# Evaluation of indoor environmental quality in Sagkeeng Junior School

By

Saule Narubayeva

A thesis submitted to the Faculty of Graduate Studies
in partial fulfillment of the requirements for the degree of

Master of Science

Department of Civil Engineering
Faculty of Graduate Studies
University of Manitoba
Winnipeg, Manitoba

# Abstract

This research involved investigating the effects of a First Nations school’s indoor environmental quality on health and human performance. This research project was conducted in partnership with the Sagkeeng First Nations community in Manitoba. The indoor environment of a school building is a complex system involving many parameters that may have an impact on indoor air quality and thermal comfort. Air quality in schools depends strongly, on one hand, on the interaction between the building and its outdoor environment, and, on the other hand, on the way a building is used, operated, and maintained. School buildings should use a properly designed heating, ventilation, and air conditioning system that maintains an adequate supply of cleaner air and sets up optimal heating.

This study provided empirical evidence to the claim that First Nations schools can be exposed to adverse indoor environmental conditions based on the school studied in this research. The evidence was based on objective measurements of indoor environmental quality and a subjective survey conducted among the school’s teachers. In addition, a series of statistical analyses in Statistical Package for Social Science 25 and Excel were performed to examine the associations between building characteristics, indoor environmental parameters, and teacher's health. Finally, thermal imaging was conducted to check the thermal performance of the building envelope. The physical measurement campaign consisted of measuring the indoor environmental parameters: indoor air temperature, relative humidity, and carbon dioxide concentrations in 9 classrooms. Consequently, along with the comprehensive physical measurements, fundamental knowledge, of the building and its systems was also needed to identify principal factors that adversely affect indoor school environments. On-site continuous records of air temperature showed underheating and overheating of the school during the year. Air temperatures as high as 35.1°C (winter season) and as low as 9.6°C (spring season) were recorded in the school during occupied hours. Indoor air was dry in the winter as relative humidity values were less than 30%. Moreover, thermal comfort parameters were found to be influenced by the heating, ventilation, and air conditioning system, poor thermal performance of the building envelope, and classroom orientation.

The results of the subjective survey demonstrated that approximately 70% of teachers reported poor indoor air quality as the biggest problem in the school. Statistically significant associations ($p < 0.05$) were found between teachers' satisfaction with classrooms' indoor air quality and their characteristics such as ventilation system, maintenance, and cleanliness. The fifth part of the school pedagogical staff pointed out that poor indoor air quality was the main source of health problems such as headaches, fatigue, aggravation of asthma and allergies, stuffy nose, and difficulties with breathing. The relationships between physical measurements (i.e., temperature, relative humidity, and carbon dioxide) and the score of having adverse health symptoms were evaluated using the linear regression model. The decrease in mean indoor air temperature was statistically significantly associated with an increase in the score of having sick building syndrome (Beta= -1.163, CI [-2.104; -0.221], $p < 0.05$) while the increase in relative humidity was statistically significantly associated with an increase in the score of having sick building syndrome (Beta = 0.783, CI [1.561; 0.005], $p < 0.05$). Furthermore, the associations between performance and satisfaction with indoor air quality, acoustics, and lighting comfort were found to be statistically significant ($p < 0.05$).

# Acknowledgments

I would like to express my sincere gratitude to my academic supervisor Dr. Miroslava Kavgic for all her guidance, help, and support. Dr. Kavgic contributed a lot to my thesis, allowing me to grow as a researcher. She provided the necessary constructive criticism and valuable feedback to refine my work and complete the thesis. I would like to take this opportunity to express my sincere appreciation and special thanks to Dr. Mohamed H. Issa – co-supervisor for his continuous encouragement, excellent supervision, support, and valuable feedback. I would also like to express my appreciation to my MSc committee members, Dr. Shawn Clark and Dr. Babak Mehran, whose continuous support was crucial for completing this MSc program. Dr. Babak Mehran helped me a lot with defining the statistical methods to analyze the research data. I am also grateful to the University of Manitoba's Research Ethics Board for reviewing and approving the protocol for this research.

My sincere gratitude goes to the University Indigenous Research Program (UIRP). This work was generously supported by the UIRP in the first 18 months. I am also grateful to the Natural Sciences and Engineering Research Council of Canada (NSERC) for the program Collaborative Research and Training Experience for Sustainable Engineering in Remote Areas. This program provided me a scholarship and one-of-a-kind experience through training, research, and industry internship. I am equally grateful for financial support from the Mitacs Accelerate program. The caring, responsive, and resourceful support from the University of Manitoba deserves special mention as the University of Manitoba supported me by not only providing scholarships such as the Antenbring Graduate Scholarship in

Engineering and the International Graduate Student Entrance Scholarship but also by resources for my physical and mental well-being.

Many other individuals provided their valuable support in developing and completing my research. I am very grateful to school principal Mr. Garry Swampy for his support of the research. Special thanks to the school staff and teachers for providing their comments, feedback, and filling out the questionnaires, the analysis of them became an important part of my research. Mr. Ali Al-Janabi (former MSc student of Dr. Kavgic) deserves particular gratitude not only for being the best family friend but also for his moral support. He also helped me develop a 3D model using Energy Plus and we had a good time working together on our university course projects. My sincere gratitude goes to Mr. Gregor Wadden for his continuous technical guidance and kind support during these three years: from setting up and helping with the collection of data from measurement devices, long-distance transporting to the site, and thermal imaging conduction. Industry partner and university colleague Mr. Daniel Kazado (former MSc student of Dr. Kavgic) helped tremendously with the Mitacs Accelerate program arrangement and provided with an internship opportunity in his company. I would like to extend special thanks to Mrs. Mahboubeh Zamani for her help in the development of the questionnaires. Finally, I would like to express my deepest appreciation to my beloved family: my husband Denis, my mom Klara Adeshkyzy, son Alen, and my brother Dauren and his family - spouse Iryna and daughter Danna-Emilia. Thank you for your endless love, patience, and support.

# Contents

# List of Tables

# List of Figures

# Abbreviations and Acronyms

| Acronyms | Description |
|---|---|
| (IEQ) | Indoor Environmental Quality |
| (IAQ) | Indoor Air Quality |
| (TC) | Thermal Comfort |
| (AC) | Acoustics Comfort |
| (VC) | Visual Comfort |
| (LEED) | Leadership in Energy and Environmental Design |
| (SBS) | Sick Building Syndrome |
| (BESTEST) | Building Energy Simulation Test |
| (ASHRAE) | American Society of Heating, Refrigerating and Air-Conditioning Engineers |
| (HVAC) | Heating, ventilation, and air conditioning |
| (T) | Temperature |
| ($CO_2$) | Carbon Dioxide |
| (PMV) | Predicted Mean Vote |
| (NRC) | National Research Council |
| (NRCan) | Natural Resources Canada |
| (MECB) | Manitoba Energy Code for Buildings |
| (RH) | Relative Humidity |
| (CWEC) | Canadian Weather for Energy Calculations |
| (R) | Correlation coefficient (Spearman's Rank Correlation Coefficient Test) |

| | |
|---|---|
| (SERA) | Sustainable Engineering for Remote Areas |
| (CREATE) | Collaborative Research and Training Experience |

# 1 Introduction

Schools are a category of buildings where good indoor environmental quality (IEQ) may considerably improve occupant’s attention, concentration, learning, and performance (Corgnati, Filippi, and Viazzo 2007). On the other hand, poor IEQ has been found to be associated with a negative impact on health (Mendell 1993; Seppänen 1999) While air pollution affects people of all ages, children are the most vulnerable layer of the population. According to the Report on Pollution in Canadian families (2006), children are especially more susceptible to poor indoor air quality (IAQ) because they breathe higher volumes of air relative to their body weights, and their tissues and organs are actively growing. Raysoni et al. (2013) echoed this finding that children are more sensitive to pollutants given their weak immune system and developing organs.

First Nations children are at an increased risk of poor IEQ compared to other children in Canada as they face unique socio-economic, cultural, and environmental risks. The Environmental Protection Agency (EPA) (2014) indicated that First Nations children with hypersensitivity, allergies, and other health issues are especially vulnerable to the effects of unhealthy indoor environments. Furthermore, these communities are mostly located in Canada’s remote and colder regions; henceforth, more likely to live in poor housing conditions than the general population. Studies conducted on First Nations communities related poor housing conditions to poor health outcomes (Jenkins et al. 2003; Polyzois et al. 2016; Kovesi et al. 2007; Knotsch and Kinnon 2011; Berghout et al. 2005).

Furthermore, IEQ in schools is important given the time children spend in schools. Additionally, teacher's health is crucial because of their role in education and the future success of children (Kielb et al. 2015). It is therefore important that schools have excellent indoor environmental quality, and in particular, indoor air quality. For example, the Environmental Protection Agency (EPA) (2014) reported that IAQ in schools could have a significant impact on children's health, learning, absenteeism, performance, and productivity (Haverinen-Shaughnessy, Moschandreas, and Shaughnessy 2011; Simons et al. 2010; Meklin et al. 2002). Additionally, several studies provided evidence that ventilation, building-related health symptoms, and reduced indoor air quality impact productivity in adults (Seppanen et al. 1999; Sundell et al. 2011; Kielb et al. 2015). Exposure to indoor air pollutants is associated with a multitude of respiratory and systemic illnesses. For instance, the poor quality of air in classrooms causes pupils health problems, such as flu, respiratory disorders, fever, and many more. Health Canada (2007) states that health problems include the development and exacerbation of asthma, airway irritation, inflammation, and non-respiratory symptoms, such as headaches, fatigue, and eye irritation. Moreover, long-term or acute exposures to high indoor pollutants can lead to lung cancer and premature death (EPA 2012).

Some authors (e.g., Sundell et al. 2011; Smedje, Mattsson, and Wålinder 2011) investigated this relationship and found that low ventilation rates are associated with increased absenteeism and more respiratory symptoms in schoolchildren. Furthermore, Almeida and De Freitas (2014) found an inadequate ventilation system to be the main reason for air quality problems. They also found that air quality problems in schools were exacerbated by uncleaned or improperly cleaned indoor surfaces and crowded classrooms. Additionally, delaying routine maintenance and servicing of indoor facilities and ventilation systems can potentially lead to IAQ problems (Guo et al. 2008). Pollution problems in schools also arise due to cheap materials being used for construction, inadequate funding leading to environmental deficiencies from poor maintenance and servicing of facilities, and inproper landscaping (Mendell and Heath 2005; Godwin and Batterman 2007).

Thermal comfort is one of the critical indoor environmental factors occupants pay the most attention to. People have different thermal sensations, even in the same environmental conditions (Djongyang, Tchinda, and Njomo 2010). Satisfaction with the thermal environment is a complex subjective response to several interacting tangible (e.g., the acceptable thermal-comfort range, the metabolic and clothing-insulation rate values) and less tangible variables (e.g., cognition, acclimatization, and expectations) (Ogbonna and Harris 2008). In comparison to adults, children are less bothered by thermally uncomfortable conditions in a classroom (Bluyssen et al. 2018). Havenith (2007) suggested that differences in metabolic rates of children and adults for typical indoor activities might explain the differences in thermal sensations when exposed to the same temperatures.

Thermal comfort dissatisfaction leads to productivity loss (Roelofsen 2016; Akimoto et al., 2010, Lan, Wargocki, and Lian 2011; Witterseh, Wyon, and Clausen 2004; Lan, Lian, and Pan 2010). The vital parameter that defines thermal comfort is the level of humidity in the air. School occupants may suffer from extremely high or extremely low humidity depending on the time of year, and both have been linked to adverse health effects (Angelon-Gaetz et al. 2015) to mold growth, all factors impacting performance, learning ability (Wargocki 2000), and absenteeism (Fischer and Bayer 2001).

Among the different parameters affecting thermal conditions, the temperature has a relevant role in the perception of the environment. When classroom temperature went down, students' performance significantly improved (Wargocki and Wyon 2007). Air temperature has a powerful effect on the prevalence of Sick building syndrome (SBS) symptoms (Jaakkola, Heinonen, and Seppänen 1989; Witterseh et al. 2004). Some studies (e.g., De Giuli, Da Pos, and De Carli 2012; Mumovic et al. 2009; Montazami and Nicol 2013) reported that thermal comfort was acceptable in school buildings even though temperatures tended to be higher (Teli, Jentsch, and James 2014). School buildings might not be currently designed according to their main occupant's thermal needs. Overheating causes thermal diversity and discomfort, which could be due to solar gains through large windows. The building design envelope has a significant impact on indoor thermal conditions. The thermal condition inside a building directly relates to the buildings’ architectural and constructional characteristics, including layout, space dimensions, window wall ratios, external shadings, and building thermal envelope properties (Zomorodian, Tahsildoost, and Hafezi 2016).

Providing people the possibility to control the indoor environment improves thermal comfort and overall satisfaction with IEQ (Frontczak and Wargocki 2011). Adaptive opportunities to restore comfort could include clothing adjustments, occupant control of heating and cooling systems (e.g., use of thermostats), opening windows, drinking cold or hot liquids, using window blinds or personal fans, or moving to another location (Karjalainen

2009; Frontczak and Wargocki 2011; Lin and Deng 2008).

Lighting comfort in schools significantly impacts learning, visual performance, and health (Korsavi, Zomorodian, and Tahsildoost 2016). Some studies suggest that daylight plays an essential role in achieving comfort and increasing productivity. For instance, Rittner and Robbin (2002) reported that daylight helps students retain and learn information. Hathaway (1983) discovered that teachers prefer daylighting. Furthermore, Lang (2002) argued that teachers like to have control over lighting levels (cited in Winterbottom and Wilkins 2009). Moreover, Lin et al. (2020) advised that “careful consideration regarding light sources should be exercised in the design and construction of buildings.”

Classroom acoustics is another crucial aspect for both teachers and students. A right acoustical environment remarkably enhances the learning, productivity, and satisfaction of building occupants. The survey conducted by Turunen et al. (2013) showed that noise was one of the most frequently reported factors causing daily inconvenience in classrooms since speaking and hearing are the most important modes of communication in teaching (Sala and Viljanen 1995). Teachers identified noise generated by students and teachers in adjacent rooms, along with the noise generated within the classroom, to be the main reasons for poor acoustics (Zannin and Marcon 2007). Poor acoustics in classes is associated with various adverse effects, including reduced concentration and performance, decreased speech communication quality, fatigue, and voice problems in teachers (Astolfi and Pellerey 2008;  Kristiansen et al. 2013; Puglisi et al. 2015).

Healthy acoustic comfort could be achieved by minimizing noise from external (e.g., traffic) and internal (e.g., HVAC, chatting) sources (Puglisi et al. 2015). External noise is higher when the schools are located near main streets, commercial areas, and airports (Puglisi et al. 2015). Acoustical satisfaction was lower in nonrenovated classrooms, e.g., without sound-absorption treatment (Astolfi and Pellerey 2008). Seep et al. (2002) stated that the main reason for acoustics issues is not the “lack of resources, but rather of perception of the problem on the part of the professionals involved and a lack of solutions” (cited in Zannin and Zwirtes 2009). Seep et al. (2002) highlighted that acoustics problems should be considered in the design stage (cited in Zannin and Zwirtes 2009). Furthermore, Lin et al. (2020) suggested that “increased spacing between respective classrooms and/or thicker walls in schools could potentially mitigate the need for teachers to overcompensate when excessive noise presents.”

Surprisingly, even though children aged 14 and younger represent 16.5 % of the Canadian population (Statistics Canada, 2010), there is little empirical evidence on IEQ in Canadian schools. Moreover, the relationship between health, absenteeism, and poor air quality has been far less studied in schools than in other building types (e.g., offices). Similarly, most studies investigated lighting in offices, and there is a scarcity of research studies on schools. There is, in particular, a knowledge gap on indoor environmental quality and its effects on occupant’s health in First Nations schools. The results and remedial measures from the previous studies are not transferable to schools in Canada, and particularly to First Nations schools, due to the complexity and specificity of the school environments across different localities and climates. Consequently, the knowledge from these previous studies cannot be applied directly to First Nations schools. Therefore, there is a great need for a holistic analysis of First Nation schools to identify associations between environmental characteristics and the health and comfort of school occupants.

## 1.1 Objectives

This interdisciplinary collaborative research study addresses the cross-cutting research theme of “Indigenous Research” and the research theme of “Integrative Research in Health and Well-Being” as defined in the University of Manitoba Strategic Research Plan 2015-2020 (University of Manitoba, 2014). The proposed research strengthens partnerships with communities by focusing on improving health and education outcomes in First Nation schools, which are strategic priorities of the University of Manitoba Strategic Plan 2015-2020 (University of Manitoba, 2014). The study is conducted in collaboration with the First Nations community of Sagkeeng. This community was chosen because of an ongoing collaboration with the University of Manitoba regarding examining IAQ in homes.

The goal of this research study is to evaluate IAQ, thermal comfort, acoustics, and lighting comfort related to health symptoms in First Nations School in Manitoba (Canada) and suggest mitigation measures.

The specific objectives include:

- Evaluating long-term physical measurements of indoor air quality and thermal comfort in school
- Evaluating occupants’ perceptions of indoor air quality and thermal comfort in First Nation school
- Assess the relationships between IAQ, thermal comfort, acoustics, and lighting

comfort, and health symptoms in school.

## 1.2 Contribution to the field

The contributions of this study are as follows:

1. It represents one of the few studies conducted on First Nations schools in Canada.
2. It strengthens partnerships with First Nations communities by focusing on improving the performance of the school, school occupants' health, and education outcomes in First Nations schools.
3. It enables a better understanding of indoor environmental quality in First Nations schools.
4. It fills a knowledge gap relating to indoor environmental quality to its adverse effects on school occupant's health in First Nations schools in Canada.

## 1.3 Thesis structure

**Chapter 2** provides an in-depth literature review on indoor environmental quality in school buildings and its influence on the health of school occupants.

