventional one was statistically significant (with $p = 0.024$ for general maintenance and $p = 0.001$ for cleanliness). Teachers in the new, LEED school and new, non-LEED school were also more satisfied with the aesthetics of their schools than teachers in the middle-aged, conventional one. The Kruskal-Wallis H test revealed a statistically significant difference in teachers' satisfaction with the aesthetics (p = 0.004). Differences between the new, LEED school and the middle-aged, conventional one (p = 0.013); and between the new, non-LEED school and middle-aged, conventional one (p = 0.026) were both statistically significant as revealed by the post hoc pairwise comparisons test. The Kruskal-Wallis H test revealed a statistically significant difference in teachers' satisfaction with space usage and availability across the three schools (p = 0.003). Teachers in the new school were also more satisfied with the usage and availability of space in their schools than teachers in the middle-aged one, with the difference being statistically significance (p = 0.004) as shown by the post hoc pairwise comparisons test. These results were expected and were very similar to the ones found by Issa et al. (2014).

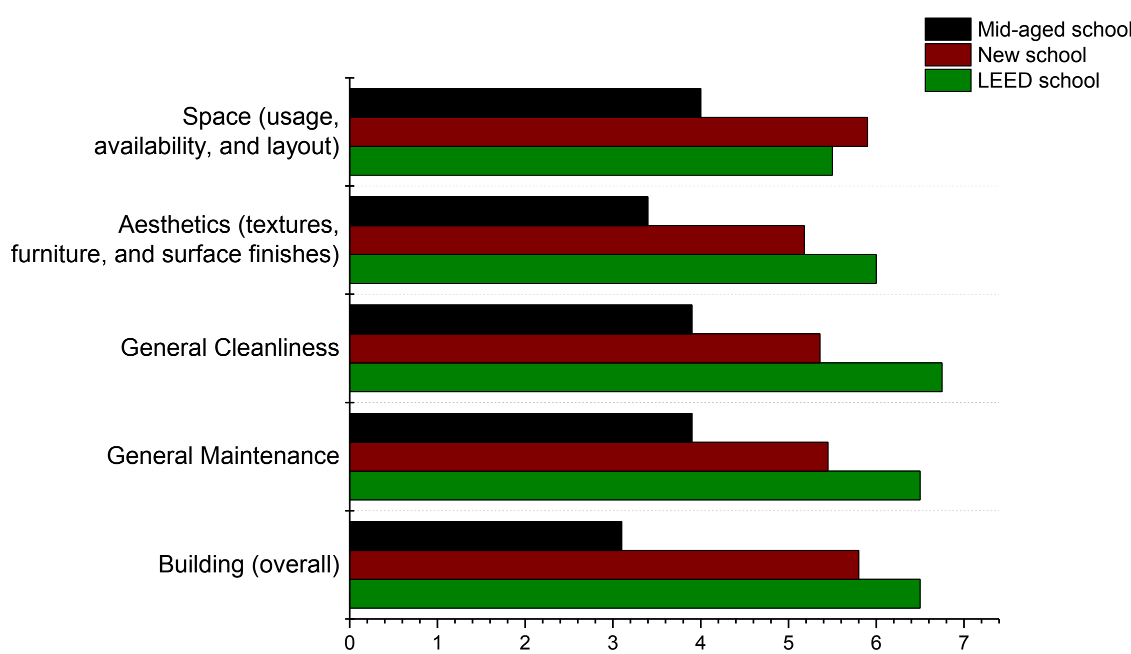

Figure 4-12 Teachers' Satisfaction with School's Overall Physical Condition

4.2.2. *Overall Indoor Environmental Quality*

The results of the Kruskal-Wallis H test showed a statistically significant difference in teachers' satisfaction with classrooms' overall IEQ across the three schools ($p = 0.002$). The results of the post hoc test revealed statistically significant differences between the new, LEED school and middle-aged, conventional one ($p = 0.023$), and between the new, non-LEED school and the middle-aged, conventional one ($p = 0.006$). Figure 4-13 also depicts how teachers in the new, LEED school were in general more satisfied with the different aspects of their classrooms' IEQ than teachers in the other schools. The Kruskal-Wallis H test showed a statistically significant difference in teachers' satisfaction with classrooms' IAQ across the three schools ($p = 0.014$). The post hoc statistical analysis of the data revealed statistically significant differences between teachers' satisfaction with IAQ in the new school and the middle-aged one ($p = 0.041$). Also the Kruskal-Wallis test showed a statistically significant difference in teachers' satisfaction with classrooms' lighting quality across the three schools ($p = 0.042$). There was also a statistically significant difference in teachers' satisfaction with lighting quality between the new, LEED school and middle-aged, conventional one ($p = 0.035$) as revealed by the post hoc test.

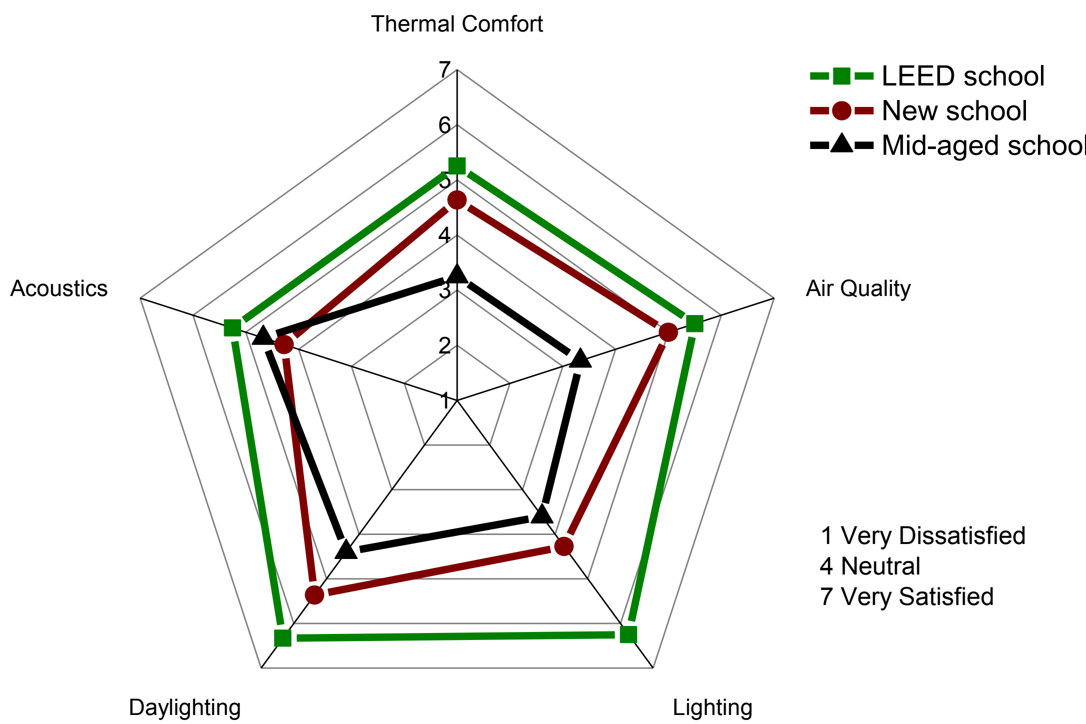

Figure 4-13 Teachers' Satisfaction with Overall IEQ

Statistically significant correlations using the Spearman's rank correlation coefficient test were also found between teachers' satisfaction with classrooms' overall IEQ and their satisfaction with specific aspects of IEQ in these classrooms. These include the ones between overall IEQ and IAQ ($r = 0.694$, $p = 0.000$), between overall IEQ and thermal comfort ($r = 0.534$, $p = 0.007$) and between IAQ and thermal comfort ($r = 0.465$, $p = 0.015$). These results are in line with the ones in the literature (e.g. Humphreys, 2005; Sadick et al., 2014b) about how IAQ tends to be the most important determinant of IEQ and how thermal comfort and IAQ are both related. Table 4-6 shows the results of all of these correlations.

Table 4-6 Correlations between Teachers' Satisfaction with Overall IEQ and their Satisfaction with Various IEQ Aspects: Statistical Analysis Results

Aspects Correlated	R	P
Overall IEQ satisfaction – Thermal comfort satisfaction	0.534*	0.007
Overall IEQ satisfaction – Air quality satisfaction	0.694*	0.000
Overall IEQ satisfaction – Lighting satisfaction	0.294	0.163
Overall IEQ satisfaction – Noise level satisfaction	0.311	0.148
Thermal comfort satisfaction - Air quality satisfaction	0.465*	0.015

*Correlation is significant at the 0.05 level

4.2.3. *Thermal Comfort*

The results of the Kruskal-Wallis H test showed how there was no statistically significant difference in teachers' satisfaction with thermal comfort across the three schools. Nevertheless, the percentage of dissatisfied teachers with thermal comfort varied across the schools as shown in Table 4-7. Even though this percentage decreased as expected from the middle-aged, conventional school to the new, non-LEED school to the new, LEED school, the percentage of dissatisfied teachers in all three schools exceeded the 20% limit recommended by the ASHRAE 55 standard. The analysis of the results also showed a consistency between actual and predicted values. The calculated PPD values were consistent with the values of the actual percentage of dissatisfied teachers and were in fact very close to them as shown in Table 4-7. The values predicted how teachers in the middle-aged, conventional school would be the least satisfied with thermal comfort whereas the ones in the new, LEED school would be the most satisfied with it: a prediction that came true as shown by actual survey responses. Moreover, even though there was a discrepancy between PMV values and actual mean rating values, Table 4-7 shows how they in fact followed a very similar trend. The PMV values predicted how teachers in the new, LEED school would be more satisfied with thermal comfort than teachers in the new, non-LEED, who would be more satisfied with it than teachers in the middle-aged, conventional school: another prediction validated by the survey. Even though further research is needed to explain the discrepancy between PMV and actual mean rating values, similar discrepancies between these two values were reported in the literature (e.g. Muhič & Butala, 2004 and Sadick et al., 2014b).

Table 4-7 Actual and Predicted Percentage of Teachers Dissatisfied with Thermal Comfort and Mean Rating for Teachers' Satisfaction with Thermal Comfort

Schools	Percentage Dissatisfied (%)	PPD (%)	Actual Mean Rating	PMV
New, LEED	25	21	5.25	-0.86
New, Non-LEED	35	34	4.60	-1.18
Middle-Aged, Conventional	60	50	3.25	-1.49

Figure 4-14 shows teachers' rating of several thermal comfort issues. These issues reflect the importance of providing teachers with personal controls of their classrooms' IEQ in order to help them address many of them. Personal control of aspects such as their classrooms' temperature and RH can be central to ensuring their comfort and satisfaction, as evidenced by the research by Baker (2011) and Lackney (2001) on teachers' preferences in classrooms.