**Chapter 3** presents the research methodology used in the research. The chapter describes how the methodology was applied to the school analyzed.

**Chapter 4** presents the results of analyzing physical long-term measurements and questionnaire responses. The discussion of those results in relation to those from previous studies is also included in this chapter.

**Chapter 5** provides a summary of the findings of this research related to indoor environmental quality parameters in the school building and its impact on the health of school occupants. This is followed by a consideration of potential future refurbishment measures to improve IAQ and thermal comfort of the school building.

**Chapter 6** presents the limitations of the research and recommendations for future research to address these limitations.

# 2 Literature review

This chapter provides a comprehensive review of studies that explored how different indoor environmental quality parameters (i.e., air quality, thermal comfort, visual comfort, and acoustic comfort) influence occupants' health and performance.

## 2.1 Indoor Environmental Quality

Canadians spend approximately 90% of their time indoors, including homes, offices, schools, and daycare centers (Matz et al. 2014). Consequently, indoor conditions have a significant impact on their health and performance (Frontczak and Wargocki 2011). The Center for Disease Control and Prevention (2013) defines indoor environmental quality (IEQ) as "the quality of a building's environment concerning the health and well-being of those who occupy space within it."

Healthy buildings with good environmental quality lead to happier inhabitants (Mendell et al., 2002). There is evidence in the literature that the improvement of IEQ will positively affect occupants' health. Furthermore, literature studies show increasing awareness with respect to IEQ and its effects on the satisfaction, and performance of occupants. For example, Miller et al. (2009) found that improving IEQ could increase productivity by 4.8% and reduce sick leave days. Singh et al. (2010) echoed these findings by reporting that improved IEQ led to reductions in absenteeism and work hours because of asthma, respiratory allergies, depression, and stress and to self-reported improvements in productivity.

However, Frontczak and Wargocki (2011) reported that even if indoor conditions were the same, occupants can have different perceptions, which leads to different subjective responses. Bluyssen et al. (2018) found that overall satisfaction was affected not only by satisfaction with indoor environmental factors but also by control over the indoor environment, the amount of privacy, office layout, decoration, and cleanliness. To improve satisfaction with indoor conditions, people need to control the indoor climate through behaviors such as the opening of windows, air-conditioning, and the control of temperature, lighting, and solar shading (Frontczak et al., 2012). As a result, IEQ has a significant impact on the energy consumption of any building.

Poor indoor environmental quality may be a risk for occupants' health. Unhealthy buildings, according to relevant studies (Daisey, Angell, and Apte 2003), have been associated with the high prevalence of sick building syndrome symptoms: headaches, dry eyes or throat, itchy eyes, sneezing, blocked and stuffy nose, runny nose, and dry or irritated skin. Similarly, Hancock and Vasmatzidis (1998) 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. Furthermore, Wargocki et al. (2000) found a relationship between poor IEQ conditions and sick building syndrome (SBS), and between good IEQ and improved health and productivity.

Poor IEQ particularly harms vulnerable population groups such as children (Vilcekova et al. 2017). Consequently, school buildings require more attention concerning the issues of IEQ compared to other structures (Allab et al. 2017).  Over the last decades, several studies investigated indoor environmental quality in school buildings worldwide, including developed countries, and reported that IEQ in school buildings played a vital role in the health and performance of school staff and students (Vilcekova et al. 2017; Bluyssen et al. 2018; Ekren et al. 2017; Dias Pereira et al. 2014; De Giuli et al. 2012). For example, Vilcekova et al. (2017) found that the main concerns for schools were high concentrations of carbon dioxide ($CO_2$), insufficient light, uncomfortable thermal conditions, and acoustic discomfort. Zhang et al. (2011) discovered the prevalence of sick building symptoms in school premises and negative relationships between the temperature, humidity, and $CO_2$ levels.

Furthermore, Bluyssen et al. (2018) reported that unacceptable environmental conditions in classrooms were due to poor ventilation, noise, inadequate heating, or lighting that affected the health, comfort, and performance of occupants. Moreover, several studies assessed the relationships of various health outcomes among occupants with indoor environmental factors in schools. For instance, Haverinen-Shaughnessy and Shaughnessy (2015) reported that poor indoor environmental quality in schools might result in illness, leading to absenteeism, adverse health symptoms, and decreased academic performance.

Teachers and other school staff also spend much of their day in school. Therefore, they are subjected to the influence of indoor environmental factors such as thermal comfort, indoor air quality, noise, and lighting. A limited number of studies concentrated on investigating the relationships between indoor environmental quality and building-related health symptoms among teachers (Kielb et al. 2015; Price 2002; Lin et al. 2017; Claudio, Rivera, and Ramirez 2016). Thus, Lin et al. (2017) reported that poor outdoor air quality in school caused by nearby traffic and improper cleaning of ventilation systems was associated with asthma, allergy, and respiratory infection among teachers. Furthermore, Claudio et al. (2016) found that respiratory infections, asthma, colds, eye irritation, nasal congestion, and sore throat were associated with the classroom environment such as dampness, dust, and inadequate indoor-outdoor air exchange. The results of their study indicated that the school environment could affect a teacher's respiratory health.

Although the indoor environmental quality in school buildings has been extensively studied in different countries with various climate conditions, only a few attempts have been made to holistically analyze the IEQ of First Nation Schools or schools for Inuit people. Moreover, the results of previous studies cannot be applied directly to First Nations schools due to the complexity and uniqueness of the school environments across different localities and climates. Therefore, this knowledge gap should be addressed in the future by conducting comprehensive IEQ investigations in Indigenous schools across Canada.

IEQ includes many parameters such as thermal comfort, indoor air quality, ventilation rates, acoustics, ergonomics, and visual comfort that may have an impact on occupants within the building. Nevertheless, the four major environmental factors are thermal Comfort (TC), Indoor Air Quality (IAQ), Acoustic Comfort (AC), and Visual Comfort (VC) (D'Ambrosio et al., 2010). Moreover, Frontczak, Andersen, and Wargocki (2012) highlighted that respondents indicated that all 4 main environmental parameters were equally important in providing a good indoor environment. Thus, the following sections discuss four major environmental factors: indoor air quality, thermal comfort, acoustic comfort, and visual comfort in detail.

### *2.1.1 Indoor Air Quality (IAQ)*

Al horr et al. (2016) defined indoor air quality (IAQ) as the degree of quality of the indoor air of a building. Hui et al. (2006) defined it as the "air, determined by cognizant authorities, not to contain known contaminants at harmful concentrations and which majority of the inhabitants (more than 80%) express satisfaction". Good indoor air quality has been linked to an increase in productivity, concentration power, and performance of a person (Pei et al. 2015). Children are more susceptible to poor air quality than adults because they breathe higher volumes of air relative to their body weights, and their tissues and organs are actively growing (Schwartz, 2004). Furthermore, children have less resistance to chemicals and allergens or irritants. The National Academy of Science (2000) named IAQ contaminants such as tobacco smoke, dust mites, mold, and bacteria as the main reasons for asthma development, particularly in children.

School buildings are subject to various conditions that can affect indoor air quality (Kielb et al. 2015). Ung-Lanki, Lampi, and Pekkanen (2017) attributed poor indoor air quality to conditions such as insufficient ventilation, thermal conditions, chemical exposures, or problems with dampness and mold. Based on previous studies, the authors concluded that all of these reasons might worsen children's performance and health. Zhao et al. (2008) echoed that indoor air quality might be further exacerbated by pollutants such as molds, volatile organic compounds, particles, allergens, bacteria, and formaldehyde. Tighter, sealed buildings combined with the presence of indoor emission sources can worsen indoor air quality compared with the outdoors (Franklin 2007; Montgomery and Kalman, 1989), which can significantly influence the health, learning, and productivity of occupants.

The quality of indoor air and the concentration of air pollutants dramatically depends on the ventilation system and its condition. According to Madureira et al. (2009), indoor air pollutants, even at a low level, can lead to the development of respiratory symptoms. Turanjanin et al. (2014) reported that the learning ability of students improves with fresh air circulation in the classrooms. Smedje and Norbäck (2000) echoed these results, relating poor indoor air quality to the increased prevalence of allergies and asthma, especially in children and school-aged individuals. Annesi-Maesano et al. (2012) reported cases of asthma and rhinitis in children in French primary schools because of poor indoor air quality.

Teachers play a significant role in the education and future success of children, thus the need to consider teachers' health. A few studies concentrated on the impact of poor IAQ on teacher's health symptoms (Kielb et al., 2015; Schneider, 2003; Ebbehoj et al., 2005). For example, Kielb et al. (2015) found that many teachers reported that the school environment caused health problems.

Indoor air quality can be improved in two main ways: by increasing the ventilation rate of outdoor air and by minimizing or controlling the air pollutant load in the air (Al Horr et al., 2016). Carbon dioxide concentration is often used as a surrogate of ventilation quality assessment (Daisey et al., 2003). According to ASHRAE Standard 62-2007 Ventilation for Acceptable indoor air quality in an occupied classroom situation, the recommended level of ventilation corresponds to $CO_2$ levels of approximately 1000-1100 ppm (ASHRAE, 2007). Indoor $CO_2$ concentrations above approximately 1000 ppm are generally regarded as indicative of unacceptable ventilation rates (Daisey et al., 2003) and possibly containing higher levels of other pollutants, harming human health (Asif, Zeeshan, and Jahanzaib 2018).

Some studies measured carbon dioxide levels in school buildings. In general, these studies showed that a significant proportion of classrooms do not meet the ASHRAE Standard for minimum ventilation rate. Brennan (1991) reported that carbon dioxide concentrations in nine United States schools ranged from about 400 to 5000 ppm, with a mean of 1480 ppm. Approximately, 74% of them had $CO_2$ levels over 1000 ppm. Swedish schools were studied by Smedje et al. (1996). Although the mean $CO_2$ concentrations in 38 schools were 990 ppm, 41% had measurements above 1000 ppm and a maximum of 2800 ppm. Additionally, Hou, Liu, and Li (2015) indicated that classroom ventilation is often inadequate, and that “it is not unusual to find $CO_2$ above 3000 ppm in classrooms”.

Some studies on IAQ reported evaluated the relationships between high concentrations of $CO_2$ and some health-related issues. These issues include SBS symptoms, allergies, and asthma symptoms (Fisk and Rosenfeld, 1997). Willers et al. (1996) revealed that 11 Swedish schools with a higher prevalence of sick building syndrome symptoms had $CO_2$ concentrations from 875 ppm to 2150 ppm with a mean of 1100 pm. Myhrvold et al. (1996), in their study of five Norwegian schools, reported a statistically significant partial correlation (i.e., one-way Anova, $p<0.001$) between symptoms of headaches, dizziness, tiredness, unpleasant odour, and high $CO_2$ concentrations.

First Nations children are at an increased risk of poor air compared to other children in Canada. They face unique socio-economic, cultural, and environmental risks (Assembly of First Nations Environmental Stewardship Unit, 2008). First Nations children with hypersensitivity, allergies, and other health issues are especially vulnerable to the effects of unhealthy indoor environments (Assembly of First Nations Environmental Stewardship Unit 2008). Kovesi et al. (2007) reported that Inuit children have the highest reported rate of hospital admissions because of lower respiratory tract infections caused by the poor indoor air quality of their houses. They found a strong association between indoor $CO_2$ levels and the risk of lower respiratory tract infection among Inuit infants and young children. Kovesi (2012) attributed the high rates of respiratory diseases among Indigenous children to poverty, overcrowding, housing in need of significant repairs and better ventilation, and increased exposure to environmental tobacco smoke. Jenkins et al. (2003) echoed that inadequate housing, including overcrowding, smoking, and inappropriate ventilation systems, increases the risk for lower respiratory tract infections among Indigenous people.

IAQ in schools is of essential importance for Indigenous children, given the time they spend in schools and poor IAQ in their homes. While improving IAQ in homes is more intensive in both time and cost, enhancing IAQ in schools can be done rapidly and affect many children positively. Nevertheless, there is a considerable research gap in investigating the relationship between schools' IAQ and the health symptoms of Indigenous children. Thus, there is a great need for research that will focus on collecting data on the health and education outcomes of Indigenous children.

### *2.1.2 Thermal comfort*

Thermal comfort is "that condition of mind which expresses satisfaction with the thermal environment" (ASHRAE, 2004). The skin perceives thermal comfort parameters, including air temperature and relative humidity (RH), so when people are thermally comfortable, they feel neither warm nor cold but neutral (Frontczak and Wargocki 2011). Comfort is only possible when body temperature is within acceptable limits when skin moisture is low, and when the physiological effort of thermal regulation is reduced (Lin and Deng 2008). Satisfaction with the thermal environment is a complex subjective response to several interacting and less tangible variables (Ogbonna and Harris 2008). Thermal comfort is dependent on some environmental (e.g., air temperature, radiant temperature, relative humidity, and air velocity) and personal factors (e.g., metabolic rate and clothing insulation) (Ravindu et al. 2015). If the thermal environment is not comfortable, occupants sometimes also adapt by regulating the indoor environment using behavioral changes such as the altering of clothing, the relaxation of expectations, and the opening of windows (Frontczak and Wargocki 2011; Lin and Deng 2008).

Thermal comfort is a subjective parameter as the perception of thermal comfort depends on the person and his physical state. It is very challenging to provide thermal comfort that satisfies everyone because people’s thermal sensations are different, even in the same environment (Djongyang et al. 2010). For example, some studies reported that the gender difference related to preferred temperature and thermal comfort between males and females is relatively small (Parsons 2002; Fanger 1970). These findings are generally based on thermal comfort responses in questionnaires. Nevertheless, a few studies (e.g., Cena and Dear 2001; Parsons 2002) argued that females express significantly more thermal dissatisfaction than males. Females are less satisfied with room temperature, prefer higher temperature, and feel both uncomfortably cold and uncomfortably hot more often than males (Karjalainen 2007). Additionally, children are usually more sensitive to changes in temperature than adults (Teli et al. 2014) due to metabolic rate, clothing, and the limited adaptive behavior of children, thus the need to comply with existing thermal comfort standards in school premises. Indoor comfort in classrooms should follow standards, such as ISO 7730, EN15251, and ASHRAE Standard 55 (Mishra et al. 2017).

Comfort in the thermal environment has been viewed as a problem of heat balance (Fanger, 1970). Previous research showed that overheating in schools is a major problem (Montazami and Nicol 2013). Teli et al. (2014) attributed this to school buildings not being design to their main occupant’s thermal needs. Thus, maintaining adequate thermal comfort is an important issue.

Thermal comfort, together with indoor air quality, has a significant influence on productivity, concentration, performance, and health of school occupants. Some studies showed a relationship between the work performance and thermal comfort of workplace occupants ((Roelofsen 2016; Al horr et al. 2016; Lan et al. 2011)). On the one hand, workers' productivity increased when an environment moved to a preferred thermal state (Al horr et al. 2016). On the other hand, workers' dissatisfaction with thermal comfort may cause productivity loss (Roelofsen 2016; Wong and Khoo, 2003; Seppanen et al. 2003).

Over the past several decades, there have been many efforts to examine the relationship between air temperature and occupant performance (Jiang et al. 2018). Temperature change within the 18°C - 30°C range can influence the performance of office occupants in tasks like typewriting, learning performance, and reading (Al horr et al. 2016). Seppanen et al. (2006) reported a decrease in occupant performance by 2% per 1°C increase in temperatures in the range of 25°C - 30°C. Cui et al. (2013) found that learning is affected by a room's temperature, while 'warm' environmental discomfort is more harmful to performance than 'cold' discomfort. Furthermore, the authors suggested that a slightly cold to neutral indoor climate would not significantly reduce the learning performance. Al horr et al. (2016) reported that despite ambient temperature playing a significant role in defining occupants' thermal comfort, personal control over that comfort is associated with higher thermal comfort satisfaction due to individual differences in comfort expectations (Moezzi 2009).

Previous research studies have focused mainly on adult perception and productivity in indoor environments (e.g., offices), with some data devoted to the thermal comfort perception and learning performance of children. Allab et al. (2016) reported high levels of dissatisfaction among students regarding thermal comfort in classrooms, including classrooms in developed countries. Some researchers found that the thermal comfort temperature of children differs from those of adults (Teli et al., 2014; Trebilcock et al. 2017). Wargocky and Wyon (2007) suggested that increased temperature harms pupils' performance. Jiang et al. (2018) agreed with the previous findings, adding that thermal discomfort caused by high or low temperatures negatively affects learning.

Another vital parameter that defines thermal comfort is the level of humidity in the air. BSRIA Applications Guide AG10/94.1 "Efficient Humidification in Buildings" concluded that RH is an essential variable for the thermal comfort of humans. ASHRAE recommends that indoor RH should be between 30-60 % (Standard 62-1999), as it allows them to function optimally (ASHRAE, 2001). The EPA recommends keeping the same indoor relative humidity level to reduce mold growth. Most health effects increase in severity with RH levels above 60% or below 40% (Arundel et al., 1986).

Although it is highly beneficial to control humidity at the school facilities, unfortunately, HVAC systems often cannot effectively manage space humidity (Fischer and Bayer 2001). RH levels below 30% adversely affect occupants' health by causing sick building syndrome (SBS). If the air is too dry, respiratory problems coupled with skin and eye irritation can occur. For example, Green (1975) combined data for 11 years from 12 Saskatoon schools and found a statistically significant linear correlation between relative humidity and absenteeism (cited Arundel et al. 1986). Absenteeism dropped by 20% when the average relative humidity increased from 22% to 35%. School occupants may suffer from extremely high and extremely low humidity, depending on the time of year, and both have been linked to adverse health effects (Angelon-Gaetz et al. 2015). Low RH may cause drying and irritation of the skin and mucous membranes, increasing viral infection (Sato, Fukayo, and Yano 2003; Wolkoff 2018); Luksco et al. 2016). RH levels lower than 50 % will increase the influenza virus spread (Hemmers et al., 1960). Excessive dampness has been associated with asthma exacerbation, coughing, wheezing, bronchitis, and upper respiratory infections (Fisk, Eliseeva, and Mendell 2010).