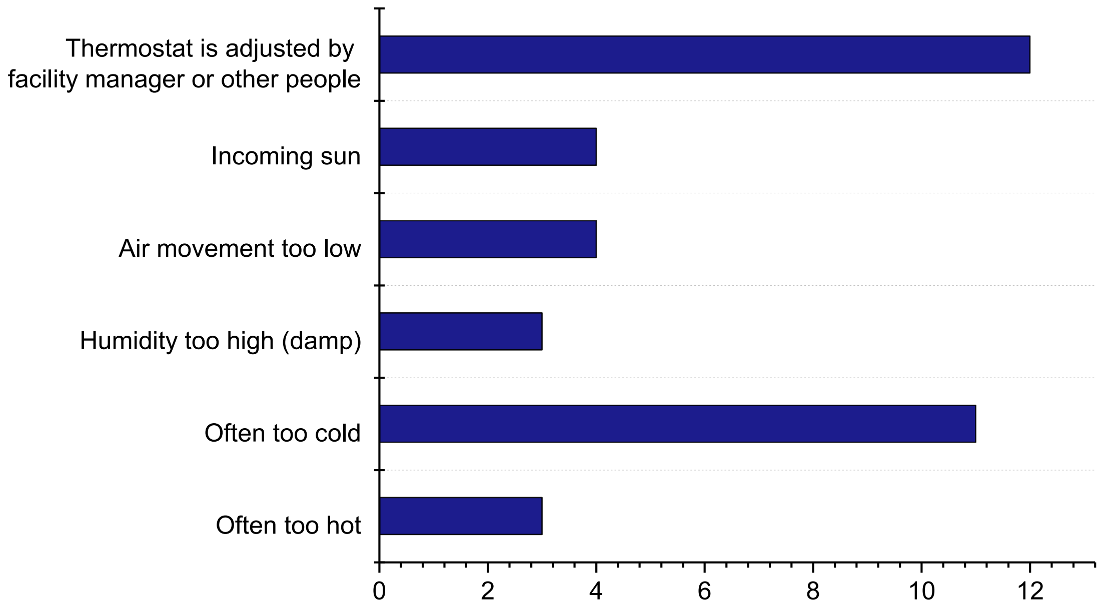

Figure 4-14 Teachers' Rating of Various Thermal Comfort Issues

The Kruskal Wallis H test found no statistically significant difference in teachers' perception of the impact of thermal comfort on their work performance across the three schools ($p = 0.12$). Nevertheless, Spearman's rho correlation test found a moderate, statistically significant correlation between teachers' satisfaction with thermal comfort and their perception of the impact of thermal comfort on their work performance ($r = 0.563$, $p = 0.002$). This highlights the importance of thermal comfort as an IEQ and work performance determinant.

4.2.4. *Indoor Air Quality*

As shown in Table 4-8, teachers in the new, LEED school were more satisfied with IAQ than teachers in the new, non-LEED and middle-aged, conventional ones. The results also show quite expectedly how teachers in the new, non-LEED school were more satisfied with IAQ than teachers in the middle-aged, conventional one. The Kruskal-Wallis H test revealed a statistically significant difference in teachers' satisfaction with IAQ across the three schools ($p = 0.014$), with the post hoc analysis revealing a statistically significant difference between the new, non-LEED school and middle-aged, conventional one ($p = 0.041$) only.

Table 4-8 Actual Percentage of Teachers Satisfied with IAQ and Mean Rating for Teachers' Satisfaction with IAQ

Schools	New, LEED	New, Non-LEED	Middle-Aged, Conventional
Mean Rating	5.5	5.0	3.3
Percentage Satisfied (%)	100	90	42

The table also shows the percentage of teachers satisfied with IAQ in every school. These percentages were higher than the percentage of teachers satisfied with thermal comfort reported in Table 4-7 for every school. Moreover, the percentage of teachers dissatisfied with thermal comfort exceeded recommended levels in all three schools, whereas the percentage of teachers dissatisfied with IAQ exceeded the 80% limit recommended by the ASHRAE 55 standard in the middle-aged, conventional school only. These observations show how teachers in the three schools felt in general much better about their classrooms' IAQ than their classrooms' thermal comfort, highlighting the need for more research to investigate the causes of this gap in perceptions. As shown in Figure 4-15, odours appeared to be most important IAQ problem experienced by teachers, followed by stuffy and stale air: results that were in line with the ones reported in the literature (e.g. Baker, 2011; Mendell & Heath, 2005). A statistically significant negative correlation ($r = -0.812$, $p = 0.05$) was found in fact between teachers' satisfaction with air quality and their satisfaction with air odours as shown in table 4-9. Teachers identified smell from outside sources such as car exhausts as the most important problematic odour, followed by sewer smell due to "not enough water going down the drain" as expressed by one teacher, and smell from the use of cleaning products.

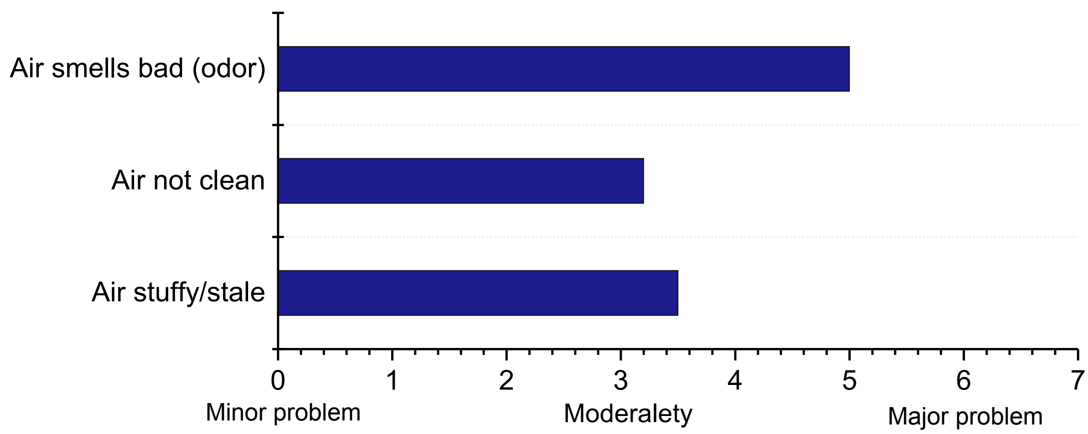

Figure 4-15 Teachers' Rating of Various IAQ Issues in Middle-Aged, Conventional School

Table 4-9 Correlations between Teachers' Satisfaction with IAQ and their Satisfaction with Various IAQ Issues: Statistical Analysis Results

IAQ Issues Correlated with IAQ Satisfaction	R	P
Air smells bad (i.e. odours)	-0.812*	0.050
Air is not clean	-0.170 N.S	0.716
Air is stuffy/stale	-0.078 N.S	0.869
*Correlation is significant at the 0.05 level		

Similarly to thermal comfort, the Kruskal Wallis H test found no statistically significant difference in teachers' perception of the impact of IAQ on their work performance across the three schools. Only 14% of teachers felt such impact. Moreover, just like for thermal comfort, a moderate, statistically significant correlation was detected between teachers' satisfaction with IAQ and the impact of IAQ on their work performance ($r = 0.571$, $p = 0.002$).

4.2.5. *Lighting Quality*

Table 4-10 shows how all the teachers in the new, LEED school were satisfied with overall lighting quality and daylighting quality specifically. Fewer teachers were satisfied with these two aspects in the new, non-LEED school, with the least amount of satisfied teachers found in the middle-aged, conventional school. Results of the Kruskal-Wallis H test revealed a statistically significant difference in teachers' satisfaction with overall lighting quality across the three schools ($p = 0.042$). The post hoc test showed a statistically significant difference in teachers' perception of overall lighting quality between the new, LEED school and middle-aged, conventional one ($p = 0.035$) only. Unlike overall lighting quality, the Kruskal-Wallis H test did not detect any statistically significant difference in teachers' satisfaction with daylighting quality across the three schools. This was surprising given the emphasis of LEED on daylighting and windows and thus the expectation that differences with the new, LEED school would be statistically significant. However, Spearman's Rho correlation test revealed a moderately strong, statistically significant correlation between teachers' satisfaction with overall lighting quality and their satisfaction with daylighting quality ($r = 0.641$, $p = 0.001$). This was expected given how daylighting quality is one component of overall lighting quality and thus any increase in satisfaction with daylighting quality should increase satisfaction with overall lighting quality.

Table 4-10 Actual Percentage of Teachers Satisfied with Overall Lighting and Daylighting Quality and Mean Rating for Teachers' Satisfaction with Overall Lighting and Daylighting Quality

Schools	Overall Lighting Quality		Daylighting Quality	
	Percentage Satisfied (%)	Mean Rating	Percentage Satisfied (%)	Mean Rating
New, LEED	100	6.25	100	6.30
New, Non-LEED	65	4.27	80	5.30
Middle-Aged, Conventional	50	3.60	66	4.40

Teachers in the middle-aged, conventional school attributed their dissatisfaction with lighting quality to "not enough daylighting" and "too much electric lighting". Some teachers reported technical issues such as flickering. One teacher complained about how even though some classrooms had two light switches to control each side of it, he or she would have preferred to be able to separately control the front and back of classrooms. This was to keep the front area where the projector screen was located as dark as possible and keep the back area where students were located lit. Other teachers complained about how fluorescent lighting affected their eyesight and gave them headaches, leading many to turn them off during the day.

Table 4-11 shows how all the teachers in the LEED school were satisfied with the controllability of daylighting and visual comfort levels across the three schools specifically. Fewer teachers were satisfied with these two aspects in the new, non-LEED school, with the least amount of satisfied teachers found in the middle-aged, conventional school. Results of the Kruskal Wallis H test showed a statistically significant difference in the level of controllability of daylighting in classrooms ($p = 0.042$) across the three schools, but not in visual comfort levels. The post hoc test did not find any statistically significant differences in controllability between any pairs of schools.

Table 4-11 Actual Percentage of Teachers Satisfied with Daylighting Controllability and Visual Comfort and Mean Rating for Teachers' Satisfaction with Daylighting Controllability and Visual Comfort

Schools	Daylighting Controllability		Visual Comfort	
	Percentage Satisfied (%)	Mean Rating	Percentage Satisfied (%)	Mean Rating
New, LEED	100	6.30	100	6.00
New, Non-LEED	90	5.45	100	5.45
Middle-Aged, Conventional	50	3.80	80	4.50

Strong and statistically significant correlations were also found between teachers' ability to control daylighting and their satisfaction with overall lighting quality ($r = 0.671$, $p = 0.000$) and daylighting quality ($r = 0.703$, $p = 0.000$). These results were expected and are in line with existing literature results (e.g. Abbaszadeh et al., 2006 and Patricia et al., 2000). Another strong correlation was also found between teachers' ability to control daylighting and their satisfaction with visual comfort (i.e. glare, reflections and contrast), which was also not surprising. Table 4-12 summarizes these results.

Table 4-12 Correlations between Teachers' Satisfaction with Overall Lighting Quality and their Satisfaction with Various Aspects of Lighting Quality: Statistical Analysis Results

Aspects Correlated	R	P
Quality of overall lighting - quality of daylighting	0.641*	0.001
Quality of overall lighting - ability to control daylighting	0.671*	0.000
Quality of overall lighting - visual comfort satisfaction	0.511*	0.011
Quality of daylighting - ability to control daylighting	0.703*	0.000
Quality of daylighting - visual comfort satisfaction	0.447*	0.028
Ability to control daylighting - visual comfort satisfaction	0.875*	0.000

*Correlation is significant at the 0.05 level

Just like for thermal comfort and IAQ, no statistically significant difference could be detected in teachers' perception of the impact of lighting on their job performance in the three different schools. Nevertheless, unlike for thermal comfort and IAQ, there was no correlation between teachers' satisfaction with lighting and their perception of the impact of lighting on their job performance, making lighting a less important determinant of IEQ and work performance than thermal comfort and IAQ.

4.2.6. *Acoustics Quality*

Table 4-13 shows how teachers in the new, LEED school seemed to be most satisfied with acoustics quality. Surprisingly, teachers in the middle-aged, conventional school were more satisfied with acoustics quality than in the new, non-LEED one, as evidenced by their mean rating and the percentage of satisfied teachers, setting a precedent with respect to teachers' satisfaction with IEQ in the middle-aged school. This could be due to the problematic HVAC system in the new, non-LEED school that was producing high background noise levels as revealed by the physical measurements. Nevertheless, none of these differences in mean ratings were statistically significant.

Table 4-13 Actual Percentage of Teachers Satisfied with Acoustics Quality and Mean Rating for Teachers' Satisfaction with Acoustics Quality

Schools	New, LEED	New, Non-LEED	Middle-Aged, Conventional
Mean Rating	5.25	4.27	4.60
Percentage Satisfied (%)	100	65	90

Teachers in every school were asked to rate their satisfaction with various sources of noise in their school. As depicted in Figure 4-17, on average, teachers seemed to find noise coming from the HVAC system to be the most problematic. A moderate, statistically significant correlation ($r = 0.46$, $p = 0.036$) was found between their satisfaction with this specific source of noise and their satisfaction with overall acoustics quality. HVAC noise seemed to be the most problematic in the new, non-LEED school which may explain why teachers in this specific school rated their satisfaction with acoustics quality the lowest. Surprisingly, teachers in the new, LEED school found noise coming from other classrooms and corridors to be most problematic, which is in line with the results by Baker (2011). It was more problematic to them in fact than to teachers in the new, non-LEED school. These results raise concerns that have been raised in the literature in the past (e.g. Issa et al., 2011; Lee & Guerin, 2009) about acoustical insulation in LEED schools.

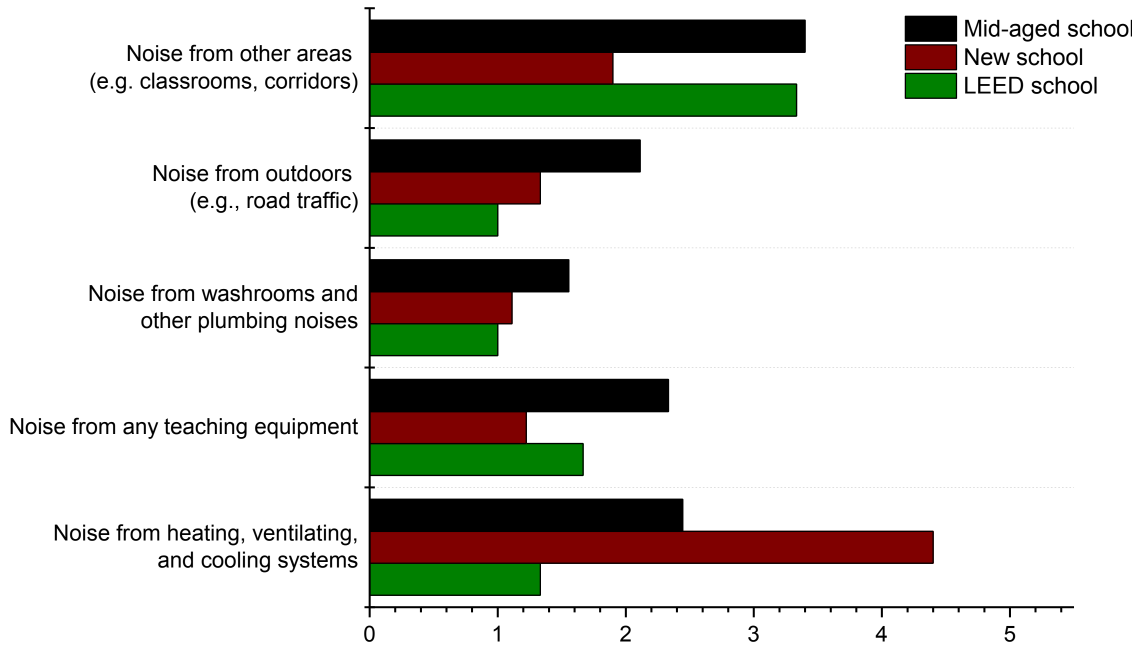

Figure 4-16 Teachers' Rating of Various Sources of Noise

Similarly to thermal comfort, IAQ and lighting quality, no statistically significant difference could be found in teachers' perception of the impact of acoustics on their work performance in the three schools. Nevertheless unlike thermal comfort and IAQ but like lighting quality, there was no correlation between teachers' satisfaction with acoustics and their perception of its impact on their work performance.

4.3. IEQ in Relation to Occupant Well-Being

This section includes the results of the analysis of the relationship between the physical measurements of IEQ, as presented in section 4.1 and teachers' perception of IEQ as presented in section 4.2.

4.3.1. *Thermal Comfort*

The physical measurements of thermal comfort showed that the middle-aged, conventional school had the lowest average air temperature and air velocity of all schools even if their values were within the recommended range of ASHRAE 55 (2004). These results were in line with the survey results which demonstrated that teachers in the middle-aged, conventional school were the most dissatisfied with thermal comfort. An investigation of the correlations between the physical measurements of IEQ and teachers' perception of thermal comfort and overall IEQ in Table 4-14 showed how teachers' satisfaction with thermal comfort was positively correlated to air velocity measurements ($r = 0.524$, $p = 0.037$). No other statistically significant correlations were detected between any of these aspects.

Table 4-14 Correlations between Teachers' Satisfaction with Thermal Comfort and Overall IEQ, and Key Thermal Comfort and IAQ Parameters: Statistical Analysis Results

Aspects Correlated		Temperature	Air Velocity	RH
Thermal Comfort Satisfaction	R	0.417	0.524*	-0.292
	P	0.109	0.037	0.273
Overall IEQ Satisfaction	R	0.407	0.508	-0.295
	P	0.132	0.053	0.286

*Correlation is significant at the 0.05 level

4.3.2. *Indoor Air Quality*

The physical measurements of IEQ showed how the middle-aged school had the highest average CO_2 (971.1 ppm) and TVOC (732.12 $\mu g/m^3$) levels of all schools. Similarly, the survey results showed how teachers in the middle-aged school were the least satisfied with IAQ as evidenced by the percentage of satisfied teachers (42% satisfied) and mean rating (3.33). A statistically significant negative relationship ($r = -0.812$, $p = 0.05$) was also found between teachers' satisfaction with IAQ and their rating of IAQ odours. These odours could be due to the high level of CO_2 and TVOCs found in classrooms (Gordon, 2010). The strong and statistically significant negative correlations between teachers' satisfaction with IAQ and TVOC levels ($r = -0.565$, $p = 0.023$) and between their satisfaction with overall IEQ and TVOC levels ($r = -0.550$, $p = 0.034$) in Table 4-15 confirm this explanation. Teachers tended to be more satisfied with their classrooms' IAQ and overall IEQ, the lower the level of TVOCs in them.

Table 4-15 Correlations between Teachers' Satisfaction with IAQ and Overall IEQ, and Key IAQ Parameters: Statistical Analysis Results

Aspects Correlated		CO_2	TVOCs
IAQ Satisfaction	R	-0.220	-0.565*
	P	0.413	0.023
Overall IEQ satisfaction	R	-0.232	-0.550*
	P	0.405	0.034
*Correlation is significant at the 0.05 level			

4.3.3. *Lighting Quality*

The physical measurements of lighting quality across the three schools showed how the average desktop illuminance level was highest in the middle-aged, conventional school. Nevertheless, the survey results showed how teachers in the middle-aged school were the least satisfied with lighting quality. This dissatisfaction was mainly due to technical problems with existing lighting systems (e.g. flickering, quality of fluorescent lighting, division of lighting circuits) and to the low level of controllability of these systems and only in very few instances to high lighting levels. This lack of direct relationship between high lighting levels and teachers' dissatisfaction with lighting quality is reflected in the absence of any statistically significant correlations between desktop illuminance levels; and teachers' satisfaction with lighting quality, daylighting quality and overall IEQ.

4.3.4. *Acoustics Quality*

The physical measurements of acoustics quality showed how average background noise levels were highest in the new, non-LEED school and lowest in the middle-aged, conventional school. The analysis of survey results showed how teachers in the new, LEED school were most satisfied with acoustics quality, followed surprisingly by teachers in the middle-aged, conventional school. Even though teachers in the middle-aged, conventional school were more satisfied with acoustics quality than teachers in the new, non-LEED school, the average background noise level in the new, non-LEED school was higher than in the middle-aged, conventional one. While these results may seem contradictory, it's important to remember that the physical measurements conducted using the IEQC were snapshot measurements rather than continuous ones. These higher background noise levels in the new, non-LEED could have been a one-time event that is uncharacteristic of the long-term performance of the building and thus of teachers' perception of acoustics quality. Therefore, there's a need for future research to measure background noise levels and other IEQ parameters over a long period of time to evaluate how these vary over the long-term. Results of the Spearman's Rho Correlation test also showed no statistically significant relationships between teachers' satisfaction with acoustics quality and IEQ in general, and measured background noise levels in the three schools.

4.4. Methodology Validation

This section focuses on validating the methodology through comparing the results of the IEQ physical measurements to the survey results to evaluate its internal consistency. To evaluate its external consistency, the results of this research were also compared to the literature results, the ultimate aim being to demonstrate the reliability and accuracy of the methodology and validate its use on this and future research studies.

4.4.1. *Internal*

Table 4-16 shows the consistency of the evidence obtained through the on-site physical measurements of IEQ and the occupant survey, with respect to thermal comfort, IAQ and lighting quality but not acoustics quality. Even though the results are inconsistent for acoustics quality, this should not automatically call into question the validity of the methodology. This is because teachers' perception of IEQ can to be quite subjective and thus very different from the objective physical measurements of IEQ.

Table 4-16 Consistency of Internal Evidence for Internal Validation of Methodology

	Physical IEQ Measurements	Occupant Well-Being Survey
Thermal Comfort	The middle-aged, conventional school had the lowest average air temperature and air velocity of all schools.	Teachers in the middle-aged, conventional school were the least satisfied with thermal comfort. Most complained about feeling cold in the classroom.
IAQ	The middle-aged, conventional school had the highest average CO_2 and TVOC levels of all schools.	Teachers in the middle-aged, conventional school were the least satisfied with IAQ. Most complained about odours. A relationship was found between their satisfaction with IAQ and TVOC levels.
Lighting Quality	Flickering lights was one of the main dissatisfaction sources with lighting in the new, non-LEED and middle-aged, conventional school.	Occupants of these two schools reported their dissatisfaction with general maintenance.
Acoustics Quality	The average background noise levels recorded in the middle-aged, conventional school were less than the average background noise of the new, non-LEED school.	Teachers in the middle-aged, conventional school were more satisfied with the acoustics quality in their school than teachers in the new, non-LEED one.

4.4.2. *External*

Table 4-17 compares the results of this research to the results of other research studies in the literature. Although these results are consistent to a large extent except for acoustics quality, inconsistent or contradictory results should not automatically called into question the research's methodology. This is because no two research studies are the same. Every research study has its own unique set of circumstances, factors and variables that affect its results, no matter how similar they may be to other studies in the field.

Table 4-17 Consistency of External Evidence for External Validation of Methodology

IEQ Aspects	Internal Evidence	External Evidence
Thermal Comfort	Teachers attributed their dissatisfaction with thermal comfort to their inability to control it.	Several studies (e.g. Swail, 2013) attributed occupants' dissatisfaction with thermal comfort to their inability to control it.
	There was a large discrepancy between PMV values and actual mean rating values.	Several studies (e.g. Muhič & Butala, 2004) reported similar discrepancies.
IAQ	Teachers found odours to be the most problematic IAQ issue. A relationship was found between teachers' satisfaction with IAQ and average TVOC levels.	Several studies (e.g. Gordon, 2010) found odours to be the most problematic issue for occupants and established a relationship between high CO_2 concentrations and unpleasant odours.
Lighting Quality	Teachers attributed their dissatisfaction with lighting quality to issues related to light flickering, the quality of fluorescent lighting and their inability to control it.	Several studies (e.g. Baker, 2011) attributed occupants' dissatisfaction with lighting quality to aspects such as insufficient daylighting, too much electrical lighting and light flickering.
	Teachers in the new, LEED school were the most satisfied with lighting quality.	Several studies (e.g. Baker, 2011) found occupants in green schools to be more satisfied with lighting quality than occupants in other schools.
Acoustics Quality	Teachers in the new, LEED school were the most satisfied with acoustics quality.	Several studies (Straka and Aleksic, 2009) surveyed teachers and students in green and non-green buildings and found similar results.