### *2.1.3 Acoustic comfort*

Navai and Veitch (2003) defined acoustic comfort as "a state of contentment with acoustic conditions." The state of contentment with acoustics is achieved when occupants are satisfied with disturbance or noise levels (Jeon et al., 2010). Frontczak & Wargocki (2011) argued that the term acoustic comfort is not commonly used and reported that "providing a good acoustic environment is mainly associated with preventing the occurrence of discomfort (annoyance)." Not many studies have been conducted to assess acoustic conditions in school classrooms and their impact on students' performance (Ricciardi and Buratti 2018; Astolfi and Pellerey 2008; Connolly et al. 2015), and teachers' performance (Klatte and Hellbroock 2010; Puglisi et al. 2015). This gap in the literature could be due to the lack of standardized measurement tools for evaluating the uncontrolled communication typically experienced in a classroom (Kennedy et al. 2006).

The main parameters of acoustic comfort are background noise and reverberation time. Both parameters determine the quality of speech intelligibility. Pekkarinen and Viljanen

(1990) found that speech intelligibility decreases due to the smoothing effect of both parameters on the temporal envelopes of speech signals (cited Sala and Viljanen 1995).

Children are more susceptible to background sounds in speech perception and listening comprehension than adults (Klatte and Hellbroock 2010). According to Astolfi and Pellerey (2008), students reported that acoustic and visual qualities have the most influence on their school performance. They expressed the same dissatisfaction with acoustic, thermal, and indoor air quality. Furthermore, the authors found that one of the most adverse consequences of poor acoustics was decreased concentration. They also highlighted that poor acoustic conditions in classrooms negatively influenced the quality of speech communication, reducing the school performance of students and causing fatigue to teachers. Furthermore, Kennedy et al. (2006) reported that accessible communication between students in the classroom is as important to the students as communication with the instructor.

Still, classrooms are a noisy and reverberant environment for speech communication (Sala and Viljanen 1995), and the reasons for poor acoustics are different. Excessive noise reduces speech intelligibility. For example, in a school when the teacher stands close to their students (from 1m to 8m), “the acceptable speech transmission can occur only when there are low noise level and good acoustic conditions” (Sala and Viljanen 1995). Furthermore, background noise in the classroom consists of a complex soundscape with various characteristics (Pakulski et al., 2016). Excessive background noise can originate from outside the school building (e.g., transport or traffic noise) or from within it (e.g., HVAC system, plumbing system, noise from adjacent classroom and hallways, or noise from student activity).

Based on results obtained from acoustic measurements and interviews, Zannin and Marcon (2007) reported that teachers and pupils found the noise generated and the voice of the teacher in neighboring classrooms as the primary sources of annoyance inside the classroom. Astolfi, Bottalico, and Barbato (2012) found that one major noise issue was the students talking in the classroom, thus students' low acoustical satisfaction. Hodgson, Rempel, and Kennedy (1999) showed that generally, many classrooms had excessive reverberation and low speech levels, especially at the back of the rooms. Also, some classes had very noisy ventilation systems. Similarly, according to Zannin and Marcon (2007), the measured background noise in classrooms was much higher than the values recommended by both national and international standards.

Furthermore, Woolner et al. (2007) investigated the impact of noise on students' learning and teachers' performance in schools. They highlighted that "pausing by teachers during bursts of external noise produces an effective reduction in teaching time" (Weinstein, 1979). Studies also showed that noise is not only the most critical source of stress for teachers (Enmarker and Boman 2004) but also the main cause for their absenteeism (Clausen, Christensen, Lund, & Kristiansen, 2009; Kristiansen, 2010). This is because stressed teachers would hardly be able to interact patiently and friendly with children (Klatte and Hellbroock 2010).

Harris (1994) reported that the other key parameter: reverberation time, is dependent on 1) room volume, 2) sound frequency in the room and 3) the total sound absorption in the room (cited Zannin and Marcon 2007). Previous studies investigated the effects of acoustics on children's performance in reverberant and non-reverberant classrooms (Klatte and Hellbroock 2010). The results based on the questionnaire showed that children from the classroom with longer reverberation time complained about higher indoor noise. Furthermore, their motivation to study was less favorable than children from less reverberant classrooms. Moreover, speech intelligibility was more mediocre in reverberant classrooms. Similalry, Hodgson, and Nosal (2002) concluded that lower reverberation time contributed to better acoustical classroom conditions. However, they warned that very low reverberation times are not desirable due to the worsening of reflected sound energy for listeners and speakers. Early sound reflections improved speech intelligibility.

Previous research studies suggest that proper acoustics is essential for children's learning (Zannin and Marcon 2007; Dockrell and Schield 2004). Therefore, there's a need to investigate factors that can influence acoustics comfort for students and teachers. However, the vast majority of these studies are conducted outside Canada and among the non-indigenous population. No research appears to have focused on the acoustics of First Nation schools in Canada. Moreover, no provincial building standards regarding classroom acoustics currently exist across Canada. These standards should be developed to ensure a better acoustic environment in classrooms and an improved learning process for children and teachers.

### *2.1.4 Lighting comfort*

Lighting comfort is another essential aspect in assessing the influence of indoor environmental quality on building occupants. Lighting comfort is defined as “a subjective condition of visual well-being induced by the visual environment” (ECSB, 2011). Lighting conditions are characterized by parameters such as luminance distribution, illuminance and uniformity, glare, color characteristics of lighting, color rendering, flicker rate, and amount of daylight (Chung and Burnett 2000). Some studies (e.g., Li et al. 2006; Xue, Mak, and Cheung 2014) point to the fact that lighting comfort is influenced not only by the physical factors but also by psychological and adaptive elements. Lighting conditions have a direct influence on occupants’ well-being and indirectly affect their work performance (Aries, Veitch, and Newsham 2010).

Some researchers investigated whether building occupants prefer daylighting to artificial lighting. Cuttle (1983) reported that 86% of office workers prefer daylighting as a source of illumination as they believed that daylighting caused less stress and discomfort than electric lighting (cited Galasiu and Veitch 2006). For Xue et al. (2014) in both offices and homes, greater exposure to daylight improved people's psychological health and productivity. Access to daylighting affected occupant’s visual perception, mood, and satisfaction with visual comfort. Xue et al. (2014) found that visual comfort is based on behavior patterns and daylight conditions. This is because the degree of visual comfort is the most affected by daylight, and the use of artificial lighting has a strong relationship with satisfaction with visual comfort. In this case, using artificial light for many hours per day resulted in poor daylighting conditions and decreased visual comfort. Veitch and Gifford

(1996) confirmed these findings by conducting questionnaires with office workers and university students, who reported that daylighting was superior to other light sources.

Lighting comfort in classrooms is a crucial factor in the learning process. Many researchers examined the effects of lighting quality in an indoor space and its impact on work performance, comfort, and occupants' satisfaction (Chung & Burnett, 2000; Veitch and Newsham 1998). However, there is limited agreement on how lighting influences human performance, comfort, and health. Knez (1995) suggested that indoor lighting influenced mood and cognition and might thus impact performance. In contrast, Veitch (1997) argued that lighting does not affect performance. One of the points of disagreement on how lighting influences performance is that quality differs from quantity (Veitch and Newsham1998). Chung and Barnett (2000) found good lighting quality to be based on the ”appropriate” quantity of light. Winterbottom and Wilkins (2009) reported that adequate lighting is not possible due to the classrooms' design and infrastructure. Their study showed that mean illuminance was more than the recommended design level in 88% of classrooms. Intense lighting and excess glare can decrease visual comfort and cause headaches and impaired visual performance. At the same time, too dim lighting was significantly associated with having lighting-related symptoms such as headaches, fatigue, eye irritation, and the inability to concentrate (Lin et al. 2020).

De Giuli et al. (2012) highlighted the need to enhance visual comfort in school buildings as children spend about 30% of their time in schools. Schools may use daylighting or artificial lighting or a combination of both. Many researchers investigated the relationship between children’s learning and different types of lighting. Daylight can influence reading (Sufar, Talib, and Hambali 2012), task involvement, productivity, mood, and health (Korsavi et al. 2016). Schreiber (1996) found that students were more relaxed and actively engaged in-class activities where brightness was reduced. Lyons (2002) suggested that the full spectrum of fluorescent lighting benefits learning (cited Winterbottom and Wilkins 2009). Karpen (1993) offered to use a combination of full-spectrum fluorescent lamps with polarized diffusers to overcome some health symptoms like headaches, eyestrain, and fatigue caused by inadequate lighting and excessive glare (cited Woolner et al. 2007).

## 2.2 The approach methods

Building performance assessment is a necessary and crucial step to provide suitable indoor environmental quality. Many research studies focused on evaluating the health effects of students and on identifying IEQ-related problems in classrooms by combining several methods for data collection (Kim et al., 2005; Van Dijken, Van Bronswijk, and Sundell 2006; Bak-Biro et al., 2012; Dorizas et al., 2015). These data collection methods typically included: (1) building inspections, (2) questionnaire surveys, and (3) the measurements of vital IEQ physical parameters.

### *2.2.1 Subjective approach*

A questionnaire is a research instrument composed of a set of questions (i.e., items) intended to capture respondents' answers in a standardized manner (Bhattacherjee, 2012). A well-designed questionnaire can provide the researcher with the needed data to conduct a comprehensive analysis. In this regard, previous research studies have shown that questionnaires are a suitable, valid, and useful tool for assessing IEQ issues including investigating indoor air problems and for assessing the associations between the indoor environment and workers' health (Reijula and Sundman-Digert 2004; Järvi et al. 2018; Dykes and Baird 2013).

However, it is not easy to obtain accurate and complete information from a survey as "response quality" may not be adequate because people tend to be busy, reluctant to open up to strangers, or consider the questionnaire as a waste of time (Johnson and Christensen 2016). The authors thus suggested applying some essential guidelines to obtain high "response quality," such as:

1) Motivate respondents so that they can take part in the questionnaire enthusiastically (i.e. offering monetary/non-monetary incentives or by highlighting the importance of the study).
2) Pre-test questionnaire to know in advance what questions work and what don't.
3) The researcher should be organized, professional, and courteous.
4) The researcher should have reasonable expectations, as it is impossible to conduct a "perfect study."

One of the major concerns associated with the subjective approach is sample-population congruence, which refers to representing the overall population by the sample of subjects (Johnson and Christensen 2016). Poor IAQ causes absenteeism. The researcher hands out the survey, but people most susceptible to poor IAQ are absent that day. In this regard, Johnson and Christensen (2016) reported that bias in how well the sample represents the population could arise at the time of the initial selection of the sample or through incomplete responses of respondents who take part in the questionnaire. The questionnaire can include open-ended and closed-ended questions. The open-ended questions allow researchers to “collect qualitative data that may generate unexpected insights” (Bhattacherjee 2012).

Dykes and Baird (2013) summarized the use of statistical methods in the assessment of questionnaires. They reported that two main approaches to present the results of the survey, including the percentage of people satisfied or dissatisfied and measures of variability (e.g., mean scores, quartiles, and standard deviations through confidence limits). The authors introduced a COPE study that displayed results with the standard deviation, kurtosis, and skewness. Hence, the COPE study enabled an overall understanding of the score distribution. Additionally, to show the satisfaction or dissatisfaction of occupants, an *n*-point scale can be used to indicate satisfaction to display the percentage of complaints. Moreover, percentiles were the most common measure of relative standing in the questionnaire examples.

### 2.2.2 *Objective approach*

Heinzerling et al. (2013), discussed in detail objective measurement methods and tools. According to their study, these include using a range of tools (i.e., devices) to assess physical parameters of indoor environmental quality such as air temperature, RH, $CO_2$, and measurement procedures. Objective data methods involve the collection of actual data through physical measurements by sensors or other tools, meter readings, billing information, and the review of design documents ( Alborz and Berardi 2015). Choosing the right tool to conduct measurements can be quite challenging as it is related to issues of ease of use, accuracy, calibration, limitations, and cost. The measurement procedure defines the use of tools to collect data, including information such as instruction on the placement of these tools. The measured values are compared to reference values such as ASHRAE 55 (i.e., Thermal Environmental Conditions for Human Occupancy) to assess indoor environmental quality parameters. After the collection of the data, the objective approach includes checking the statistical validity of the data, the testing of the hypothesis and research questions using statistical analysis, and the interpretation of results.

### *2.2.3 Mixed approach*

Because occupants have different perceptions of IEQ even in the same indoor environment, it is necessary to complement an objective approach with a subjective approach (Berquist, Ouf, and O'Brien 2019). Thus, the mixed approach relies on a holistic research method that includes assessing quantitating and qualitative datasets. Both types of data have their strengths and limitations and provide different types of information. A convergent parallel mixed method is typically adopted when two databases are analyzed separately. Then datasets are merged using two approaches: side-by-side comparison and data transformation (Creswell 2014). The side-by-side comparison reports the quantitative statistical results and then discusses the qualitative findings that confirm or disconfirm the statistical results.

The data transformation includes the coding of qualitative data to form quantitative data to count.

There are some limitations to mixed methods. Usually, the set of qualitative data is smaller than the collection of quantitative data. For example, one approach assumes that individuals for the sample of qualitative participants also should be individuals in the quantitative sample. It means that an unequal sample size between qualitative and quantitative data may provide a less accurate picture when both sets of data “may yield incomparable and difficult to merge findings” (Creswell 2014). Berquist et al. (2019) argued that longitudinal measurements of IEQ parameters and perceived occupant comfort surveys should be conducted simultaneously to get more reliable results. The study presented a novel method that combined continuous IEQ measurements over an extended period. Using electronic survey devices provided hundreds of unique data points to assess occupant comfort and its relationship with IEQ simultaneously.

# 3 Methodology

This chapter describes the data gathering and analysis process used in this research study. The first section describes the school analyzed in this research. The second section presents the methods used to collect IEQ parameters and occupant health symptoms data in the school. These methods involved using objective and subjective approaches. The third section describes the methods used to analyze the collected data. Each of these sections is presented below.

## 3.1 School Characterization

The research method used a holistic and integrated approach focused on the improvement of building envelope and heating, ventilation, and air-conditioning system (HVAC). Thus, the assessment of indoor air quality (IAQ) in the schools was composed of four main parts: 1) school building inspection, 2) physical measurements, 3) subjective evaluations, and 4) data processing and recommendations. It is important to note that before the start of this research project, we obtained approval from the Education/Nursing Research Ethics Board (ENREB) to conduct the measurements in Sagkeeng First Nation school.

### *3.1.1 School Selection*

The Sagkeeng junior high school was selected for a number of reasons. First, the school had high energy bills and occupants' complaints about indoor environmental quality. Second, the school was easy to access due to its close location to the University of Manitoba. Participation of the Sagkeeng elementary school was voluntary and was acquired through the Chief and Council and of the school principal at the time: Mr. Garry Swampy.

### 3.1.2 *School characteristics*

The Sagkeeng junior high school is located on the territory of Sagkeeng First Nation. The Sagkeeng First Nation is an Anishinabe First Nation who inhabit land on the east of Lake Winnipeg, 120 kilometers north of Winnipeg (Manitoba). Figure 1 shows the views of the school from the Provincial Trunk Highway 11 along with the top-down view of the school and its surrounding.

Figure 1 Sagkeeng Junior High School (Google maps, 2020)

The Sagkeeng junior high school is a one-floor building without a basement constructed in 2003. The building area is 4,155 m$^2$. The orientation of the building is 28° to the west of true north. As presented in Figure 2, the school complex is comprised of a circular central block (rotunda) that connects the west and east wings with the common entrance area. The roof form and centralized layout of the building reflect an Indigenous architectural precedent. The building structure is made of reinforced steel; parts of the construction were done in exposed brickwork (see Figure 3). The school windows are wooden, framed, and double-glazed.