5.0 Chapter 5: Conclusion and Recommendations

This chapter presents the conclusions of this research based on each set objective, its limitations with recommendations for future research to address them and ends with concluding remarks about it.

5.1. Conclusions Based on Research Objectives

This study provided empirical evidence to the claim that green schools can offer more comfortable environments to their occupants than other conventional schools based on the sample studied in this research. The new, LEED school in this research offered classrooms with better thermal comfort, indoor air quality, lighting quality and acoustics quality than the new, non-LEED school and the middle-aged, conventional one. The evidence provided in this research was based on objective quantitative physical measurements of these aspects and subjective qualitative feedback from school teachers about them.

The first objective of this research aimed to develop a thorough methodology to evaluate IEQ in relation to occupant well-being in school buildings. The developed methodology included three main components or methods. The first involved on-site physical measurements of a number of IEQ parameters. This component entailed identifying the specific thermal comfort, IAQ, lighting and acoustics parameters to measure, the specific sensors needed to measure them, recommended values for each parameter and the set standards to follow to evaluate each of those parameters in school buildings specifically. A cart made up of a number of sensors was then used to conduct on-site physical measurements of these parameters in every school.

The second component involved the administration of an occupant well-being survey to all teachers working in every school. A survey was developed to evaluate school teachers' perception and satisfaction with their classrooms' IEQ. The survey comprising a total of 40 questions enquired about teachers' demographics, their satisfaction with temperature and thermal comfort, lighting quality and acoustics quality. The third component involved developing and using a field observation form to collect other information about the physical conditions of the classrooms not captured by the on-site physical measurements and occupant survey. Photographs were also taken to complement the data captured by the field observation form.

The second objective of the research entailed evaluating IEQ in relation to occupant well-being in a sample of conventional and green school buildings using the developed methodology. Three school buildings from three different school divisions were selected for the evaluation: a new, LEED school, a new, non-LEED one, and a middle-aged, conventional one. The evaluation involved selecting six classrooms from every school for the on-site physical measurements. The occupant survey was administered to the teachers working in every school with a field observation form filled out for each classroom visited on the day of the physical measurements.

The analysis of the thermal comfort data collected showed how the middle-aged, conventional school had the lowest average air temperature and air velocity of all schools, yet the air temperature values were still within the recommended range. Survey results showed how teachers in the middle-aged, conventional school were the least satisfied with thermal comfort while teachers in the new, LEED school were the most satisfied with it. Teachers' satisfaction with thermal comfort was positively correlated to air velocity measurements specifically.

The physical measurements of IAQ showed how the average CO_2 and TVOC levels were highest in the middle-aged, conventional school and lowest in the new, LEED school. CO_2 levels for all schools were all within the recommended range whereas TVOC levels were all above the recommended range. Survey results showed how teachers in the new, LEED school were the most satisfied on average with IAQ whereas teachers in the middle-aged, conventional school were the least satisfied with it. A statistically significant correlation was also found between teachers' satisfaction with IAQ and the level of TVOCs in classrooms such that the lower this level in classrooms, the more satisfied teachers were with these classrooms' IAQ.

The physical measurements of lighting quality showed how desktop illuminance was highest in the middle-aged, conventional school and lowest in the new, LEED school, with all average values being within the recommended range. Despite the high lighting levels in the middle-aged, conventional school, survey results showed how teachers in this school were the least satisfied with lighting quality, mainly due to technical problems with existing lighting systems and the lack of occupant control of lighting. All teachers in the new, LEED school were satisfied with lighting quality.

Finally, the analysis of acoustics quality showed how teachers in the middle-aged, conventional school were more satisfied with acoustics quality than teachers in the new, non-LEED school in addition average background noise levels were highest in the new, non-LEED school and lowest in the middle-aged one. Surprisingly, average background noise levels were found to be within the recommended range only in the middle-aged, conventional school.

The last objective of the research entailed validating the developed methodology through comparing the results of the IEQ physical measurements to the survey results to demonstrate its internal consistency. To demonstrate its external consistency, the results of this research were also compared to the literature results, the ultimate aim being to confirm the reliability and accuracy of the methodology and validate its use on this and future research studies.

5.2. Limitations and Recommendations for Future Research

Despite the significance of this research, there were a number of limitations to it that will need to be addressed in future work.

The most important limitation of the research was its small sample size. The research focused on evaluating three Southern Manitoban rural schools only. Only one school had received LEED certification in Manitoba at the start of this research and could therefore be included in the sample. Moreover, the research involved conducting on-site physical measurements of IEQ, which despite their objectivity are a rigorous and time-consuming process. This is because of the need to make arrangements to recruit, visit and evaluate every school separately, making it difficult to evaluate more than three schools given the time and financial constraints of the research. The research also focused on conducting physical measurements of a number of IEQ aspects (i.e. thermal comfort, IAQ, lighting and acoustics) and not just one, and thus involved the use of many sensors and more rigorous evaluation protocols to complete the measurements. Given the small sample size, the population of teachers surveyed was also small. All 32 teachers in the three schools were invited to participate in the survey. Fortunately, 27 of them responded making for an excellent overall response rate of 84% approximately, with response rates per school varying from 100% to 50%, and thus making for a representative sample of these schools' teachers. Future research on the population of schools in these three school divisions should focus on evaluating a sample of 15 schools to ensure the sample is representative enough of the 50 schools in the population.

This research was also limited by the specific factors and variables considered in the research and controlled for statistically. There are many other variables that could have affected the results and that would need therefore to be considered in future research. These variables include physical variables such as the specific location of every school and socio-economic variables such as the neighbourhood in which these schools were located and the socio-economic background of the students and teachers in every school. The maintenance of a school may impact its IEQ performance. Economics may impact the ability of a school division to pay for renovations, upgrades, and maintenance of facilities. Certain behaviours of occupants may impact the performance of systems (such as closing blinds, covering over ventilation, etc.). Other factors include technical variables such as the nature and configuration of the HVAC systems used in each school, behavioural variables associated with students and teachers' use of the space and financial variables associated with the operation and maintenance of these schools.

Another limitation of the research was its focus on surveying teachers alone. Even though many studies seem to have done the same (e.g. Baker, 2011 and Sanoff et al., 2001), surveying students in addition to teachers would have made for a more accurate assessment of occupant well-being, given how students make up a significant portion of school occupants. Nevertheless, this was difficult to achieve in practice given the more rigorous ethics approval process this research would have had to go through and the need to obtain' parents' consent. The school divisions and individual schools were also not comfortable with the idea of surveying students. This being said, a review of the literature showed how students may not always fully understand survey questions and respond appropriately to them (Kim et al., 2013). Teachers were sometimes deemed to be more reliable in evaluating students' well-being given the time they spend with them and their higher level of familiarity and awareness of IEQ issues in comparison with students (Rowan et al., 2002 and Schneider 2002).

The third limitation of this research was with the fact that the survey and physical measurements were not conducted at the same time. The teachers' survey was administered in early September 2014 whereas the physical measurements were conducted in end of June 2014. This is because of delays with approving the survey by the University of Manitoba Research Ethics Board that made it impossible to administer the survey before the start of the summer months. At the same time, it was very difficult to repeat the IEQ physical measurements again in September given time and logistical constraints. Even though outdoor weather conditions were very similar in end of June and early September of 2014, making for similar indoor environmental conditions too, this limitation may have skewed the results and needs therefore to be avoided in future work.

Given these limitations, future research should focus on evaluating a larger sample of schools using on-site physical measurements and repeating these measurements throughout the year to investigate how outdoor weather conditions affect indoor ones and occupants' perceptions of them. Future research should also focus on conducting the physical measurements of IEQ at the same time as the occupant survey to avoid any changes in indoor weather conditions or occupancy that may therefore skew the results. There is also a need to focus on surveying students in addition to teachers to more accurately evaluate how IEQ affects students' well-being and how satisfied students are with their classrooms' IEQ. More in-depth observations of students and teachers' behaviour in the classroom could potentially uncover variables that can have a significant impact on the results. Other recommendations not directly related to this research include evaluating students and teachers' performance and productivity quantitatively and relating them to schools' IEQ. There is also a need to evaluate the relationship between schools' energy consumption and their IEQ given the intricate relationship between these two aspects. Future research should also focus on assessing IEQ across school buildings certified using different green building rating systems to investigate the impact of these different systems on IEQ and occupant well-being.

5.3. Contributions to Knowledge and Overall Implications of Research

This research is one of the first to develop and validate a comprehensive methodology to evaluate IEQ and occupant well-being in school buildings in Canada. The methodology relies on quantitative empirical evidence of IEQ in addition to qualitative empirical evidence of occupant well-being to achieve its objectives. This methodology can be used and built upon by other researchers and industry practitioners to evaluate and benchmark the performance of existing school buildings, thereby improving their actual operation and maintenance. It can also be used to improve the design of new school buildings, thereby offering improved conditions to students, teachers and other school occupants. This and other research studies should contribute to the development of 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 conditions and higher comfort and satisfaction levels.

This research also focuses on school buildings rather than office buildings and evaluates many aspects of IEQ rather than just IAQ as is common with other studies. The research also provides a dataset for evaluating these aspects in Manitoba school buildings in particular. This is a dataset that can grow significantly through the contributions of other researchers in Canada (e.g. Issa et al. 2011, Swail 2013) and industry practitioners, and can thus help identify common trends for IEQ and occupant well-being in other schools across the country.

5.4. Concluding Remarks

While there are many claims to the superior performance of green buildings with respect to IEQ and occupant well-being, there is not enough empirical evidence in the literature to substantiate these claims. This research aimed to develop and validate a methodology to evaluate the relationship between IEQ and occupants' well-being. It also aimed to evaluate the indoor environments of green and conventional school buildings and occupants' perception of them.

The research provided clear empirical evidence based on actual physical measurements and occupant feedback supporting many of these claims. This research combined with similar research conducted about green school buildings in Canada (Issa et al. 2011 and Swail 2013) should help develop a body of knowledge informing the design, construction operation and maintenance of Canadian schools. There is a need for more collaboration between researchers to undertake larger-scale studies at the national level. There is also a need for more interdisciplinary research collaborations across scientific disciplines spanning the natural sciences, the social sciences and the humanities. These collaborations should expand to include industry practitioners, educators, clients, policy-makers and the general public to foster and drive change at the most fundamental level.

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APPENDIX I: HUMAN ETHICS APPROVAL

UNIVERSITY OF MANITOBA | Research Ethics and Compliance
Office of the Vice-President (Research and International)

Human Ethics
208-194 Dafoe Road
Winnipeg, MB
Canada R3T 2N2
Phone +204-474-7122
Fax +204-269-7173

APPROVAL CERTIFICATE

August 13, 2014

NSERC
39043

TO: **Mohamed Issa**
Principal Investigator [redacted]

FROM: **Lorna Guse, Chair**
Education/Nursing Research [redacted] (ENREB)

Re: **Protocol #E2014:077**
"An Evaluation of the Indoor Environmental Quality of Manitoba School Buildings"

Please be advised that your above-referenced protocol has received human ethics approval by the **Education/Nursing Research Ethics Board**, which is organized and operates according to the Tri-Council Policy Statement (2). **This approval is valid for one year only**.

Any significant changes of the protocol and/or informed consent form should be reported to the Human Ethics Secretariat in advance of implementation of such changes.

Please note:

- **If you have funds pending human ethics approval, please mail/e-mail/fax (261-0325) a copy of this Approval (identifying the related UM Project Number) to the Research Grants Officer in ORS in order to initiate fund setup. (How to find your UM Project Number: http://umanitoba.ca/research/ors/mrt-faq.html#pr0)**

- **If you have received multi-year funding for this research, responsibility lies with you to apply for and obtain Renewal Approval at the expiry of the initial one-year approval; otherwise the account will be locked.**

The Research Quality Management Office may request to review research documentation from this project to demonstrate compliance with this approved protocol and the University of Manitoba *Ethics of Research Involving Humans*.

The Research Ethics Board requests a final report for your study (available at: http://umanitoba.ca/research/orec/ethics/human_ethics_REB_forms_guidelines.html) **in order to be in compliance with Tri-Council Guidelines.**

umanitoba.ca/research

APPENDIX II: FIELD OBSERVATION FORM

University of Manitoba

Indoor Environment Quality Field Observation Form

School: ____________________
Classroom orientation & number: _
Date: DD / MM /2014 Time: _____

A. Weather

Sky is: ☐ Clear ☐ Mixed (sun + clouds) ☐ Overcast

External temperature___

B. Equipment in Classroom

☐ Printer [No.] ☐ System unit [No.] ☐ Monitor [No.] ☐ Laptop [No.]
☐ Projector [No.] ☐ Fridge [No.]
Others: ___________________________________

C. Classroom Characteristics/Controls

No. of students [No.] Students' Level_______ *Ceiling height* _______ *m*

***Finishes**:* Wall _________________ Floor _________________ Ceiling _____________

***Light**:* Luminaire type _______________ Lamp type ____________(No. [ON] No. [OFF])

- Shades: [Yes/No], Type _____,[Opened/Closed], % opened ______, Opacity _____
- Blinds controls [Yes/No]
- Window: In classroom [Yes/No], Operable [Yes/No], opened [Yes/No]

***Air**:* Air inlet: [Yes/No], Type ________, No. [ ], - Air outlet: [Yes/No], Type _____, No. [ ]
- Door: [Opened/Closed]

***General**:* Plant/Flower pot: [Yes/No], No. [ ] - Aquarium: [Yes/No]
- Pictures: [Yes/No], No. [ ]

Controls/Adaptation:

- Portable heater [Yes/No], [On/Off] - Thermostat [Yes/No]
- Portable fan [Yes/No], [On/Off] - Light dims [Yes/No]

***Temperature**:* Thermostat: Setting ________ °C, Reading _________ °C
- Heat Radiator: [Yes/No], [On/Off]

D. Mounting heights: Level 1 ________ , Level 2: _____ , Level 3: _____ , Level 4:_____

E. Workstation Layout

(Sketch should include windows, doors, work area, S for speaker location in adjoining workstation , M for microphone and wall heights)	General Notes:

APPENDIX III: SCHOOLS' PRELIMINARY DATA FORM

Please fill out this form to the best of your knowledge, please type N/A for fields which are not applicable to the school

School Name:
School Division:

Contact Information

School Address

Phone Number
Fax Number

Detailed School Information

School type

- ☐ Elementary School
- ☐ Middle School
- ☐ High School
- ☐ K-12

Total building floor area *(If more than one, please indicate the total floor area of each building,)*

Number of floors in the building *(If more than one, please indicate the number of floors in each building)*

Available non-classroom facilities *(If more than one, please indicate the number)*

☐ Gymnasium ☐ Swimming Pool ☐ Auditorium ☐ Laboratory

☐ Other (Please Specify)

Are any school facilities open for community use? ☐ Yes ☐ No

If yes, please list facilities open for community use

Number of occupants for the 2012/2013 academic year

Students Teachers Staff Other *(If applicable)*

On average, how many hours/day is the school building(s) occupied?

On average, how many days/week is the school building(s) is occupied?

Number of years for which school's energy consumption data is available

Building Age and Maintenance

Start date of school operation

Was the school recently energy retrofitted? ☐ Yes ☐ No

If no, are there plans for future energy retrofitting? ☐ Yes ☐ No

If you answered yes to any of the previous two questions please complete the following
Please indicate the date/planned date for executing energy retrofitting

Energy retrofits implemented or planned if any

- ☐ HVAC ☐ Building Insulation ☐ Lighting fixtures change
- ☐ Addition of automatic controls *(lighting, temperature, water…etc.)*
- ☐ Windows Change ☐ Low flow plumbing fixtures
- ☐ On-site electricity production ☐ Use of low-VOC products
- ☐ Other *(Please Specify)*

Is there a maintenance backlog for the school building? ☐ Yes ☐ No

Green Features

Is the school building(s) LEED® certified?

- ☐ Yes ☐ Certification in progress ☐ No
- ☐ No, LEED® shadowing ☐ No, other rating system *(Please Specify)*

If yes, what is the certification date?

Available automatic controls for each classroom/space

- ☐ Lighting ☐ Temperature ☐ Water Fixtures
- ☐ Other *(Please Specify)*

Type of ventilation of the school building(s)

- ☐ Natural Ventilation ☐ Mechanical Ventilation
- ☐ Mixed-mode ventilation

Type of fuel used for heating/cooling

- ☐ Electricity ☐ Gas ☐ Other *(Please Specify)*

Are floors/spaces or building(s) sub-metered? ☐ Yes ☐ No

APPENDIX IV: OCCUPANTS' WELL-BEING SURVEY

1. E-mail Invitation:

Sent: mm, dd, yyyy
From: U of M Research team [research.you@myumanitoba.ca]
To:

Subject: IEQ Online Survey Invitation

You are invited to participate in an online survey administered by the University of Manitoba concerning our school's indoor environmental quality (IEQ). Participation should take you about 20 minutes. Your participation is voluntary and you can withdraw from this study at any time.

This research has been approved by the University of Manitoba Education/ Nursing Research Ethics Board. If you have any concerns or complaints about this project you may contact any of the above-named persons or the University's Human Ethics Coordinator: Mrs. Margaret Bowman at 474-7122 or by email at Margaret.Bowman@umanitoba.ca.

To participate in this survey, please click this link (link to online survey). They survey will be available for two weeks (until <date>) and you may visit whenever it is convenient to you.

Best wishes

U of M Research Team

2. Web-based Consent Form

Project Title: An Evaluation of the Indoor Environmental Quality of Manitoba School Buildings

Why have you been invited to participate?
You are being invited to participate in a study aiming to evaluate the Indoor Environmental Quality (IEQ) of Manitoba school buildings. Please read this consent form carefully before deciding whether or not to participate. Your participation is voluntary and therefore you may withdraw at any time prior to submitting your responses at the end of the survey. Your decision to participate or not will not be shared with the school administration or the school division.

Project team
The project team includes Dr. Mohamed Issa and Mr. Ahmed Radwan. Mr. Radwan is an MSc student working under the supervision of Dr. Issa on this project. He will be the one responsible for conducting the physical measurements and communicating with the participating schools for the administration of the survey.

Why is the study being done?
There is a lack of empirical evidence for claims that poor indoor environmental conditions in schools can have an impact on students' health and performance and that green schools offer improved indoor environments than conventional ones. Only small-scale post occupancy surveys about school buildings' IEQ appear to have been conducted up to this point, raising concerns about the accuracy of these results and their applicability to the wider green building industry.

What are you asked to do?
You are asked to complete an online survey regarding your satisfaction with the indoor environment of your classroom and how it affects your ability to do work. They survey should take about 20 minutes of your time.

Risks and benefits
There is no known harm or direct benefits to participating in the study. However, your participation will help us better identify the physical conditions affecting productivity and well-being and thus contribute to improving those aspects.

Privacy and confidentiality
All data will be transmitted through a secure, encrypted internet connection and stored on secured servers. Only members of the University of Manitoba research team will have access to the raw data. All information gathered from you will be strictly confidential. The information will be completely anonymized to ensure that your responses do not reveal your identity. Reports and research publications resulting from this study will be based on aggregated averages but not on individual responses. Your employer will not be given access to the individual responses. Only aggregated data will be provided to them.
All individual survey response will be permanently deleted from the SurveyMonkey

server by November 30th, 2014. Tabulated primary survey response downloaded from the SurveyMonkey server will also be permanently deleted from Dr. Issa and Mr. Radwan's computers by that date.

Dissemination
At the end of this study, a report will be prepared using the anonymized and aggregated data and submitted to your school administration and school division. The purpose of this will be to provide the school and school division with the necessary information required to make necessary changes to the indoor environment in order to improve it. Furthermore, the key findings and the methods employed will be presented at research conferences and also submitted to academic journals for publication. This will add to the growing body of literature on IEQ in school buildings and how it influences occupants' satisfaction, wellbeing, and performance.

You have the right to change your mind
By entering your access code and clicking "start survey" at the end of this form, you agree to the information contained herein and to participating in the study. In no way does this waive your legal rights nor release the researchers, or your employer from their legal and professional liabilities. You are free to withdraw from the study at any time, and to refrain from answering any questions, without prejudice or consequence. Simply close your web browser if you decide to do so. You will not be required to provide an explanation for doing so.

This research has been approved by the University of Manitoba Education/ Nursing Research Ethics Board. If you have any concerns or complaints about this project you may contact Dr. Issa at Mohamed.issa@umanitoba.ca or the Human Ethics Coordinator (HEC) at 474-7122 or email at Margaret.Bowman@umanitoba.ca.

Can you request a summary of the study results?
You can request a summary of the study results either in electronic or printed version. This summary will be available by the end of December 2014. To request this summary, or to ask questions about this study, please contact the principal investigator Dr. Mohamed Issa at Mohamed.Issa@umanitoba.ca or at (204) 474-8786.

Should you have any questions or concerns regarding this research study, you are welcomed to contact the Head of the University of Manitoba's Department of Civil Engineering as follows:

Dr. Ahmed Shalaby, Ph.D., P.Eng.
Professor and Head
Department of Civil Engineering
University of Manitoba
E1-368 EITC, 15 Gillson Street,
Winnipeg, MB R3T 5V6
E1-368 EITC,

15 Gillson Street,
Winnipeg, MB R3T 5V6

p: (204) 474-6818, c: (204) 295-6818
e: Ahmed.Shalaby@umanitoba.ca

How to participate
If you agree to participate in this survey and agree to the information contained herein, please click the "start survey" button.

3. Survey questionnaire

A. Core Module:

A.1 Demography

1- What is the name of the school you are working in?

2- For how long have you been working in this school?

Less than 1 year   1-2 years   3-5 years   More than 5 years

3- What is your sex?

Female   Male

4- What is your age?

30 or under   31-50   over 50

5- How many hours per week do you spend in classrooms?

10 or less   11 to 30   More than 30

6- In which part of the building is your most frequent classroom located?? Choose one

7- On average, how many students do you have in your most frequent classroom in the past school year?

A.2 School's building physical information

	Very 3	2	1	Moderately	-1	-2	Not at all -3
8- Are you satisfied with your school's workspace in terms of use, availability, and layout?	☐	☐	☐	☐	☐	☐	☐
9- Are you satisfied with the colors and textures of flooring, furniture, and surface finishes?	☐	☐	☐	☐	☐	☐	☐
10- Are you satisfied with your school's overall cleanliness?	☐	☐	☐	☐	☐	☐	☐
11- Are you satisfied with your school's overall maintenance?	☐	☐	☐	☐	☐	☐	☐
12- Are you satisfied with your school's overall condition?	☐	☐	☐	☐	☐	☐	☐

B. Module 1

B.1 Thermal comfort

13- Which of the following do you personally adjust or control in your classroom? (check all that apply)

- ☐ Window blinds or shades
- ☐ Operable window(s)
- ☐ Temperature control thermostat
- ☐ Portable fan
- ☐ Ceiling fan
- ☐ Adjustable air vent (diffuser)
- ☐ None of the above
- ☐ Other (please indicate) [ ]

	Very 3	2	1	Moderately	-1	-2	Not at all -3
14- Are you satisfied with the temperature in your classroom	☐	☐	☐	☐	☐	☐	☐

15- If you selected -1, -2, or -3 in question 14 above, which of the following could best describe your source(s) of dissatisfaction with temperature? (Check all that apply).