Table 1 Sagkeeng junior high school constructions and materials

| Construction type | Constructions and materials |
|---|---|
| Exterior wall | - 100mm x 200mm x 400mm full split-faced concrete block and 100x100x400 giant brick<br>- masonry ties<br>- 25mm air gap<br>- 75mm polyisocyanurate insulation<br>- Air/vapor barrier<br>-13mm O.S.B. sheathing<br>-92mm steel studs@400mm<br>-16mm F.R.G. to 2440 AFF<br>-16mm GWB from 2440 to U/S roof deck |
| Exterior wall | - 100mm x 200mm x 400mm full split-faced concrete block and 100x100x400 giant brick<br>- masonry ties<br>- 25mm air gap<br>- 75mm polyisocyanurate insulation<br>- Air/vapor barrier<br>-190mm concrete block |
| Exterior wall | - stucco<br>- sheathing paper<br>- metal channels horizontal<br>- 75mm polyisocyanurate insulation<br>- Air/vapor barrier<br>-92mm steel studs@400mm/152mm steel studs around rotunda only<br>-16mm F.R.G. to 2440 A.F.F.<br>-16mm GBW from 2440 to U/S roof deck |
| Exterior wall | - stucco<br>- sheathing paper<br>- 13mm O.S.B. sheathing<br>- 38x140 wood studs<br>-16mm F.R.G. |
| Interior wall | - 16mm F.R.G. on both sides to 2400 A.F.F.<br>- 16mm GWB from 2400 to U/S deck, both sides<br>- 152mm steel studs@400mm O/C<br>Use 92mm steel studs@classroom to classroom demising walls<br>- 90mm fiberglass insulation |

| | |
|---|---|
| Interior wall | - 100mm concrete block to 100mm above a ceiling |
| Interior wall | - 16mm GWB-office side<br>- 152mm steel studs@400mm O.C.<br>- 16mm F.R.G.-vestibule/corridor side |
| Interior wall | - 16mm GWB or F.R.G.<br>- 64mm steel studs@400mm O.C. |
| Interior wall | - 16mm Type “X” F.R.G both sides<br>- 92mm steel studs@400mm O.C.<br>- 90mm fiberglass insulation |
| Interior wall (Elders area) | - 16mm GWB<br>- 92mm steel studs@400mm O.C.<br>- 13mm plywood<br>- 16mm GWB |
| Interior wall (Rotunda) | - 100x200x400 colored concrete block<br>-100x200x400 full-face split concrete block<br>- 152mm steel studs@400mm O.C.<br>- 92mm steel studs@400mm O.C.<br>- 16mm GWB |
| Interior wall (Elders area) | - fiberglass panels<br>- 38x89 wood studs@300mm O.C. |
| Roof | - 22 GA, metal standing seam roof panel<br>- thermal spacer<br>- sheathing paper<br>- 150mm DP metal sub-girts, GA to suit snow loads<br>- 2 layers R.S.I. 3.5 extruded polystyrene insulation, max depth 150mm<br>- air/vapor barrier<br>- 13mm exterior grade GWB mechanically fastened to roof deck<br>- metal roof deck<br>-O.W.S.J.(except rotunda roof)<br>-wood trusses (only for rotunda roof) |
| Roof (change building) | - 22 GA, metal standing seam roof panel<br>- building paper<br>-pre-fab wood trusses<br>-RSI 8.4 batt insulation<br>- 6 mil poly v.b.<br>-16mm F.R.G. |
| Floor Mezzanine level | - 87mm reinforced concrete topping<br>-38mm metal decking<br>-O.W.S.J. or channels |
| Floor | - 125mm reinforced concrete structural slab<br>-6mm poly<br>- 6mm hardboard<br>-150mm void form<br>-granular base |

| | |
|---|---|
| Floor Mezzanine level | - 38 mm deep steel bar grating<br>- channels/beam supports |

The electric lighting installations in the school were technically obsolete (i.e. outdated) thus saved off the light but caused high electricity consumption. The hydronic radiation floor system served by two electric boilers delivers heat to the classrooms, whereas the air handling units provide occupants with fresh air. The school served approximately 250 students in both elementary and secondary grade levels. The school has 23 classrooms, two nurseries, and two kindergartens. Furthermore, Figure 4 shows one of the typical elementary classrooms in the school. Classes went from 8:30 to 15:45 on weekdays with 40-minute classes, a 15 minutes break, and a 1-hour lunch break.

Figure 2 Sagkeeng Junior High School entrance and layout

Figure 3 Sagkeeng Junior High School South-West wall

Figure 4 Typical classroom in the school

## 3.2 Data Collection

### *3.2.1 School building inspection*

Inspection of the school building included visual observation of indoor and outdoor conditions as well as the collection of building operations, and maintenance information. Visual inspection using walk-through surveys helped us identify classrooms to monitor, detect any visible mold and moisture-damage, and verify building construction and ventilation system characteristics. Furthermore, visual observation helped detect external and internal factors that influence the IEQ of the school. In this regard, external factors included the school's geographical location, surroundings, disposition, and exterior envelope conditions. Internal factors of the school building included the layout and position of the classrooms and other premises, damages to the building envelope such as cracks, leaks, and mold, mechanical and electrical systems, including heating, ventilation, and air-conditioning (HVAC), hot water, and lighting.

Furthermore, meetings with the building operation and maintenance personnel enabled the gathering of information related to building system operations, maintenance practices, and any problems they have with the building systems. The research included collecting as-built drawings of the school. Visual inspection coupled with information provided by the school principal and building manager enabled the selection of the classrooms where IEQ physical parameters were monitored.

### *3.2.2 Weather parameters*

The Sagkeeng junior high school is located in climate zone 7 A, as defined by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE 90.1, 2016). Climate zone divisions are determined by degree days, including heating degree days (HDD) and cooling degree days (CDD). Thus, HDD is used for the calculation of a building's heating energy requirements, and they are a measure of how much in degrees, and for how long in days, the outside air temperature was lower than a specific "base temperature" (usually 18 ºC). On the other hand, CDD is used for calculations of a building's cooling requirements, and they are a measure of how much in degrees and for how long in days, outside air temperature, was higher than a specific base temperature (usually 18 ºC).

Climate zone 7 A is characterized as a cold and moist climate with between 5000 to 5999 HDD. Victoria Beach is the closest weather station to the Sagkeeng school. The CWEC.epw weather file contains 12 typical meteorological months composed of hourly weather data records that are selected from a 30-year database of Canadian Weather Energy and Engineering Datasets to predict the average heating and cool loads in buildings (NRCan 2014). Furthermore, Figure 5 shows CWEC's monthly maximum, minimum, and average outdoor air dry-bulb temperatures along with relative humidity (RH) and solar radiation for the Victoria Beach area. As illustrated, the area is under high seasonal outdoor air temperature fluctuations and elevated average RH throughout the year. Thus, the school experiences temperature and RH variations ranging from +32 ºC in summer to -39 ºC in winter, and from 66% in April to 84% in November, respectively. Moreover, because of the cold and long winter season (e.g., five months with below 0 ºC average outdoor air temperatures) and school year period from September to June, the school has significantly higher heating than cooling needs.

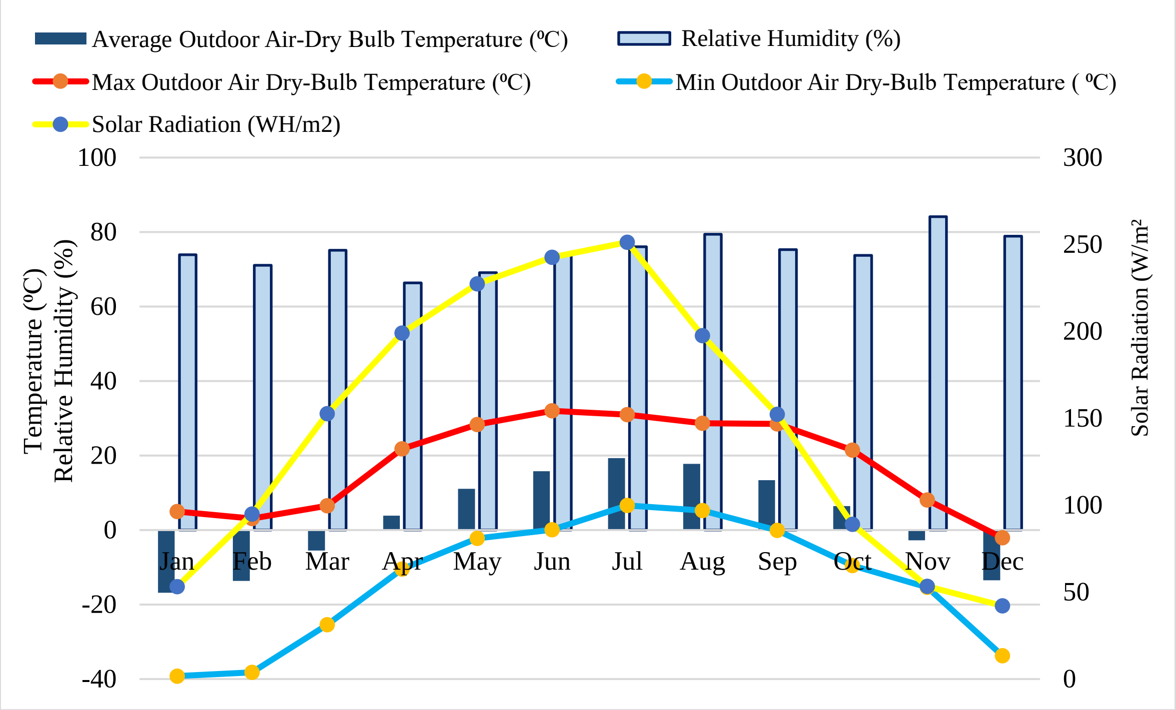

Figure 5 Monthly outdoor air dry-bulb temperatures, RH, and solar radiation

### 3.2.3 *The objective approach*

Physical measurements were conducted through continuous monitoring of three physical parameters that impact the building's indoor environmental quality and energy consumption from November 17th, 2017, until December 5th, 2018: indoor air temperature, relative humidity (RH), and carbon dioxide ($CO_2$) concentration. The first round of data collection included data from 11/17/17 to 03/26/18 while the second round - from 03/26/18 to 12/15/18. The first round covered 11 classrooms, whereas the second covered only 10 classrooms (due to a missing device).

The HOBO MX1102 loggers presented in Figure 6 were used to measure the three physical parameters at 15-minute intervals. This measurement frequency required downloading the data every three to four months and the replacement of the battery every six months. Before the deployment, the loggers were calibrated and synchronized according to the manufacturer's recommendations to ensure accurate monitoring (Hobo Loggers and Sensors, 2020). The accuracy of the temperature sensor is ±0.21°C from 0° to 50°C. The accuracy of the RH sensor is ±2% from 20% to 80% and ±6% below 20% and above 80%. The accuracy of $CO_2$ is ± 50 ppm from 0 to 5,000 ppm.

Figure 6 HOBO MX1102 Logger used for the long-term measurements at the school

Initially, in total, 12 classrooms, six in the East, and six in the West wing were selected for monitoring based on the following limitations and criteria. First, the total number of loggers was defined based on the available budget. Second, the same quantity of classes in both wings ensured their equal representation. Classrooms were further selected based on their position and orientation to capture the conditions throughout the school. Thus, chosen rooms consisted of those at the end, in the middle, and towards the center of the building. In particular, it was essential to capture rooms with the two external walls at the end of each wing to see whether they have lower air temperatures, due to the higher heat losses.

Likewise, it was critical to include classes towards the center of the building to investigate whether they have, on average higher temperatures, due to their proximity to the kitchen area. The loggers were also placed in the south and north-facing rooms to capture the impact of the building orientation. At the end of the monitoring period, 10 out of 12 data loggers were returned from four classrooms (i.e., 120, 123, 126, and 129) in the West wing and six classrooms (i.e., 158, 163, 164, 166, 171, and 178) in the East wing. One data logger fell off the wall and broke, whereas the other went missing. Figure 7 shows selected classrooms, with red circles denoting returned loggers, and black-dotted squares lost ones.

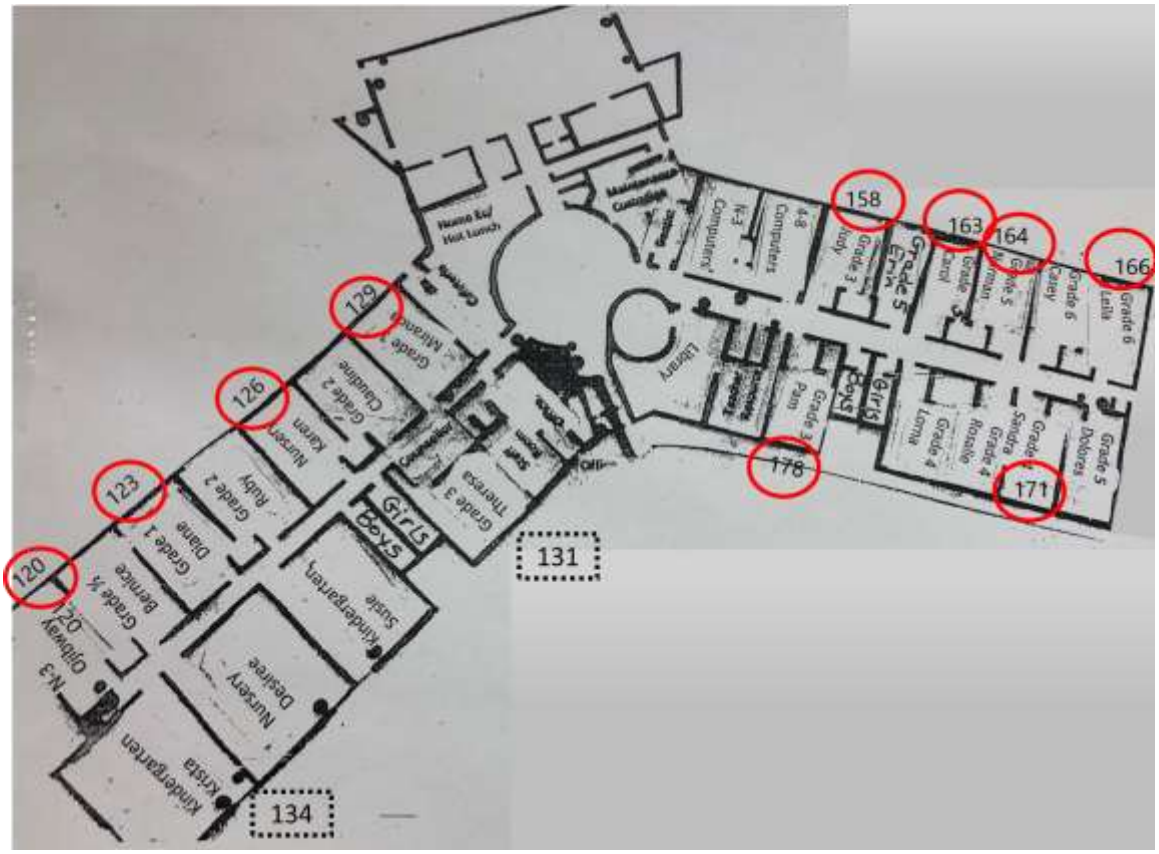

Figure 7 Location of the monitored classrooms

The standard EN ISO 7726:2001 provides methods for measuring the physical parameters of the thermal environments. According to this standard, the exact location of thermal measurements should represent the actual worker’s location in the space, that is their work-stations. Therefore, the instruments should be placed at 1.7 m height when standing and at 1.1 m height when sitting. The data loggers were placed in the classrooms by following the EN ISO 7726:2001 recommendations, with some modifications to make it practical for the classes with young children. Thus, data loggers were placed at 1.5 m to 1.7 m of height away from the children's reach, direct solar radiation, and external walls. It should also be noted that peoples’ evaluation of the thermal comfort in buildings is associated with both indoor air temperature and the temperature of surrounding walls and surfaces (EN 15251, 2007). Figure 8 depicts the placement of the data loggers in some of the classrooms.

Figure 8  Examples of data loggers in classrooms

The assessment of the hygrothermal performance of the building's envelope using an infrared camera was conducted in the winter season of 2017-2018. Infrared thermography of the building envelope is a non-destructive test that can identify heat losses, air leaks, insulation defects, and moisture accumulation (Cerdeira et al., 2011). Therefore, thermal imaging helped identify opportunities for the upgrade of the building envelope that could have a positive impact on both building energy performance and indoor environmental quality. The thermal heat camera used in this research was a Flir E60bx camera with an accuracy of ±2 ˚C or ±2%. The camera is shown in Figure 9.

Figure 9  Flir E60bx camera

### 3.2.4  *The subjective approach*

This research used a group –administrated questionnaire to investigate respondents' perceptions of comfort and health. According to Bhattacherjee (2012), questionnaires provide a high response rate. In this regard, on November 17th, 2017, from 9:30 am to 10:30 am, we brought together all respondents at the same time and asked each to complete it independently. The questionnaire survey was anonymous and voluntary. Participants were informed they were free not to answer questions they perceived uncomfortable. Due to the complexity of the developed questionnaire and challenges with surveying children, only teachers and staff (i.e., 56 people) completed the questionnaire. Furthermore, the sample should match the population thus reflecting key demographic variables such as age, gender, and ethnicity (Johnson and Christensen 2016). Therefore, the questionnaire results are limited to adults and are not relevant to children.

School teachers had many complaints related to air quality and adverse health symptoms before this research took place. Therefore, they were motivated to provide accurate and thoughtful information related to IEQ issues of the school and their health issues. Furthermore, to obtain accurate and complete information from the respondents, we followed the guidelines provided by Johnson and Christensen (2016). In this regard, the questionnaire was designed to collect all the necessary information promptly and easily to minimize fatigue or boredom when filling it out. Thus, the questions were mostly close-ended (i.e., choosing the answer from the list), and a few were open-ended to obtain additional IEQ related clarifications. In general, it took each respondent 30 min to an hour to fill out the paper-based questionnaire. Furthermore, before the distribution of the questionnaire, the research team clarified the aim and the objectives of the survey. If respondents did not understand specific questions, they asked for clarification from the research team.

The questionnaire applied in the SINFONIA project (Kephalopoulos et al. 2014) was used as a starting point for the development of our survey. The developed questionnaire contained seven sections: 1) Demography, 2) School's condition, 3) Indoor air quality, 4) Thermal comfort, 5) Health Syndromes, 6) Lighting, 7) Acoustics. Appendix A shows the questionnaire used in this study.

The "Demography" section included questions about teacher demographics (i.e., age range, gender); employment characteristics (i.e., number of years teaching, number of hours spent in the classroom, grades taught). The "School's condition" section contained general questions related to teachers' satisfaction or dissatisfaction with school conditions such as overall cleanliness, overall maintenance, and ventilation system. The votes for satisfaction with cleanliness, maintenance, and ventilation system were based on a seven-point Likert scale, with 1 indicating very dissatisfied, 4 neutral, and 7 very satisfied. The "indoor air quality (IAQ)" section investigated IAQ in school premises. The votes for perceived air quality (i.e., stuffed air, dusty or bad) were based on a seven-point Likert scale, with 1 indicating not a problem at all, 4 neutral, and 7 a significant problem. Teachers were also asked about aspects of the school environment potentially related to poor IAQ, including the presence of mold, moisture problems, and recognition of sources of poor IAQ in the classroom (i.e., washroom smells, dust, moldy or cellar-like odour, furniture, chemical substances, smoking, and cooking).

The fourth section related to thermal comfort. Teachers were asked to share their perceptions of indoor temperature, air humidity, and air movement. The votes for perceived indoor air temperature were based on a seven-point Likert scale, with 1 indicating cold, 4 -

neutral, and 7- hot conditions. The votes for perceived indoor RH, air movement, surface temperature were based on a seven-point Likert scale, with 1 indicating very dissatisfied, 4 neutral, and 7 very satisfied.

The fifth section covered questions related to the presence of any health syndromes experienced during the working day. The health problem questions were focused on symptoms of the mucous membrane and the upper respiratory tract, such as nose congestion, mouth, throat, difficulty breathing and eye irritation symptoms, and neurobehavioral symptoms including headache, attention, dizziness, tiredness. Teachers were asked if they currently had asthma and about non-school based environmental factors potentially related to health outcomes (e.g., smoking). Next, teachers were asked about their satisfaction or dissatisfaction with lighting quality. The final section covered questions related to noise levels and acoustics quality inside the building.

## 3.3 Data Analysis

Long-term measurements of indoor environmental parameters such as temperature, relative humidity, and $CO_2$ were analyzed using charts, descriptive statistics, and box plots. Box plots showed the magnitude and variability of environmental parameters.

For the analysis of questionnaire data, MS Excel has been used while the statistical analysis was conducted using Statistical Package for Social Science 25 (SPSS 25). If the respondent gave multiple responses to the question that did not have the option of multiple responses, these responses were not included in the analysis. Variables from the questionnaires were assessed for normality using the Shapiro-Wilk test to ensure that non-parametric tests could be used on them.  For the most part, the data failed the normality test so non-parametric tests were used. In analyzing the statistics of the responses, Spearman rank correlation coefficient, The Mann-Whitney U test, and linear regression were applied to identify particular aspects of responses and relationships between physical measurements and questionnaire responses. Statistical significance was defined as $p < 0.05$.

As the questionnaire data were nonnormal, the textbooks most frequently suggested using the Spearman rank correlation coefficient test (Bishara and Hittner 2012). Moreover, the previous research papers related to the evaluation of indoor environmental quality showed that the most popular measure of the correlation between occupant’s satisfaction with indoor environmental quality parameters was the Spearman rank correlation coefficient test (Radwan 2014; Sadick 2018; Akom 2019).

The Spearman rank correlation coefficient test was carried out using two-tailed significance testing to assess the strength and statistical significance of relationships between:

- Teacher’s satisfaction with various indoor environmental quality aspects;
- Teacher’s self-reported health symptoms and environmental exposure to the school;
- Teacher’s self-reported health symptoms and teacher's performance.

Following examples in the literature (Bae, Martin, and Asoio 2020; Zuo and Malonbeach 2017), the Mann-Whitney U test was used to assess the statistical significance of the differences between two groups: males and females. For example, Bae et al. (2020) run the

Mann-Whitney U test to analyze how male and female student's satisfaction levels differed across IEQ factors. This test is easy to conduct, simple to interpret and no assumptions required for normality or outliers (Ouf 2017). The statistical significance of the differences between males and females were examined with respect to:

- Teacher's satisfaction with every indoor environmental quality aspect (i.e., indoor air quality, thermal comfort, lighting, and acoustics).

Univariate linear regression was performed to predict the effects of T, RH, and $CO_2$ on the likelihood that participants have SBS. Univariate linear regression focuses on determining relationships between one independent (explanatory) variable and one dependent variable. It is more appropriate to use linear regression when the relationships between the two variables are linear (Ouf 2017).

Table 2 summarizes the specific research questions answered through the research and the statistical tests used to answer these questions.

Table 2 Research questions and statistical analysis used for the answers

| **Research Questions** | **Statistical Tests** |
|---|---|
| How do the schools' physical measurements such as temperature, relative humidity, and carbon dioxide compare with recommended values? | Descriptive statistics (Maximum, Minimum, Standard deviation, and Mean values) |
| Are there statistically significant differences in satisfaction with IAQ, thermal comfort, lighting quality, and acoustics quality across genders? | Mann-Whitney U test |
| Are there statistically significant correlations between satisfaction with IAQ and classroom characteristics? | Spearman's Rho correlation test |
| | Spearman's Rho |

| | |
|---|---|
| Are there statistically significant correlations between satisfaction with IAQ, thermal comfort, acoustic quality, and teacher's performance | correlation test |
| Are there statistically significant correlations between satisfaction with lighting quality, glare and reflection, and use of daylighting | Spearman's Rho correlation test |
| Are there statistically significant correlations between satisfaction with lighting quality, glare and reflection, and the need for lighting control | Spearman's Rho correlation test |
| Are there statistically significant correlations between satisfaction with lighting quality, glare and reflection, and teacher's performance | Spearman's Rho correlation test |
| Are there statistically significant correlations between satisfaction with acoustics quality, quality of speech communication, and different sources of noise | Spearman's Rho correlation test |
| Are there statistically significant correlations between satisfaction with acoustics quality, quality of speech communication, and teacher's performance | Spearman's Rho correlation test |
| Are there statistically significant correlations between self-reported health symptoms and teachers' performance | Spearman's Rho correlation test |
| Are there statistically significant correlations between self-reported health symptoms and environmental parameters in the school | Spearman's Rho correlation test |
| Are there statistically significant associations between the physical measurements data (temperature, relative humidity, and CO2) and teachers' self-reported health symptoms | Linear Regression |

# 4 Results and Discussion

This chapter presents the results of the data analysis. The first section focuses on the results of the physical measurements of temperature, relative humidity, and carbon dioxide ($CO_2$). The chapter further discusses the main findings of the physical measurements using descriptive statistics and Spearman’s rank correlation coefficient test. The second section focuses on the findings of the questionnaire, including the results of the correlation regarding the occupants' perception of IEQ obtained through the Spearman’s rank correlation coefficient test and the Mann-Whitney U test. The third section describes the associations between indoor air quality, thermal comfort, and health symptoms among teachers based on the results obtained by using the Spearman rank correlation test and linear regression results. The final section presents the results of thermal imaging.

## 4.1 Objective measurements

### *4.1.1 Temperature*

Figure 10 depicts the mean monthly indoor air temperature in the classrooms of the school for the observed period and recommended values by ASHRAE standard 55 (20°C -24.5°C). The values of indoor air temperature are shown for occupied hours from 8:30 am to 4:00 pm on weekdays: Monday to Friday.

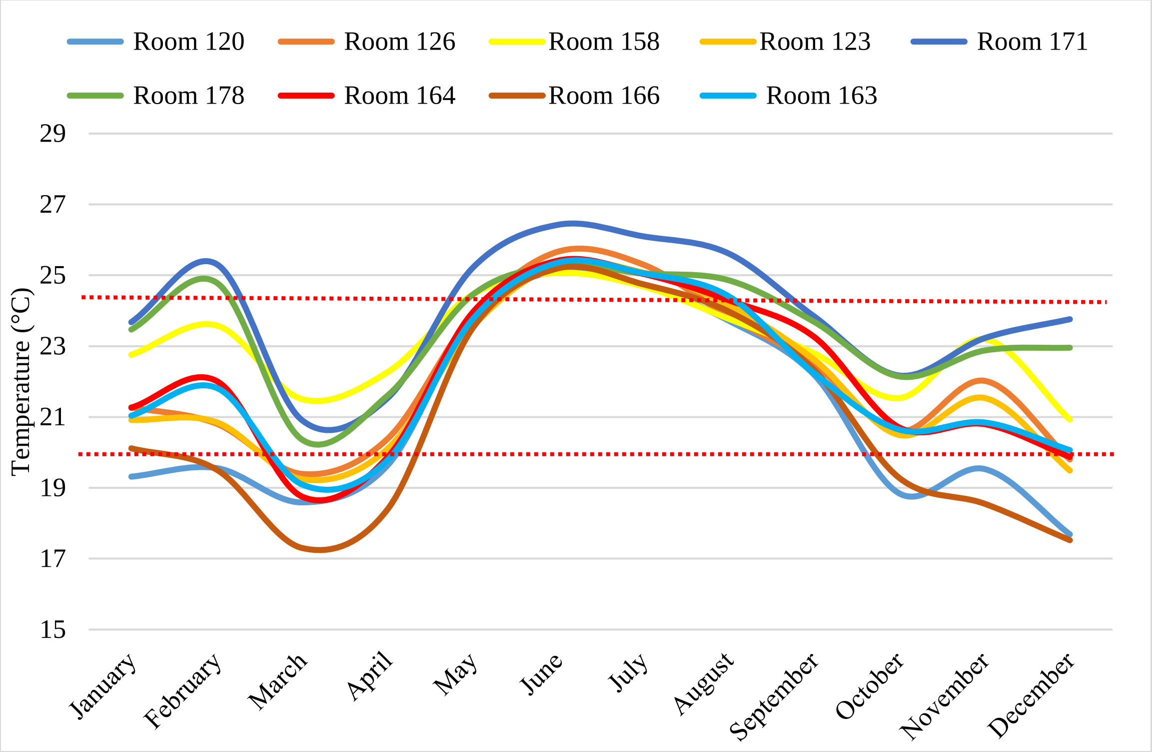

Figure 10 The mean monthly indoor air temperature. Red lines represent the lower (20°C) and higher (24.5°C) reference levels.

Table 3 summarizes the measured temperature values for 9 classrooms. Mean, maximum and minimum values of indoor air temperature were calculated during the workday from 8:30 am – 4:00 pm.

Table 3 Descriptive statistics of indoor air temperature

| | Mean (ºC) | | | | SD (ºC) | | | |
|---|---|---|---|---|---|---|---|---|
| | *Fall* | *Winter* | *Spring* | *Summer* | *Fall* | *Winter* | *Spring* | *Summer* |
| *120* | 20.1 | 18.9 | 20.7 | 24.5 | 2.1 | 2.0 | 3.3 | 1.5 |
| *123* | 21.5 | 20.4 | 21.0 | 24.8 | 1.6 | 1.8 | 2.7 | 1.4 |
| *126* | 21.7 | 20.6 | 21.3 | 24.9 | 1.6 | 1.9 | 2.6 | 1.5 |
| *171* | 23.0 | 24.2 | 22.6 | 26.0 | 2.5 | 4.5 | 3.2 | 1.5 |
| *178* | 22.9 | 23.7 | 22.2 | 25.1 | 2.1 | 4.0 | 2.9 | 1.0 |
| *158* | 22.5 | 22.4 | 22.8 | 24.5 | 1.3 | 2.0 | 2.1 | 1.2 |
| *163* | 21.2 | 21.0 | 20.9 | 24.9 | 1.8 | 2.1 | 2.8 | 1.2 |
| *164* | 21.5 | 21.0 | 20.9 | 24.9 | 1.9 | 2.3 | 3.0 | 1.2 |
| *166* | 20.0 | 19.1 | 19.8 | 24.6 | 2.5 | 3.3 | 3.6 | 1.6 |
| | Min (ºC) | | | | Max (ºC) | | | |
| *120* | 13.7 | 13.0 | 9.9 | 20.9 | 25.0 | 22.5 | 30.7 | 27.8 |
| *123* | 16.2 | 15.0 | 12.8 | 19.6 | 25.1 | 24.7 | 27.6 | 28.5 |
| *126* | 16.6 | 15.5 | 14.3 | 22.0 | 26.0 | 25.6 | 28.0 | 28.5 |
| *171* | 16.1 | 14.7 | 13.4 | 21.5 | 29.9 | 35.1 | 29.9 | 30.5 |
| *178* | 15.6 | 13.7 | 14.0 | 22.0 | 28.9 | 32.9 | 28.3 | 27.4 |
| *158* | 18.4 | 14.9 | 17.1 | 21.4 | 25.8 | 26.3 | 27.9 | 27.1 |
| *163* | 15.4 | 13.8 | 14.8 | 22.0 | 26.0 | 26.7 | 28.0 | 27.3 |
| *164* | 15.4 | 13.7 | 13.2 | 21.9 | 26.4 | 29.5 | 28.2 | 27.3 |
| *166* | 12.2 | 10.7 | 9.6 | 20.5 | 26.6 | 34.0 | 27.9 | 27.6 |

Multiple factors contributed to the variation in indoor air temperature values. These include factors such as outdoor conditions, the orientation of rooms, and heating or cooling settings. The results showed that an enormous variability in indoor air temperatures of all classrooms was observed during the year. Air temperatures as high as 35.1°C (winter season) and as low as 9.6°C (spring season) were recorded in the school during working hours. Fall and spring are mild seasons, and it is expected to have indoor air temperature in the comfort range. Nevertheless, the minimum and maximum values of indoor air temperature in all classrooms exceeded the maximum and minimum recommended values in the fall and spring seasons. However, mean values in the fall and spring seasons were within the comfort range of 20°C-24.5°C except classroom 166. The mean values were outside that range in the summer months (i.e., June, July, and August). The school was unoccupied in July and August.

During the monitoring, it came to light that indoor air temperature was unacceptable in classrooms 171 and 178 across the seasons due to overheating. Moreover, the highest variance in the temperature range during the winter was observed in the same classrooms: 171 and 178. Figures 11 presents the indoor air temperature in classroom 171.

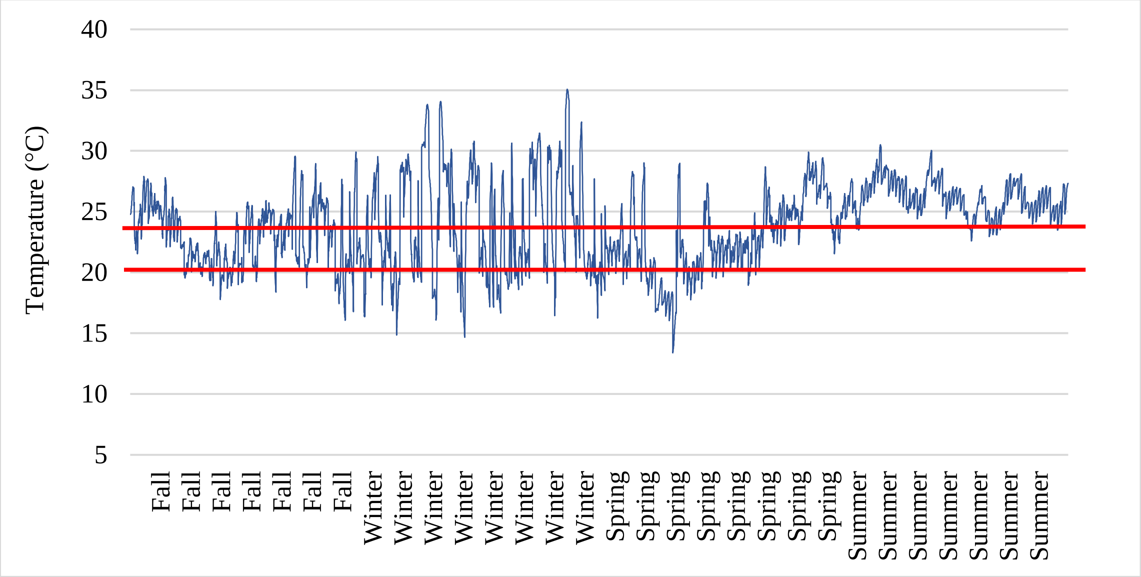

Figure 11 Chart of 15-minute interval indoor air temperature in classroom 171.

Figure 12 depicts box plots of the temperature for each season measured during the survey in classroom 171. The blue lines and crosses inside each box represent the median ($50^{th}$ percentile) and mean values, respectively. The boxes' lower and upper limits are the 25th and the $75^{th}$ percentiles, respectively. The whiskers mark the $10^{th}$ and $90^{th}$ percentiles, and the data points show the extreme values.

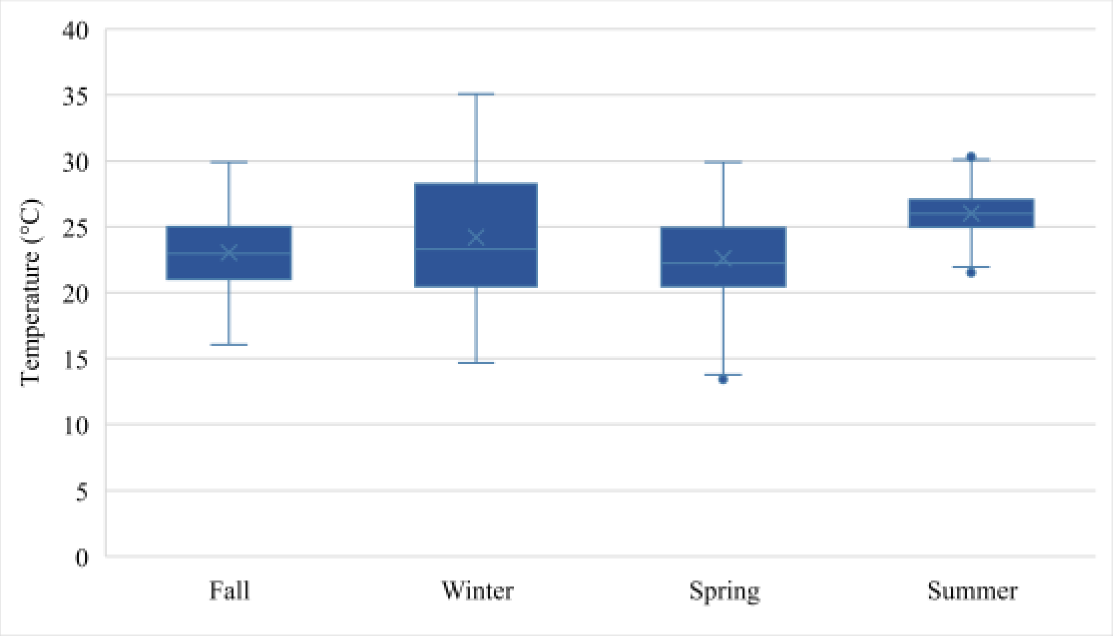

Figure 12 Box plots of indoor air temperature in classroom 171

The temperature in classrooms 171 and 178 followed the same pattern: the highest temperature point was over 30°C, and the lowest was less than 15°C. This may have had an impact on teachers' thermal adaptation. Classrooms 171 and 178 are facing south and located closer to the center of the building. Both classrooms experienced excessive heating across the seasons, particularly during the winter and summer, as seen in Table 4. Mumovic et al. (2009), in their study of schools in England, described two south-oriented classrooms that were exceptionally warm in the winter due to solar gains. Wargocki and Wyon (2007) echoed the conclusion that high temperatures are quite common even in northern cold areas, as the classroom ventilation rate is too low to remove the excess from heat load caused by sunshine.