☐ Often too hot	☐ Often too cold
☐ Humidity too high (damp)	☐ Humidity too low (dry)
☐ Air movement too high	☐ Air movement too low
☐ There is no window in my classroom	☐ Windows are not operable
☐ Incoming sun	☐ Heat from teaching equipment (projector, overhead...etc.)
☐ Thermostat is inaccessible	☐ Thermostat is adjusted by other people (facility manager or supervisor)
☐ Drafts form windows or vents	☐ Hot/cold surfaces (floor, ceiling, walls, or windows)
☐ Clothing policy is not flexible	☐ Adjustable air vent (diffuser)
☐ None of the above	☐ Other (please indicate) [ ]

16- Have you complained to a facility manager or supervisor this season about thermal conditions in your classroom?

◉ Yes ○ No

17- If yes, please indicate what was your complain about?

	Enhances 3	2	1	Neutral	-1	-2	Interferes -3
18- Overall, do the thermal conditions in your classroom enhance or interfere with your ability to get your job done?	☐	☐	☐	☐	☐	☐	☐

19- Please indicate the clothing ensemble you typically wear in your classroom in this season (or indicate the ensemble most similar to the one you typically wear):

- ☐ Shorts or knee-length skirt, short-sleeve shirt
- ☐ Shorts or knee-length skirt, short-sleeve shirt, sweater or jacket
- ☐ Shorts or knee-length skirt, long-sleeve top
- ☐ Shorts or knee-length skirt, long-sleeve shirt, long-sleeve sweater or jacket
- ☐ Trousers or ankle-length skirt, short-sleeve shirt
- ☐ Trousers or ankle-length skirt, short-sleeve shirt
- ☐ Trousers or ankle-length skirt, short-sleeve shirt, sweater
- ☐ Trousers or ankle-length skirt, long-sleeve shirt
- ☐ Trousers or ankle-length skirt, long-sleeve shirt, sweater
- ☐ Trousers or ankle-length skirt, long-sleeve shirt, suit jacket
- ☐ Trousers or ankle-length skirt, long-sleeve shirt, suit jacket, vest or T-shirt
- ☐ Trousers or ankle-length skirt, long-sleeve shirt, suit jacket, sweater, vest or T-shirt

20- Are there any other issues related to being too hot or too cold in your classroom?

C. Module 2

C.1 Air Quality

	Very 3	2	1	Moderately	-1	-2	Not at all -3
21- Are you satisfied with the air quality in your classroom (i.e. stuffy/stale air, cleanliness, & odors)?	☐	☐	☐	☐	☐	☐	☐

22- If you selected -1, -2, or -3 in question 21 above, which of the following could best describe your source(s) and level of dissatisfaction with air quality? (3 being minor problem and -3 being major problem).

	Minor 3	2	1	Moderately	-1	-2	Major -3
Air is stuffy/stale	☐	☐	☐	☐	☐	☐	☐
Air is not clean	☐	☐	☐	☐	☐	☐	☐
Air smells bad (odours)	☐	☐	☐	☐	☐	☐	☐

23- If the air smells bad in your classroom, which of the following would you perceive as the likely source(s)? (Check all that apply)

- ☐ Tobacco smoke
- ☐ Food
- ☐ Carpet or furniture
- ☐ Perfume
- ☐ Cleaning products
- ☐ Outside sources (car exhaust, smog)
- ☐ Other (please indicate) ______

	Enhances 3	2	1	Neutral	-1	-2	Interferes -3
24- Overall, does the air quality in your classroom enhance or interfere with your ability to get your job done?	☐	☐	☐	☐	☐	☐	☐

25- Are there any other issues related to air quality in your classroom?

D. Module 3

D.1 Lighting

26- Which of the following controls do you have over the lighting in your classroom? (check all that apply)

- ☐ Window blinds or shades
- ☐ Light switch
- ☐ Light dimmer
- ☐ None of the above
- ☐ Other (please indicate)

	Very 3	2	1	Moderately	-1	-2	Not at all -3
27- Are you satisfied with the quality of lighting in your classroom?	☐	☐	☐	☐	☐	☐	☐

28- If you selected -1, -2, or -3 in question 27 above, which of the following could best describe your source(s) of dissatisfaction with lighting quality? (Check all that apply).

- ☐ Too dark
- ☐ Too bright
- ☐ Daylight not enough
- ☐ Daylight too much
- ☐ Electric lighting not enough
- ☐ Electric lighting too much
- ☐ Electric lighting flickers
- ☐ Shadows on the desks
- ☐ None of the above
- ☐ Other (please indicate)

	Very 3	2	1	Moderately	-1	-2	Not at all -3
29- Are you satisfied with the quality of daylighting (natural lighting) in your classroom?	☐	☐	☐	☐	☐	☐	☐

30- If you selected -1, -2, or -3 in question 29 above, please describe why you are not satisfied with the quality of daylight in your classroom?

	Very 3	2	1	Moderately	-1	-2	Not at all -3
31- Are you satisfied with the ability to control the amount of daylight in your classroom?	☐	☐	☐	☐	☐	☐	☐
32- Are you satisfied with the visual comfort (e.g. glare, reflections, & contrast) in your classroom?	☐	☐	☐	☐	☐	☐	☐

	Enhances 3	2	1	Neutral	-1	-2	Interferes -3
33- Overall, does the lighting quality in your classroom enhance or interfere with your ability to get your job done?	☐	☐	☐	☐	☐	☐	☐

34- Are there any other issues related to lighting in your classroom?

E. Module 4

E.1 Acoustic Quality

	Very 3	2	1	Moderately	-1	-2	Not at all -3
35- Are you satisfied with the noise level in your classroom?	☐	☐	☐	☐	☐	☐	☐

36- How disturbing would you rate the following sounds in your classroom?

	Very 3	2	1	Moderately	-1	-2	Not at all -3
Noise from heating, ventilating, and cooling systems	☐	☐	☐	☐	☐	☐	☐
Noise from any teaching equipment	☐	☐	☐	☐	☐	☐	☐
Noise from washrooms and other plumbing noise	☐	☐	☐	☐	☐	☐	☐
Noise from outdoors	☐	☐	☐	☐	☐	☐	☐
Noise from other areas (e.g. classrooms, corridors)	☐	☐	☐	☐	☐	☐	☐

	Very 3	2	1	Moderately	-1	-2	Not at all -3
37- In your classroom, how understandable are the sounds from other classrooms in your building?	☐	☐	☐	☐	☐	☐	☐

	Enhances 3	2	1	Neutral	-1	-2	Interferes -3
38- Overall, does the acoustics quality in your classroom enhance or interfere with your ability to get your job done?	☐	☐	☐	☐	☐	☐	☐

39- Are there any other issues related to acoustics in your classroom?

	Very 3	2	1	Moderately	-1	-2	Not at all -3
40- In general, with the consideration of all the previous IEQ factors, how satisfied are you with the overall indoor environment in your school?	□	□	□	□	□	□	□

APPENDIX V: SUMMARY OF SURVEY RESPONSES

1. Core module:

1. What is the name of the school you are working in?

Answer Options	Response Percent	Response Count
The LEED school	14.8%	4
The new school	40.7%	11
The mid-aged school	44.4%	12

2. For how long have you been working in this school?

Answer Options	Response Percent	Response Count
Less than 1 year	11.1%	3
1-2 year	18.5%	5
3-5 year	18.5%	5
More than 5 years	51.9%	14

3. What is your sex?

Answer Options	Response Percent	Response Count
Female	70.4%	19
Male	29.6%	8

4. What is your age?

Answer Options	Response Percent	Response Count
30 or under	11.1%	3
Between 31 and 50	66.7%	18
Over 50	22.2%	6

5. How many hours per week do you normally spend in classrooms?

Answer Options	Response Percent	Response Count
10 or less	7.4%	2
Between 11 and 30	25.9%	7
More than 30	66.7%	18

6. In which part of the building is your most frequent classroom located?

Answer Options	Response Percent	Response Count
North	26.9%	7
East	19.2%	5
South	19.2%	5
West	19.2%	5
Core	7.7%	2
Don't know	7.7%	2
Other (please specify)		3

7. On average, how many students did you have in your most frequent classroom in the past school year?

Answer Options	Response average
	24

8. Are you satisfied with your school's workspace in terms of usage, availability, and layout?

Answer Options	Not at all satisfied	Dissatisfied	Slightly dissatisfied	Neutral	Slightly satisfied	Satisfied	Very satisfied
	0	3	2	2	8	9	3

9. Are you satisfied with the colors and textures of flooring, furniture, and surface finishes?

Answer Options	Not at all satisfied	Dissatisfied	Slightly dissatisfied	Neutral	Slightly satisfied	Satisfied	Very satisfied
	1	4	2	4	6	9	1

10. Are you satisfied with your school's overall cleanliness?

Answer Options	Not at all satisfied	Dissatisfied	Slightly dissatisfied	Neutral	Slightly satisfied	Satisfied	Very satisfied
	0	2	5	1	7	9	3

11. Are you satisfied with your school's overall maintenance?

Answer Options	Not at all satisfied	Dissatisfied	Slightly dissatisfied	Neutral	Slightly satisfied	Satisfied	Very satisfied
	1	3	3	2	3	11	4

12. Are you satisfied with your school's overall condition?

Answer Options	Not at all satisfied	Dissatisfied	Slightly dissatisfied	Neutral	Slightly satisfied	Satisfied	Very satisfied
	1	2	4	3	2	13	2

2. Module 1 - Thermal Comfort

13. Which of the following do you personally adjust or control in your classroom? (check all that apply)

Answer Options	Response Percent	Response Count
Window blinds or shades	73.1%	19
Operable window(s)	65.4%	17
Temperature control thermostat	0.0%	0
Portable fan	3.8%	1
Ceiling fan	7.7%	2
Adjustable air vent (diffuser)	0.0%	0
None of the above	11.5%	3
Other (please specify)		2

14. Are you satisfied with the temperature in your classroom?

Answer Options	Not at all satisfied	Dissatisfied	Slightly dissatisfied	Neutral	Slightly satisfied	Satisfied	Very satisfied
	2	4	6	2	2	9	1

15. If you selected "Not at all satisfied", "Dissatisfied", or "Slightly dissatisfied" in the question above, which of the following could best describe your source(s) of dissatisfaction with temperature? (Check all that apply).

Answer Options	Response Percent	Response Count
Often too hot	18.8%	3
Often too cold	68.8%	11
Humidity too high (damp)	18.8%	3
Humidity too low (dry)	0.0%	0
Air movement too high	0.0%	0
Air movement too low	25.0%	4
Windows are not operable	0.0%	0
There is no windows in my classroom	18.8%	3
Heat from teaching equipment (projector, overhead...etc.)	0.0%	0
Incoming sun	18.8%	3
Thermostat is inaccessible	18.8%	3
Thermostat is adjusted by other people (facility manager or supervisor)	75.0%	12
Hot/cold surfaces (floor, ceiling, walls, or windows)	0.0%	0
Clothing policy is not flexible	0.0%	0
Adjustable air vent (diffuser)	0.0%	0
None of the above	0.0%	0
Other (please specify)		2

16. Have you complained to a facility manager or supervisor this season about thermal conditions in your classroom?

Answer Options	Response Percent	Response Count
Yes	50.0%	13
No	50.0%	13

17. If yes, please indicate what was your complain about?

Answer Options	
	Too cold
	Too hot but it was fixed and set at a good temperature
	On occasion it will be very cold in the room.
	It was too cold.
	Heat and humidity also how cold it was in winter
	Lack of heat, smell of gas coming from air vent, dusty lights
	My office is freezing cold.
	Most of the day too cold and water dripping from the ceiling
	Too hot or too cold
	Temperature
	Too cold

18. Overall, do the thermal conditions in your classroom enhance or interfere with your ability to get your job done?

Answer Options	Highly interferes	Moderately interferes	Slightly interferes	Neutral	Slightly enhances	Moderately enhances	Highly enhances
	1	2	5	14	2	2	0

19. Please indicate the clothing ensemble you typically wear in your classroom in this season (or indicate the ensemble most similar to the one you typically wear):

Answer Options	Response Percent	Response Count
Shorts or knee-length skirt, short-sleeve shirt	3.8%	1
Shorts or knee-length skirt, short-sleeve shirt, sweater or jacket	7.7%	2
Shorts or knee-length skirt, long-sleeve top	0.0%	0
Shorts or knee-length skirt, long-sleeve shirt, long-sleeve sweater or jacket	3.8%	1
Trousers or ankle-length skirt, short-sleeve shirt	19.2%	5
Trousers or ankle-length skirt, short-sleeve shirt, sweater	23.1%	6
Trousers or ankle-length skirt, long-sleeve shirt	15.4%	4
Trousers or ankle-length skirt, long-sleeve shirt, sweater	19.2%	5
Trousers or ankle-length skirt, long-sleeve shirt, suit jacket	0.0%	0
Trousers or ankle-length skirt, long-sleeve shirt, suit jacket, vest or T-shirt	0.0%	0
Trousers or ankle-length skirt, long-sleeve shirt, suit jacket, sweater, vest or T-shirt	7.7%	2

20. Are there any other issues related to being too hot or too cold in your classroom?

Answer Options	Response
	Would love to have some sunshine to warm things up.

3. Module 2 – Indoor air quality

21. Are you satisfied with the air quality in your classroom? (i.e. stuffy/stale air, cleanliness, & odors)?

Answer Options	Not at all satisfied	Dissatisfied	Slightly dissatisfied	Neutral	Slightly satisfied	Satisfied	Very satisfied
	2	4	6	2	2	9	1

22. If you selected "Not at all satisfied", "Dissatisfied", or "Slightly dissatisfied" in question 24 above, which of the following could best describe your source(s) and level of dissatisfaction with air quality? (1 being minor problem and 7 being major problem).

Answer Options	Minor problem			Moderately			Major problem
Air is stuffy/stale	1	1	1	1	0	1	1
Air is not clean	1	1	1	1	0	2	1
Air smells bad (odors)	1	0	1	1	1	3	0

23. If the air smells bad in your classroom, which of the following would you perceive as the likely source(s)? (Check all that apply)

Answer Options	Response Percent	Response Count
Tobacco smoke	0.0%	0
Food	0.0%	0
Cleaning products	16.7%	1
Carpet or furniture	16.7%	1
Perfume	16.7%	1
Outside sources (e.g. Car exhaust)	50.0%	3
Other (please specify)		3

24. Overall, does the air quality in your classroom enhance or interfere with your ability to get your job done?

Answer Options	Highly interferes	Moderately interferes	Slightly interferes	Neutral	Slightly enhances	Moderately enhances	Highly enhances
	1	1	2	18	2	2	0

25. Are there any other issues related to air quality in your classroom?

Answer Options	Responses
	No

4. Module 3 – Lighting

26. Which of the following controls do you have over the lighting in your classroom? (check all that apply) (Check all that apply)

Answer Options	Response Percent	Response Count
Light switch	96.0%	24
Light dimmer	0.0%	0
Window blinds or shades	68.0%	17
None of these	4.0%	1
Other (please specify)		0

27. Are you satisfied with the quality of lighting in your classroom?

Answer Options	Not at all satisfied	Dissatisfied	Slightly dissatisfied	Neutral	Slightly satisfied	Satisfied	Very satisfied
	0	5	4	6	0	8	2

28. If you selected "Not at all satisfied", "Dissatisfied", or "Slightly dissatisfied" in the previous question above, which of the following could best describe your source(s) of dissatisfaction with lighting quality? (Check all that apply).

Answer Options	Response Percent	Response Count
Too dark	0.0%	0
Too bright	0.0%	0
Daylight not enough	33.3%	3
Daylight too much	11.1%	1
Electric lighting not enough	11.1%	1
Electric lighting too much	33.3%	3
Electric lighting flickers	44.4%	4
Shadows on the desks	0.0%	0
None of the above	11.1%	1
Other (please specify)		3

29. Are you satisfied with the quality of daylighting (natural lighting) in your classroom?

Answer Options	Not at all satisfied	Dissatisfied	Slightly dissatisfied	Neutral	Slightly satisfied	Satisfied	Very satisfied
	3	1	2	1	0	12	5

30. If you selected "Not at all satisfied", "Dissatisfied", or "Slightly dissatisfied" in the previous question above, please describe why you are not satisfied with the quality of daylight in your classroom?

Answer Options	
	I get the first am sun and that's it. To have fluorescent lights is an issue in itself.
	Need more natural light
	Could be more natural lighting, but only 2 windows.

31. Are you satisfied with the ability to control the amount of daylight in your classroom?

Answer Options	Not at all satisfied	Dissatisfied	Slightly dissatisfied	Neutral	Slightly satisfied	Satisfied	Very satisfied
	1	3	2	3	2	9	4

32. Are you satisfied with the visual comfort (e.g. glare, reflections, & contrast) in your classroom?

Answer Options	Not at all satisfied	Dissatisfied	Slightly dissatisfied	Neutral	Slightly satisfied	Satisfied	Very satisfied
	0	1	1	6	2	14	0

33. Overall, does the lighting quality in your classroom enhance or interfere with your ability to get your job done?

Answer Options	Highly interferes	Moderately interferes	Slightly interferes	Neutral	Slightly enhances	Moderately enhances	Highly enhances
	0	1	4	12	1	4	2

34. Are there any other issues related to lighting in your classroom?

Answer Options	Response Count
	No

5. Module 4 – Acoustics

35. Are you satisfied with the noise level in your classroom?

Answer Options	Not at all satisfied	Dissatisfied	Slightly dissatisfied	Neutral	Slightly satisfied	Satisfied	Very satisfied
	0	1	4	7	4	8	0

36. How disturbing would you rate the following sounds at your classroom?

Answer Options	Very			Moderately			Not at all
Noise from heating, ventilating, and cooling systems	1	3	3	1	4	4	6
Noise from any teaching equipment	0	0	1	2	1	4	13
Noise from washrooms and other plumbing noises	0	0	0	1	0	3	17
Noise from outdoors (e.g., road traffic)	0	0	0	2	2	3	14
Noise from other areas (e.g. classrooms, corridors)	1	1	3	3	1	6	8

37. In your classroom, how understandable are the sounds from other classrooms in your building?

Answer Options	Very			Moderately			Not at all
	3	1	5	3	3	6	3

38. Overall, does the acoustics quality in your classroom enhance or interfere with your ability to get your job done?

Answer Options	Highly interferes	Moderately interferes	Slightly interferes	Neutral	Slightly enhances	Moderately enhances	Highly enhances
	0	1	3	12	2	5	1

39. Are there any other issues related to acoustics in your classroom?

Answer Options	Response Count
	No

40. Are you satisfied with the noise level in your classroom?

Answer Options	Not at all satisfied	Dissatisfied	Slightly dissatisfied	Neutral	Slightly satisfied	Satisfied	Very satisfied
	0	1	4	2	5	12	0

APPENDIX VI: DETAILED IEQ ON-SITE PHYSICAL MEASUREMENTS

Table 0-1 Full Measurements of All Thermal Comfort Parameters

		Temperature (°C)			Air Velocity (m/s)			
Schools	Classrooms	Feet	Chest	Head	Feet	Chest	Head	RH (%)
New, LEED	1	22.96	24.24	24.82	0.418	0.921	0.738	42.67
	2	22.62	23.96	24.53	0.445	0.458	0.321	40.61
	3	23.39	25.46	25.84	0.463	0.232	0.212	46.25
	4	22.85	24.61	25.26	0.377	0.712	0.668	47.00
	5	22.36	23.51	23.82	0.311	0.543	0.445	44.03
	6	22.55	23.66	24.12	0.252	0.427	0.446	43.75
New, Non-LEED	1	23.14	23.25	23.20	0.517	1.094	1.398	50.99
	2	22.71	22.91	22.81	0.381	0.642	1.295	48.02
	3	23.54	23.88	23.91	0.429	1.552	1.454	52.48
	4	21.33	21.22	21.17	0.887	1.108	1.021	57.02
	5	23.22	22.91	22.78	0.489	0.675	0.670	58.15
	6	22.99	23.88	24.12	0.207	0.382	0.451	49.20
Middle-Aged, Conventional	1	20.77	21.34	21.43	0.215	0.364	0.465	56.52
	2	20.77	21.13	21.16	0.619	0.839	0.653	54.03
	3	22.20	23.25	23.48	0.218	0.423	0.523	51.84
	4	22.28	23.09	23.35	0.187	0.364	0.430	55.73
	5	22.37	23.26	23.39	0.260	0.473	0.592	50.81
	6	22.68	23.46	23.58	0.281	0.526	0.570	51.06
Recommended Values			20 to 25.5			0.1 to 0.2		30 -65

Table 0-2 Full Measurements of all IAQ Parameters

Schools	Classrooms	CO_2 concentrations (ppm)	TVOCs ($\mu g/m^3$)
New, LEED	1	691.50	280.64
	2	741.00	308.13
	3	765.43	457.09
	4	767.50	418.39
	5	664.80	331.12
	6	629.17	272.21
New, Non-LEED	1	743.50	322.74
	2	910.13	211.13
	3	580.31	561.77
	4	1145.40	479.94
	5	1225.20	672.00
	6	833.18	206.18
Middle-Aged, Conventional	1	862.77	750.60
	2	871.18	627.53
	3	966.77	626.69
	4	957.60	988.56
	5	1114.50	686.70
	6	1054.26	712.63
Recommended Values		<1,100	<300

Table 0-3 Full Measurements of All Lighting Quality Parameters

Schools	Classrooms	Desktop illuminance (Lux)
New, LEED	1	141.84
	2	800.41
	3	874.75
	4	315.49
	5	637.29
	6	403.89
New, Non-LEED	1	434.89
	2	495.37
	3	647.74
	4	743.05
	5	202.04
	6	693.13
Middle-Aged, Conventional	1	739.31
	2	824.88
	3	646.40
	4	546.29
	5	676.13
	6	595.06
Recommended Values		300-700

Table 0-4 Full Measurements of All Acoustics Quality Parameters

Schools	Classrooms	Background noise (dB)
New, LEED	1	62.72
	2	55.96
	3	56.48
	4	64.80
	5	57.62
	6	47.35
New, Non-LEED	1	59.85
	2	70.29
	3	58.59
	4	60.98
	5	55.33
	6	55.85
Middle-Aged, Conventional	1	55.59
	2	52.24
	3	50.33
	4	49.04
	5	63.51
	6	54.70
Recommended Values		35 – 55