In contrast, some classrooms such as classrooms 166 and 120 experienced underheating. Both classrooms are facing north and located at the end of the wing. Classroom 120 is located at the end of the West wing while classroom 166 is located at the end of the East wing. These classrooms are colder than other classrooms based on the physical measurements shown in Table 4.

Figures 13 and 14 show, for each season, charts and box plots of the temperature measured during the survey in Classroom 120.

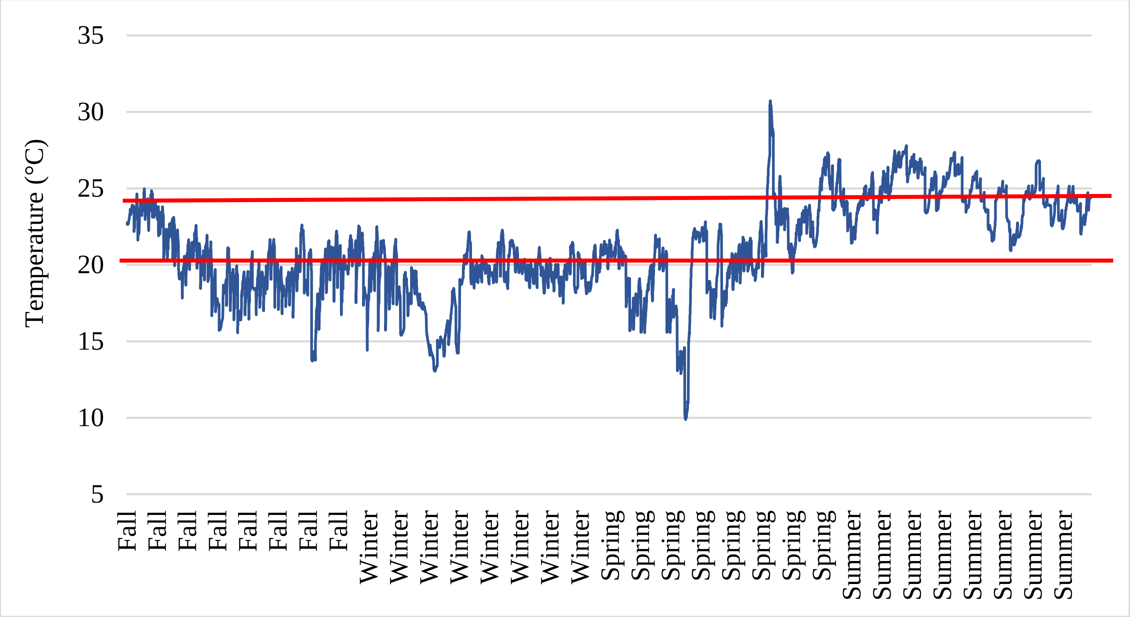

Figure 13 Chart of 15-minute interval indoor air temperature in classroom 120

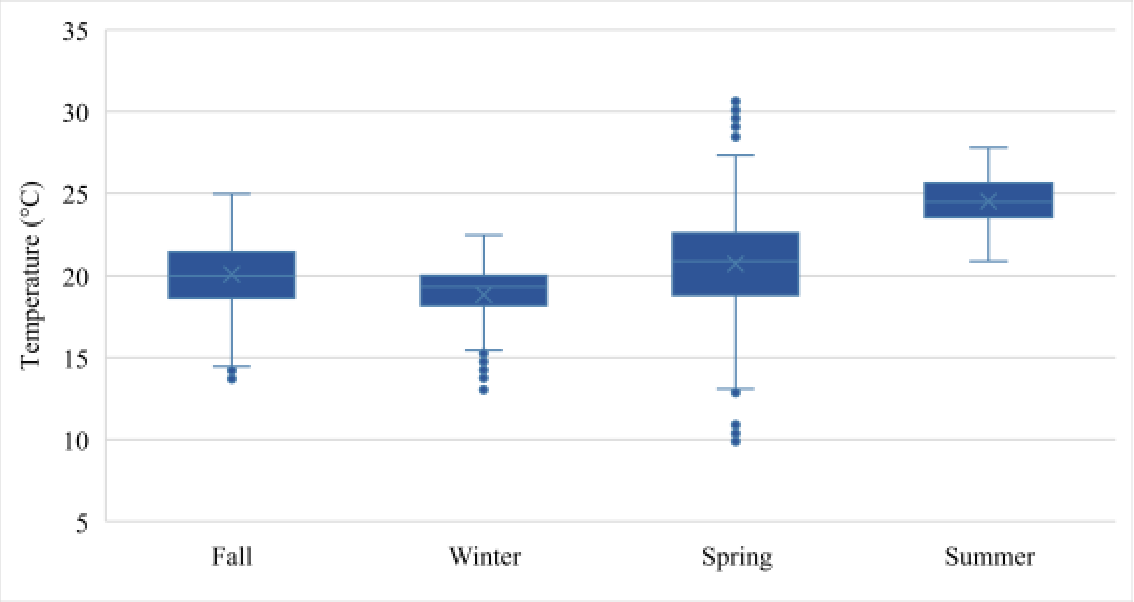

Figure 14 Box plots of indoor air temperature in classroom 120

The results of the evaluation of the temperature compliance percentage with the reference values are presented in Table 4. If the indoor air temperature was below 20°C, we assumed that the classroom experienced underheating. If it was above 24.5 °C, we considered it was overheating.

Table 4 Compliance (°C) with the ASHRAE standard for indoor air temperature (occupied period)

| | Underheating | | | | Overheating | | | |
|---|---|---|---|---|---|---|---|---|
| Class-rooms | Fall | Winter | Spring | Summer | Fall | Winter | Spring | Summer |
| 120 | 49.8 | 73.4 | 37.1 | 0.0 | 0.9 | 0.0 | 11.0 | 50.0 |
| 123 | 14.0 | 31.2 | 32.6 | 0.2 | 1.3 | 0.1 | 9.1 | 58.8 |
| 126 | 12.9 | 30.8 | 29.6 | 0.0 | 3.0 | 0.5 | 11.4 | 56.0 |
| 158 | 4.4 | 8.9 | 7.9 | 0.0 | 4.4 | 13.1 | 15.9 | 53.0 |
| 163 | 27.2 | 31.6 | 44.9 | 0.0 | 4.1 | 3.6 | 11.8 | 64.2 |
| 164 | 21.6 | 33.1 | 36.6 | 0.0 | 10.0 | 6.8 | 13.2 | 62.9 |
| 166 | 55.9 | 70.9 | 56.5 | 0.0 | 5.7 | 5.1 | 11.8 | 56.4 |
| 171 | 11.3 | 19.4 | 19.5 | 0.0 | 32.9 | 44.6 | 28.6 | 84.4 |
| 178 | 8.9 | 17.5 | 29.2 | 0.0 | 23.7 | 42.0 | 16.2 | 72.9 |

The results of the physical measurements showed that the school classrooms experienced underheating and overheating during the year. These results were similar to the ones reported in other studies (e.g., Almeida and De Freitas 2014; Järvi et al. 2018; Mumovic et al. 2009). Almeida and De Freitas (2014) reported that classrooms were thermally uncomfortable with temperatures below recommended levels.  Järvi et al. (2018) found that more than half of the classrooms in their study had a very high temperature in the winter season.

These results pave the way for a discussion on how to control the temperature using the HVAC system inside the classrooms. The space-heating season lasts from mid-October to mid-April. Currently, the school cannot maintain a stable temperature and suffers from significant indoor air temperature fluctuations during the year. It seems reasonable to conclude that the school staff felt thermally uncomfortable with the indoor air temperatures that exceeded both upper and lower reference values. These findings were in line with the results of the questionnaire. The school staff pointed out that the biggest problem was overheating and underheating when the classrooms were occupied. Hence, sometimes teachers reported feelings “too cold” and “too hot” in the same classroom.

One of the critical components of the HVAC system is temperature sensors. These provide feedback about heating, and they can be used to monitor or control the heating process. Programming thermostats to perform setbacks when the temperature set point on the thermostat is changed during unoccupied times could be one of the energy conservation measures to use (Angelon-Gaetz et al. 2015). One of the problems might be the placement of sensors in the wrong place. The school had significant temperature variations, and one of the solutions was to define the optimality of sensor placement for efficient energy use. Furthermore, more than half of the school staff (i.e., 57%) explained they did not have the option to control or adjust the temperature using thermostats. Angelon-Gaetz et al. (2015) reported that older school facilities lacked temperature sensors in each room, limiting the ability to control the indoor environment. Moreover, school management reported high utility bills. This fact is consistent with Wang et al. (2014). They reported that an increase from 18°C to 20°C in the set temperature of space heating buildings could increase energy consumption by 4.5%.

### *4.1.2 Relative humidity*

The amount of humidity in the air has a direct impact on thermal comfort, which in turn impacts the health of building occupants. According to ASHRAE Standards 62 (1999), the relative humidity should be maintained between 30% and 60%. Table 5 shows the percentage by which recorded relative humidity exceeded recommended levels. Low RH refers to the percentage of values that were less than 30% and High RH to the percentage of values that were more than 60%.

Table 5 Compliance (%) to ASHRAE standard for relative humidity (occupied period)

| | Low RH | | | | High RH | | | |
|---|---|---|---|---|---|---|---|---|
| | Fall | Winter | Spring | Summer | Fall | Winter | Spring | Summer |
| 120 | 20.8 | 91.3 | 53.9 | 0.0 | 6.6 | 0.0 | 2.8 | 18.7 |
| 123 | 24.8 | 94.5 | 62.7 | 0.0 | 2.0 | 0.0 | 2.5 | 10.0 |
| 126 | 26.4 | 95.7 | 59.5 | 0.0 | 1.8 | 0.0 | 1.6 | 7.0 |
| 158 | 25.3 | 96.3 | 67.0 | 0.0 | 3.6 | 0.0 | 1.5 | 4.1 |
| 163 | 18.3 | 91.3 | 56.6 | 0.0 | 2.9 | 0.0 | 3.2 | 5.1 |
| 164 | 20.6 | 92.7 | 52.2 | 0.0 | 1.6 | 0.0 | 2.8 | 6.6 |
| 166 | 17.0 | 91.6 | 45.9 | 0.0 | 6.2 | 0.0 | 5.2 | 12.7 |
| 171 | 41.0 | 98.7 | 70.4 | 0.0 | 1.6 | 0.0 | 0.0 | 2.5 |
| 178 | 41.8 | 97.5 | 71.7 | 0.1 | 1.2 | 0.0 | 0.4 | 2.6 |

These results demonstrated that the level of relative humidity when the classroom was occupied had not reached the lower end of the recommended value of 30% in the winter season. More than 90% of records in all surveyed classrooms were out of the recommended range.  Spring season was also characterized by non-compliance with the lowest reference value, as the relative humidity was relatively low. RH levels did not go below the lower reference RH value (less than 30%) in the summertime as the relative humidity values elevated and mostly were inside the recommended level. However, the school was unoccupied for an extended period. Fischer and Bayer (2001) recommended avoiding high humidity levels in the school facilities to prevent microbial infestation.

Figure 15 depicts the mean relative humidity levels in 9 classrooms. The red lines represent the lower (30%) and higher (60%) reference levels by ASHRAE.

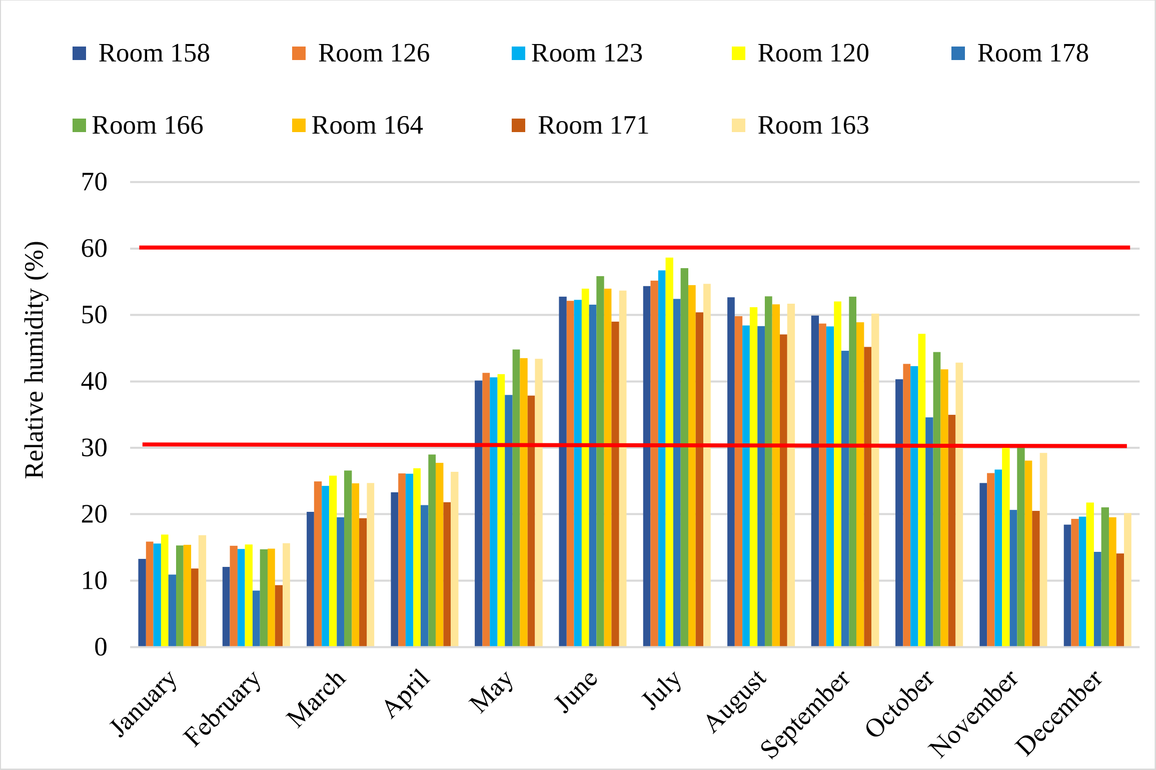

Figure 15 Average level of humidity in 10 classrooms

Figure 15 showed that RH mean values in the classrooms during the winter were lower than 30%. Winter is cold and dry in Manitoba, and, respectively, the indoor air is typically dry. The relative humidity tends to be relatively low in wintertime in buildings heated to comfortable temperatures in Canada (Hutcheon, 1960). RH mean values were less or close to the lowest reference value in April, staying within the recommended level during the summertime and going down in November. The average humidity level in the classrooms, being less than 30% in winter and the first two months of spring seasons, significantly affect the health of occupants causing sick building syndrome (SBS). This is because humidity affects the rate of water evaporation in the air and the balance of energy inside the body and, therefore, the thermal comfort of human beings (Fischer and Bayer 2001).

Table 6 illustrates the descriptive statistics of relative humidity measurements. Thus, the lowest relative humidity value of ~1% was found in 3 of the 10 observed classrooms during the winter. The highest value was 75.4% in the summer season.

Table 6 Descriptive statistics of relative humidity measurements (occupancy period: 8:30 am – 4:00 pm)

| | Mean (%) | | | | SD (%) | | | |
|---|---|---|---|---|---|---|---|---|
| | *Fall* | *Winter* | *Spring* | *Summer* | *Fall* | *Winter* | *Spring* | *Summer* |
| *120* | 43.0 | 18.0 | 31.5 | 54.6 | 12.1 | 7.8 | 11.2 | 6.6 |
| *123* | 38.9 | 16.7 | 30.5 | 52.4 | 11.3 | 7.8 | 10.8 | 6.6 |
| *126* | 38.9 | 16.8 | 31.0 | 52.3 | 11.3 | 7.9 | 10.5 | 5.8 |
| *171* | 33.2 | 11.8 | 26.6 | 48.8 | 12.5 | 7.5 | 11.1 | 5.3 |
| *178* | 32.9 | 11.3 | 26.6 | 50.7 | 12.2 | 7.6 | 11.9 | 5.2 |
| *158* | 38.0 | 14.6 | 28.2 | 53.2 | 12.6 | 7.3 | 12.1 | 4.3 |
| *163* | 40.5 | 17.6 | 31.8 | 53.3 | 10.7 | 8.0 | 11.3 | 4.6 |
| *164* | 39.3 | 16.6 | 32.2 | 53.3 | 10.6 | 8.0 | 11.1 | 4.6 |
| *166* | 42.2 | 17.0 | 33.7 | 55.2 | 11.6 | 8.9 | 11.4 | 4.5 |
| | Min (%) | | | | Max (%) | | | |
| *120* | 10.7 | 5.5 | 14.7 | 36.2 | 72.6 | 42.9 | 69.6 | 72.7 |
| *123* | 9.7 | 3.8 | 15.5 | 35.6 | 68.7 | 38.5 | 68.8 | 72.6 |
| *126* | 8.5 | 2.9 | 15.0 | 38.2 | 66.7 | 38.5 | 65.1 | 75.4 |
| *171* | 7.7 | 0.7 | 7.8 | 34.4 | 65.9 | 37.3 | 58.8 | 68.1 |
| *178* | 8.0 | 0.4 | 8.1 | 29.3 | 65.4 | 36.3 | 61.1 | 63.6 |
| *158* | 11.0 | 2.2 | 8.6 | 35.9 | 68.8 | 43.5 | 68.3 | 63.8 |
| *163* | 14.0 | 4.1 | 14.9 | 38.6 | 66.7 | 39.7 | 68.3 | 67.5 |
| *164* | 13.4 | 2.6 | 15.6 | 42.8 | 67.0 | 40.5 | 67.3 | 65.6 |
| *166* | 13.9 | 0.3 | 16.6 | 42.2 | 69.8 | 46.0 | 68.6 | 72.0 |

Figure 16 depicts the temperature and relative humidity in the winter season for classroom 178.