APPENDIX VII: CBE THERMAL COMFORT TOOL

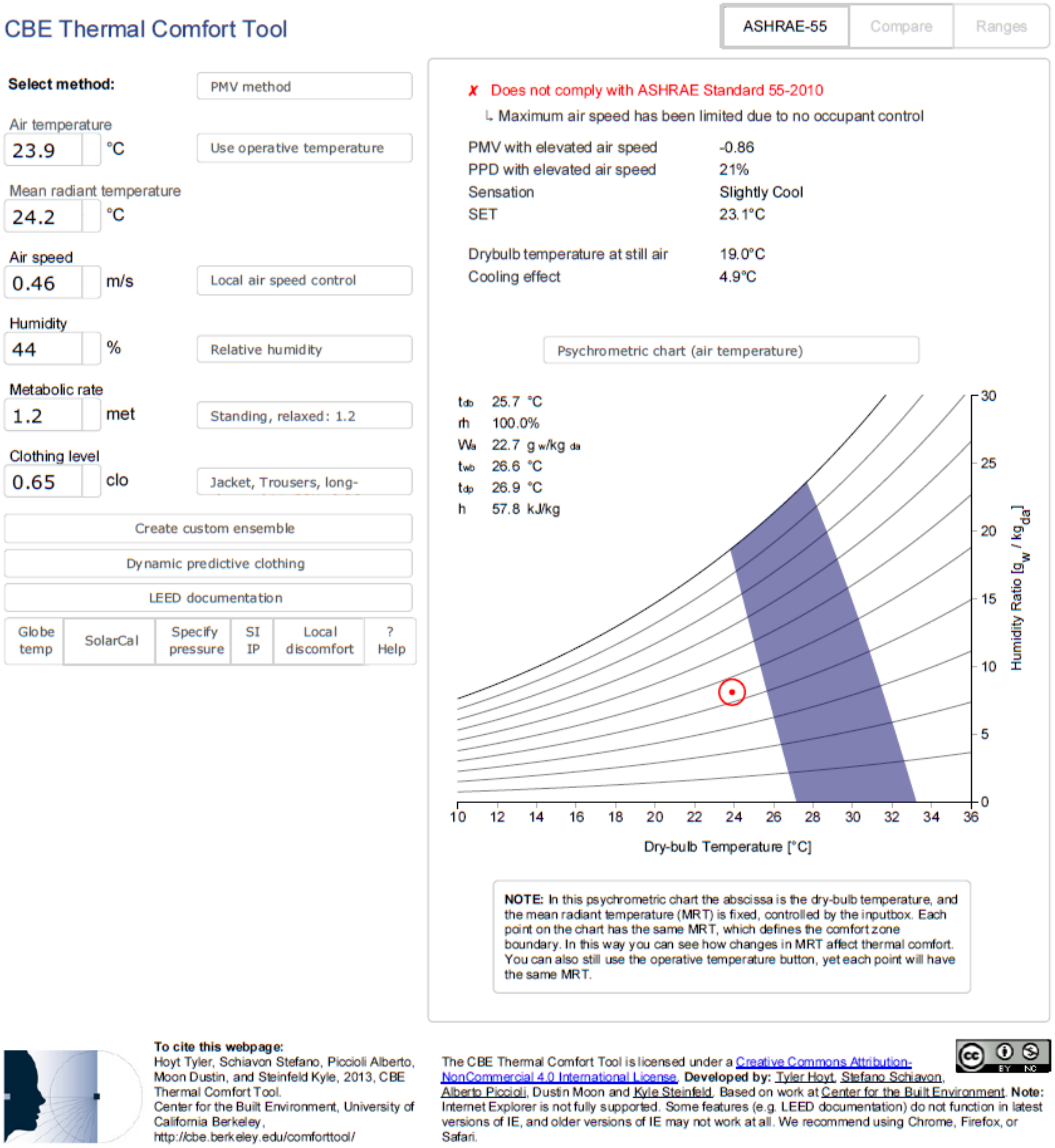

Figure 0-1 CBE Thermal Comfort Tool for New, LEED School

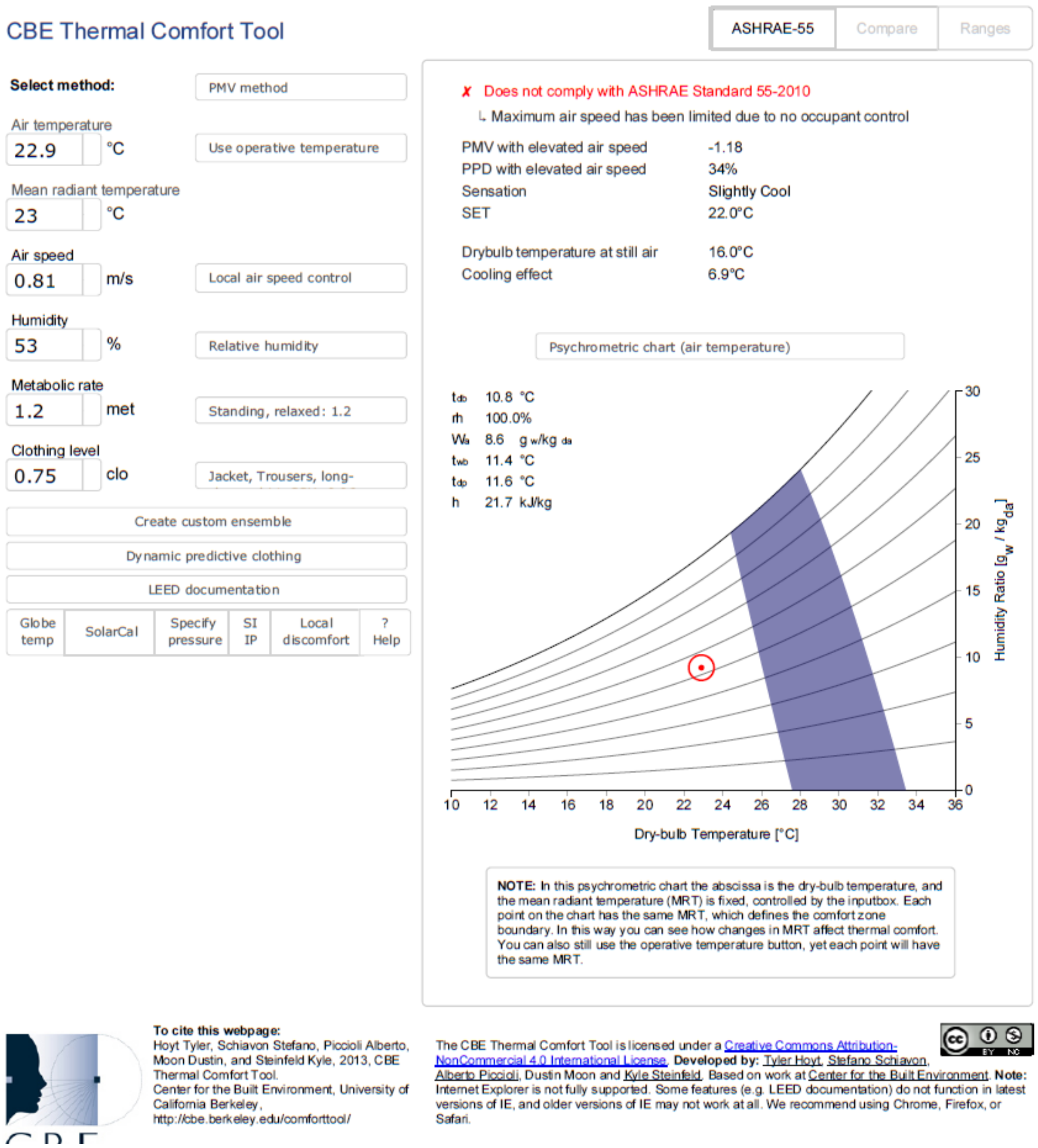

Figure 0-2 CBE Thermal Comfort Tool for New, Non-LEED School

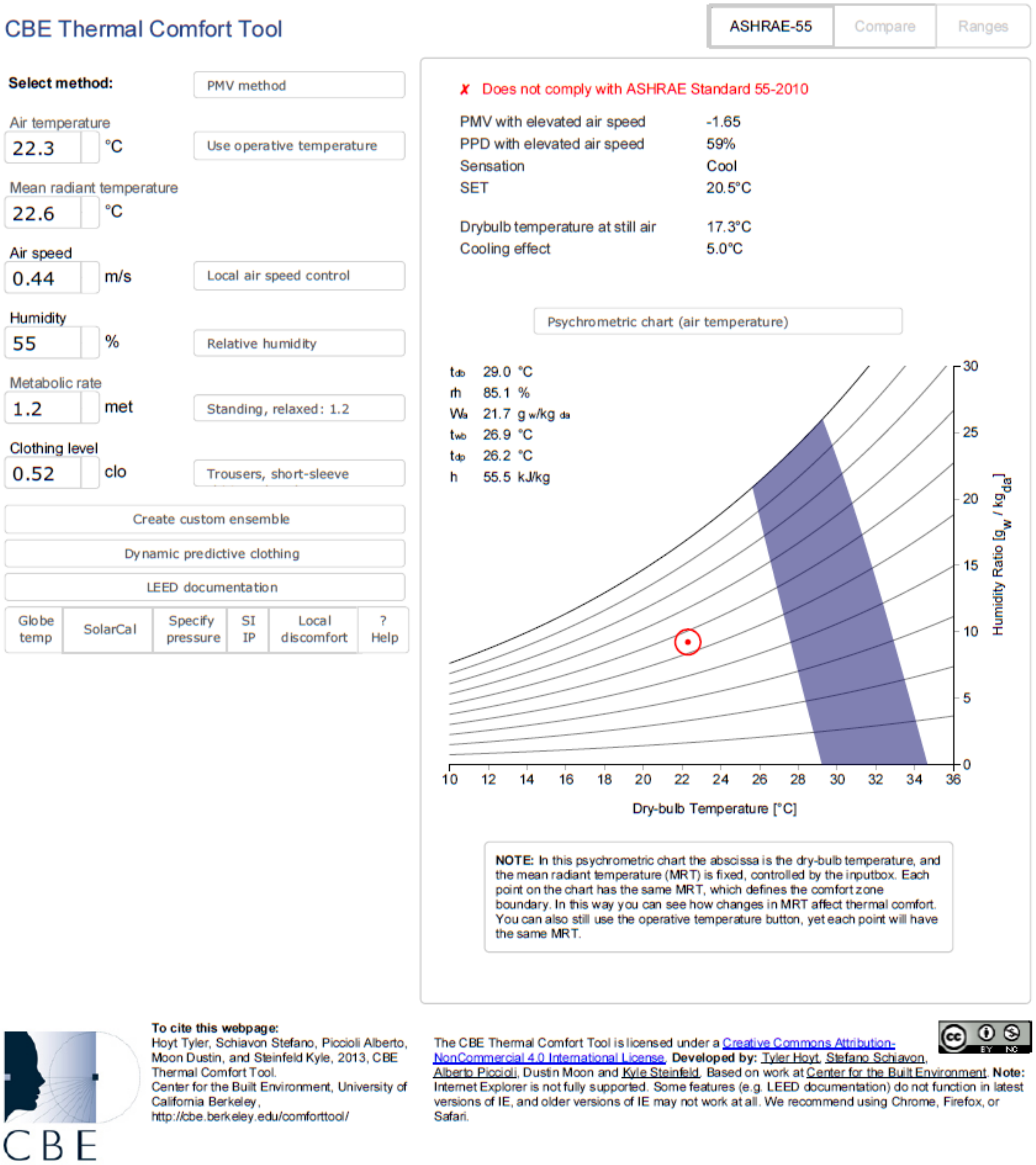

Figure 0-3 CBE Thermal Comfort Tool for Middle-Aged, Conventional School