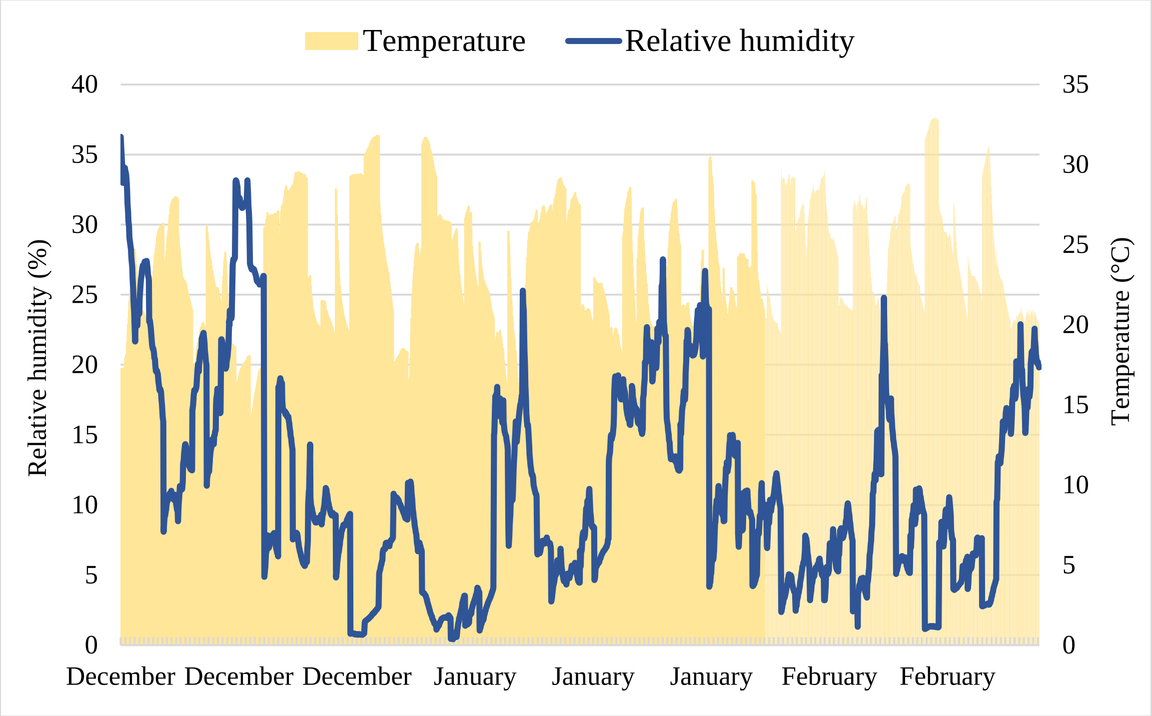

Figure 16 Indoor air temperature and relative humidity values in classroom 178 in the winter season

Figure 16 showed that the lowest relative humidity values were mostly observed when the temperature range in this classroom was between +28 - 32°C. Classrooms 171 and 166 followed the same pattern as Classroom 178 while their maximum temperature was over 32°C. These results are in line with Järvi et al. (2018), who also reported that the lowest measured value was too low, e.g., 3,2% in their study of Finnish schools in the winter season. Jarvi et al. (2018) explained the phenomena of extremely low humidity, particularly in the wintertime that indoor temperatures are often too high during the heating season and mechanical ventilation desiccates indoor air. Classrooms in buildings that were built before the year 2004 had a higher risk of having RH less than 30% compared to younger buildings. This is because older HVAC systems may have been designed to dehumidify the school building as much as possible without concern about the possible health effects of extremely low humidity (Angelon-Gaetz et al., 2015). Another reason for the inability of designed HVAC systems in school facilities to manage space humidity effectively was quoted by Fischer and Bayer (2001) is the tight budget and capital allocated to mechanical equipment. This has led 20% of surveyed schools in the US to suffer from poor IAQ, and 36% to have “less than adequate” HVAC systems (Fischer and Bayer 2001).

### *4.1.3 $CO_2$ measurements*

According to ASHRAE Standards 62.1-2016, $CO_2$ concentration should be 700 ppm above outdoor $CO_2$ levels (300-500ppm). Table 7 shows the percentage by which monitored $CO_2$ concentrations exceed the limits from reference standards (>1000 ppm) during the occupational period.

Table 7 Exceedance (ppm) to ASHRAE standard for values of $CO_2$ (occupied period)

| | Fall | Winter | Spring | Summer |
|---|---|---|---|---|
| 120 | 63.7 | 56.9 | 46.2 | 2.3 |
| 123 | 62.8 | 57.8 | 46.2 | 3.8 |
| 126 | 57.5 | 60.7 | 56.5 | 5.4 |
| 158 | 61.7 | 50.0 | 50.7 | 9.6 |
| 163 | 56.4 | 51.9 | 49.8 | 12.2 |
| 164 | 64.6 | 51.8 | 55.5 | 12.3 |
| 166 | 53.3 | 43.1 | 60.3 | 15.7 |
| 171 | 31.7 | 25.6 | 35.9 | 7.0 |
| 178 | 35.7 | 30.3 | 32.7 | 9.9 |

Comparison with ASHRAE standards showed $CO_2$ concentrations exceeded the recommended range frequently during the occupational period but less in the summer season. The lowest carbon dioxide concentrations were recorded in Classrooms 171 and 178.

The mean $CO_2$ concentration values are depicted in Figure 17. In general, the mean values of $CO_2$ were not higher than 1,400 ppm in the surveyed classrooms.

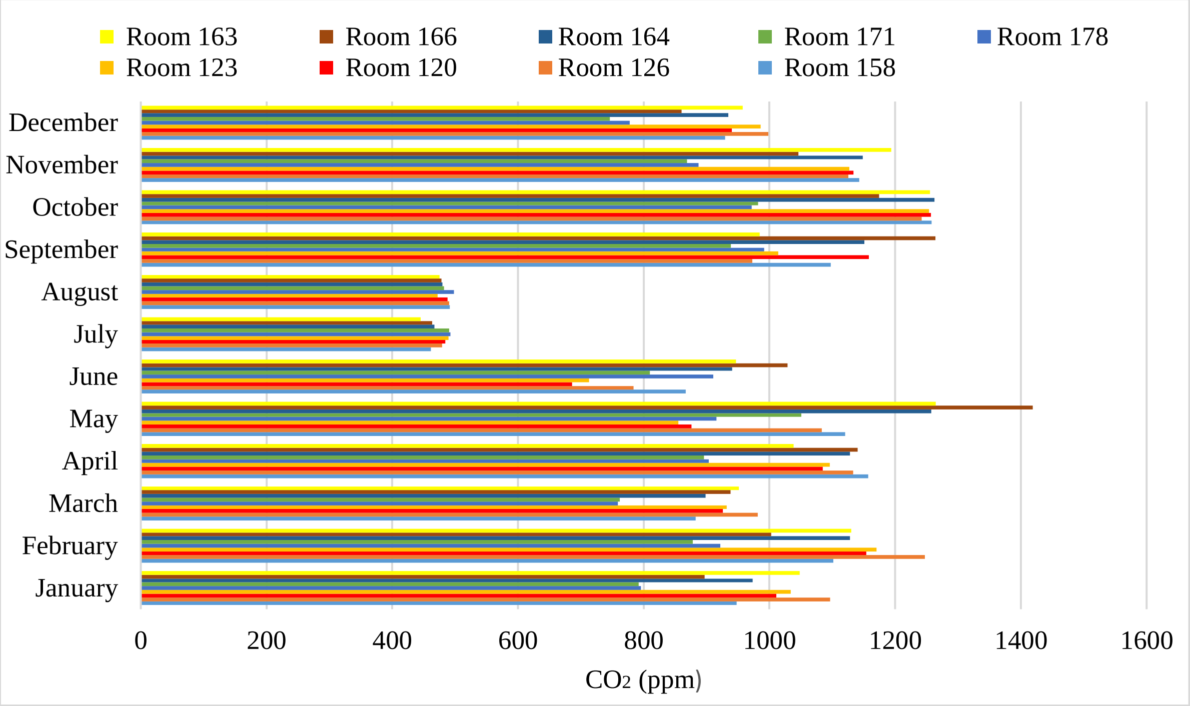

Figure 17 Mean values of $CO_2$

The variations of $CO_2$ concentrations in selected classrooms during school working hours are shown in Table 8.

Table 8 Descriptive statistics of $CO_2$ measurements (occupancy period: 8:30 am-4:00 pm)

| | Mean (ppm) | | | | SD (ppm) | | | |
|---|---|---|---|---|---|---|---|---|
| | *Fall* | *Winter* | *Spring* | *Summer* | *Fall* | *Winter* | *Spring* | *Summer* |
| *120* | 1185 | 1032 | 959 | 550 | 485 | 434 | 403 | 148 |
| *123* | 1137 | 1061 | 957 | 555 | 430 | 444 | 383 | 170 |
| *126* | 1120 | 1111 | 1065 | 580 | 442 | 482 | 452 | 189 |
| *171* | 930 | 804 | 906 | 589 | 481 | 268 | 394 | 212 |
| *178* | 949 | 829 | 860 | 627 | 406 | 275 | 349 | 291 |
| *158* | 1170 | 990 | 1053 | 601 | 521 | 430 | 478 | 248 |
| *163* | 1151 | 1044 | 1089 | 615 | 529 | 492 | 530 | 305 |
| *164* | 1190 | 1009 | 1097 | 622 | 512 | 443 | 505 | 299 |
| *166* | 1159 | 918 | 1171 | 649 | 575 | 395 | 538 | 344 |
| | Min (ppm) | | | | Max (ppm) | | | |
| *120* | 358 | 337 | 292 | 392 | 2932 | 2208 | 2233 | 1461 |
| *123* | 378 | 388 | 355 | 349 | 3268 | 2252 | 2074 | 1548 |
| *126* | 388 | 362 | 350 | 357 | 2947 | 2550 | 3338 | 1703 |
| *171* | 316 | 383 | 356 | 375 | 3558 | 1867 | 2845 | 1947 |
| *178* | 319 | 388 | 342 | 396 | 2727 | 1561 | 2340 | 2738 |
| *158* | 370 | 345 | 357 | 381 | 3614 | 2336 | 3154 | 2310 |
| *163* | 369 | 342 | 375 | 371 | 3448 | 2290 | 3303 | 2418 |
| *164* | 379 | 377 | 366 | 367 | 3637 | 2630 | 3461 | 2471 |
| *166* | 363 | 347 | 381 | 363 | 3412 | 2216 | 3152 | 2439 |

The present study found high $CO_2$ concentrations in classrooms during the occupied period; however, the mean concentration values of $CO_2$ in all classrooms were close or less than the level recommended by ASHRAE. The highest $CO_2$ concentrations where values greater than 3,600 ppm in the fall season, 2,300 ppm during the winter, and 3,100 ppm in the spring were recorded in Classrooms 158 and 164. The records of $CO_2$ concentrations showed that the highest peak was observed at 3,637 ppm in Classroom 164. The high concentrations of indoor $CO_2$ represent a significant problem for the school's indoor environmental quality (Vilcekova et al., 2017). Asif et al. (2018) assumed that the accumulation of $CO_2$ at such high levels indicates a possible buildup of pollutants that needs to be further investigated.

Air refreshment depends on the teacher's ability to perceive the quality of the indoor air and to take necessary measures, such as opening a window for natural ventilation (Theodosiou and Ordoumpozanis 2008). The largest values of $CO_2$ in all classrooms were observed in the fall season. About 45% of teachers opened windows in the school in the fall season for more than three hours. The fall season could be cold in Manitoba with an outside temperature falling below zero, and not all teachers were willing to open windows to let cold air inside. The other reason not to open windows during the fall was dusty or smelly odour (see Table 19). Figure 18 shows the variations of mean $CO_2$ values inside the three classrooms (i.e., 164, 178, and 123) from 8.30 am to 4 pm in the fall season. The results indicate that $CO_2$ concentrations fluctuated during school hours, accumulating towards mid-day, and gradually decreasing by the end of the day.

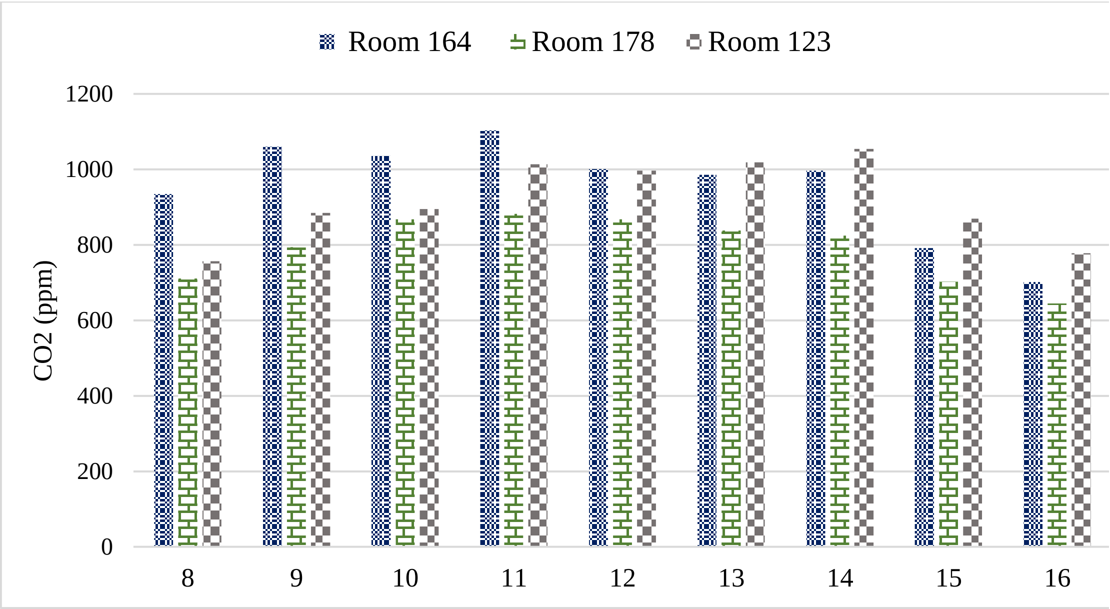

Figure 18 Variations of indoor $CO_2$ concentrations in the atmospheres of classrooms 164,178 and 123 at the occupied hours (8:00 am – 4:00 pm) measured for the fall season

The concentration of $CO_2$ decreased after school time and reached approximately 500 ppm in the morning (as seen in Figure 19).

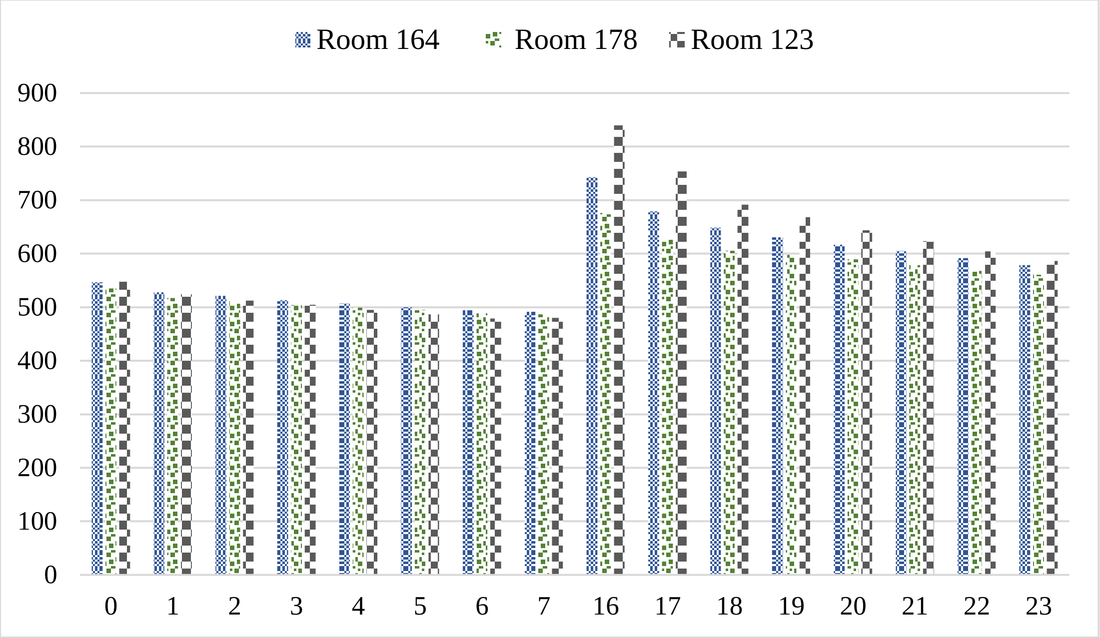

Figure 19 Variations of indoor $CO_2$ concentrations in the atmosphere of classrooms 164, 178, and 123 at the unoccupied hours (00:00-7:59 am and 4:00 pm – 11:59 pm) for the fall season

These results are in line with Theodosiou and Ordoumpozanis (2008), who showed that concentrations of $CO_2$ decreased after school time and reached almost atmospheric conditions (430-480 ppm), depending on the airtightness of each school building,.

Previous studies showed that high concentrations of indoor $CO_2$ are among the main problems in the school's indoor environment quality (Van Dijken et al. 2006; Myhrvold et al., 1996; Hou, Liu, and Li 2015; Turanjanin et al., 2014). Van Dijken et al. (2006) found that

$CO_2$ levels above recommended levels are usually registered in the school classrooms. Turanjanin et al. (2014) reported that measured indoor $CO_2$ concentrations in five Serbian schools exceeded 1,000 ppm in over 50% of the occupied time, and $CO_2$ concentration reached a maximum value of about 3,600 ppm. Smedje and Norbäck (2000) studied $CO_2$ in 181 classrooms in 40 schools in Sweden. They observed $CO_2$ concentrations > 1,000 ppm in 40% of classrooms, with a mean $CO_2$ concentration of 950 ppm. Levels of $CO_2$ greater than 1,000 ppm generally indicate inadequate ventilation (Corsi, Torres, and Sanders 2002). Corsi et al. (2002) reported that the reasons for insufficient ventilation vary considerably from school to school and even from classroom to classroom.

These high levels of $CO_2$ in the school could be associated with poor building design, the absence or insufficient use of ventilation provisions, or occupation density higher than that expected in the ventilation system design phase (Griffits and Eftekhari 2008; Amouei et al. 2019). Moreover, the concentrations of $CO_2$ below 1,000 ppm do not always mean that the ventilation rate is adequate for removing air pollutants from other indoor sources (Seppänen 1999). It is difficult to adequately analyze indoor $CO_2$ concentrations as they are a function of occupancy and ventilation rate (Daisey et al. 2003). During the long-term measurements of $CO_2$ concentrations, knowing the ventilation rate is needed to evaluate indoor $CO_2$, and its impact on health and performance.

## 4.2 Questionnaire

### *4.2.1 Participant characteristics*

A total of 56 teachers participated in the survey. The vast majority of the participants (~77%) were females, and 23% were males (as shown in Table 9). One teacher worked only in the fall, and winter seasons so did not answer questions related to the spring season. Of the entire population of 56 surveyed teachers, 56 completed the survey resulting in a total response rate of 100%. The response rate related to questions of the survey is provided in Appendix 1.

Table 9 Participant characteristics

| Characteristics | Number | Percent (%) |
|---|---|---|
| Female | 43 | 77 |
| Male | 13 | 23 |
| Hours spent in classrooms >=30 h/week | 33 | 59 |
| Years working in school >=3 years | 36 | 64 |

The current study showed that approximately 59% of respondents worked over 30 hours per week, while more than two-thirds had worked for more than three years at this school. As a result, the responses of the participants are based on a considerable amount of time spent in the school throughout different seasons (the fall, winter, and spring). Furthermore, several studies reported that females were less satisfied with room temperature, preferred higher temperature, and felt both uncomfortably cold and uncomfortably hot more often than males (Cena and de Dear 2001; Parsons 2002; Karjalainen 2007). In contrast, other studies discovered relatively small differences regarding preferred indoor air temperature and thermal comfort between males and females (Parsons 2002; Fanger 1970). These contrasting findings reinforced the need to include the gender of the respondents as one of the variables in the analysis.

### *4.2.2 Indoor Air Quality*

The answers to the question "How are you satisfied/dissatisfied with IAQ in the classrooms you use the most?" were overwhelming. Many teachers (~70%) found poor indoor air quality to be the most significant problem in the school.

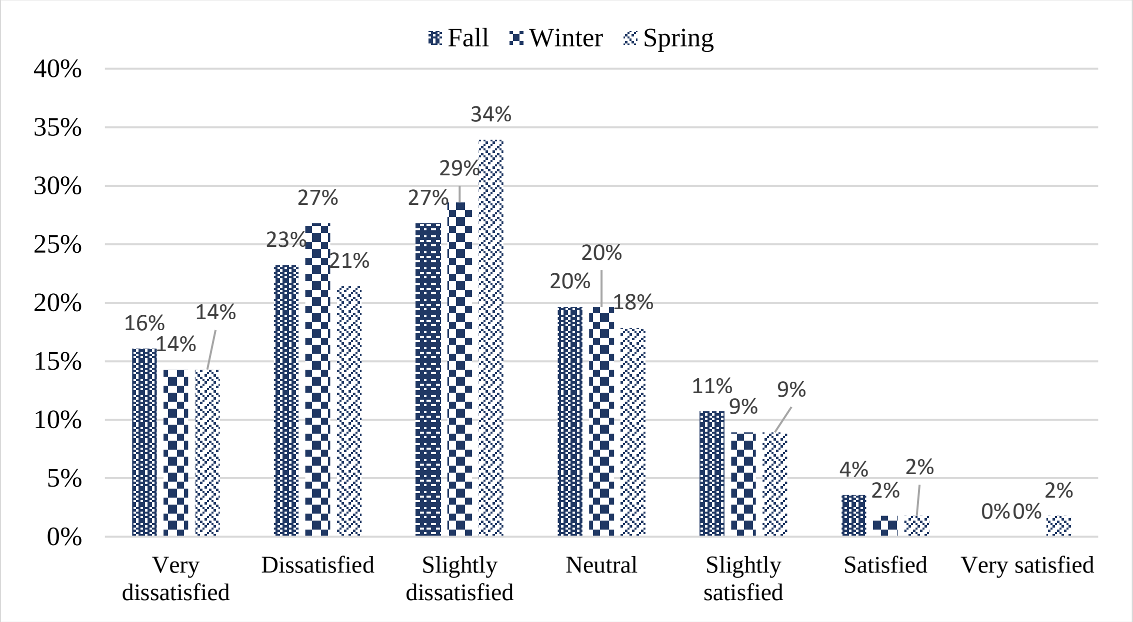

Figure 20 Satisfaction with IAQ

From 11% to 15% of respondents expressed different satisfaction levels with IAQ across the seasons. Approximately, one-fifth of teachers had neutral feelings. Teacher's answers varied between 'slightly dissatisfied' across the three seasons: fall (27%), winter (29%), spring (34%) to ‘very dissatisfied’ in fall (16%), winter (14%), and spring (14%). These results were in line with the ones reported in the literature. A study by Schneider (2003) who surveyed two large school districts showed that most teachers reported “fair” to ”poor” IAQ in schools. In the United States, 18% of schools rated their IAQ as unsatisfactory, and 26% rated their ventilation as inferior (U.S. Department of Education, 2000). On the other hand, in two other studies, 69% of teachers rated their IAQ in the school as good (Lin et al. 2017) and 100% of teachers in the survey by Vilcekova et al. (2017) as acceptable.

The Mann-Whitney U test was run to test whether satisfaction with indoor air quality differed between genders (Table 10).

Table 10 Cross-tabulation of IAQ with gender

| Season | Gender | Satisfaction with indoor air quality | | | | | | | U (value) | p-value | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | | | |
| Fall | Male | 0 | 3 | 2 | 5 | 3 | 0 | 0 | 172.5* | 0.033 | 3.62 |
| | Female | 9 | 10 | 13 | 6 | 3 | 2 | 0 | | | 2.77 |
| Winter | Male | 0 | 2 | 3 | 6 | 2 | 0 | 0 | 147.5* | 0.008 | 3.62 |
| | Female | 8 | 13 | 13 | 5 | 3 | 1 | 0 | | | 2.65 |
| Spring | Male | 0 | 2 | 3 | 5 | 2 | 0 | 1 | 148.5* | 0.009 | 3.85 |
| | Female | 8 | 10 | 16 | 5 | 3 | 1 | 0 | | | 2.72 |

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

The Mann-Whitney U test detected statistically significant associations between gender and satisfaction with indoor air quality (p-value>0.05). The results of the test showed that females were less satisfied than males with indoor air quality during the fall, winter, and spring seasons. The mean satisfaction level for females is between 2.65-2.77, which is lower than ‘slightly dissatisfied’ while the level for males is 3.62-3.85, which is almost ‘neutral.’ Approximately, 74 to 79% of female participants expressed feeling 'very dissatisfied' to 'slightly dissatisfied' across the seasons, and 21% to 26% of them felt 'neutral' to 'very satisfied' with IAQ of the school (as seen in Figure 21).

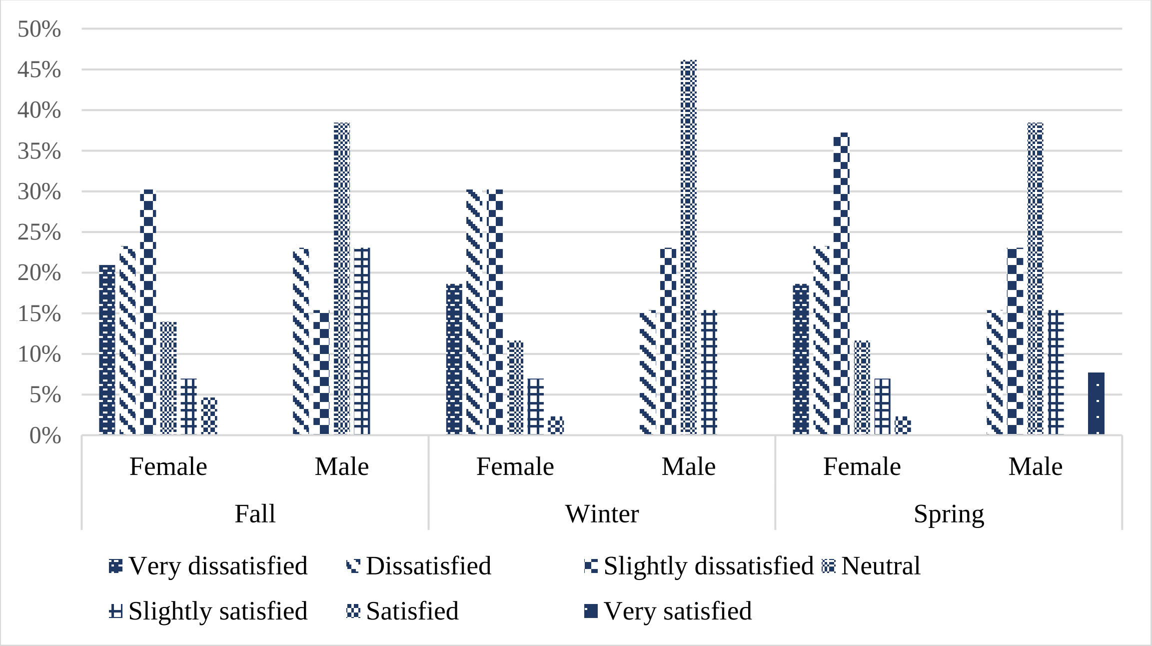

Figure 21 Satisfaction with IAQ by genders

In contrast, 62% of male participants voted to feel from 'neutral' to 'very satisfied' with the IAQ of the school, and 38% of them felt from 'very dissatisfied' to 'slightly dissatisfied.'

This is in line with previous indoor climate studies that found, in general, females complained more about indoor air quality than males (Stenberg and Wall 1995; Andersson et al. 2002; Reijula and Sundman-Digert 2004).

Respondents emphasized indoor air issues such as stuffy, bad, or dusty air and complained about insufficient ventilation. Figure 22 illustrates the subjective answers of respondents to the question: "On average, how do you rate indoor air quality issues in the classroom that you use the most?"

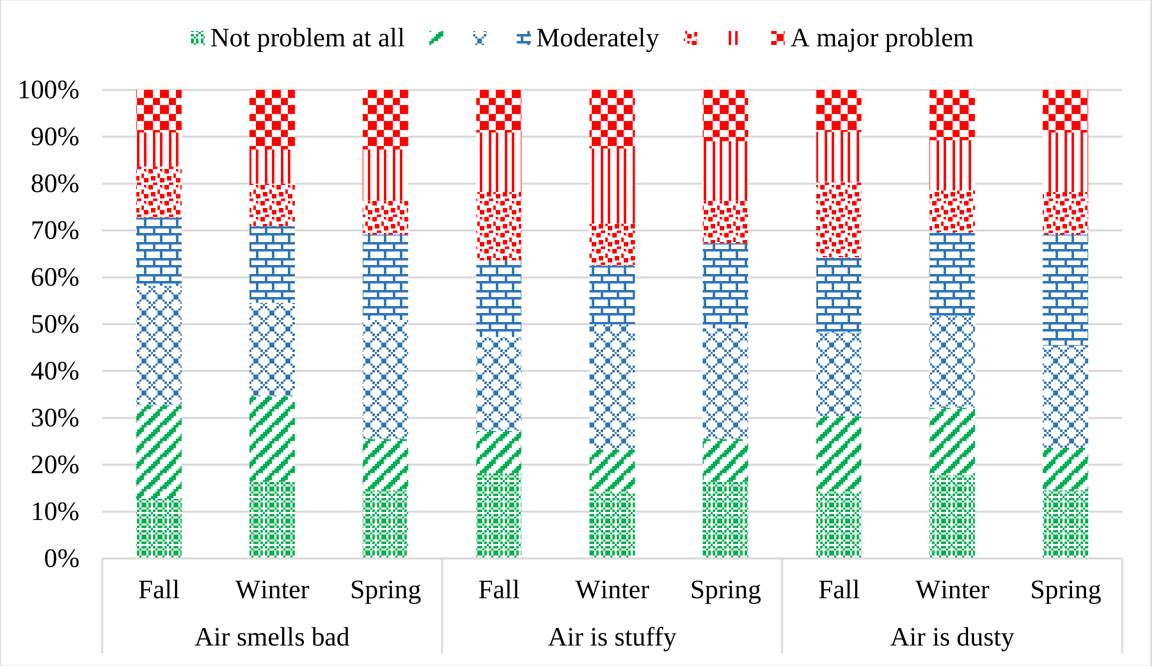

Figure 22 "*Air smells bad*"/"*Air is stuffy*"/"*Air is dusty*" votes

With respect to indoor air issues, more than 60% of the teachers found them to be between 'not a problem at all' and 'moderately a problem'. The highest satisfaction was with "Air smells bad" as 73% of respondents voted between 'not a problem at all' and 'moderately' during the fall. 38% of respondents expressed "Air is stuffy" as the biggest problem in the winter while 36% of them indicated that the "Air is dusty" problem got worse in the fall compared to winter and spring seasons.

It is obvious from the abovementioned analysis that odours and stuffy or dusty air appeared to be important IAQ problems experienced by teachers. 23% of teachers expressed their negative feelings, such as: "*The air is very stuffy, dry. I have students that have nose bleeding due to the air*."; "*It is very stuffy, air circulation is bad*," "*Stuffy*," "*Super stuffy*".

Table 11 shows the results of the Spearman Rho test used to investigate teachers' satisfaction with IAQ and their satisfaction with air odours.

Table 11 Correlations between teacher's satisfaction with IAQ and their satisfaction with indoor air issues: results of Spearman's Rho test

| | | IAQ | | |
|---|---|---|---|---|
| | | Fall | Winter | Spring |
| Air smells bad | R | -0.326* | -0.435** | -0.201 |
| | p-value | 0.015 | 0.001 | 0.141 |
| Air is stuffy | R | -0.299* | -0.317* | -0.233 |
| | p-value | 0.026 | 0.017 | 0.086 |
| Air is dusty | R | -0.276* | -0.356** | -0.154 |
| | p-value | 0.040 | 0.007 | 0.262 |

*. Correlation is significant at the 0.05 level (2-tailed)

**. Correlation is significant at the 0.01 level (2-tailed)

As shown in Table 11, statistically significant, negative correlations were found between "Satisfaction with IAQ" and "Air smells bad" in the fall (weak value) and winter (moderate value) seasons. Statistically significant weak negative correlations were found between "Satisfaction with IAQ" and "Air is stuffy" in the fall and winter seasons. Statistically significant weak negative correlations were revealed between "Satisfaction with IAQ", and "Air is dusty" in the fall and the winter. The test did not reveal any statistically significant correlations between "Satisfaction with IAQ" and indoor air issues in the spring.

Previous studies also showed evidence of frequently reported IAQ-related problems such as "stuffiness/dry air" (Vilcekova et al. 2017; Järvi et al. 2018; Turunen et al. 2013). Among pedagogical staff, 60% were concerned with stuffy (i.e., bad) air in the school and emphasized worse air on Monday morning than other times (Vilcekova et al. 2017). Simultaneously, the complaint of "bad odour of air" was often associated with high $CO_2$ levels (Daisey et al. 2003). Gordon (2010) also suggested that these odours could be due to high $CO_2$ and total volatile organic compounds (TVOC) levels in classrooms.

The survey's data related to teachers' perception of relationships between IAQ and classroom characteristics are summarized below. Participants were asked to rate their satisfaction with the school's conditions, including cleanliness, overall maintenance, and performance of the ventilation system. Table 12 shows the percentage of respondents' satisfaction with different aspects of the school's conditions.

Table 12 Level of IAQ satisfaction

| | Very dissatisfied | Moderately dissatisfied | Slightly dissatisfied | Neutral | Slightly satisfied | Moderately satisfied | Very Satisfied |
|---|---|---|---|---|---|---|---|
| | | | *Overall Cleanliness* | | | | |
| Fall | 14% | 14% | 23% | 21% | 16% | 7% | 4% |
| Winter | 22% | 16% | 27% | 16% | 13% | 4% | 2% |
| Spring | 18% | 22% | 27% | 18% | 11% | 2% | 2% |
| | | | *Overall Maintenance* | | | | |
| Fall | 11% | 9% | 21% | 30% | 13% | 11% | 5% |
| Winter | 15% | 9% | 22% | 24% | 16% | 11% | 4% |
| Spring | 13% | 9% | 22% | 25% | 16% | 11% | 4% |
| | | | *Ventilation System* | | | | |
| Fall | 25% | 14% | 39% | 13% | 4% | 2% | 4% |
| Winter | 33% | 15% | 35% | 13% | 4% | 2% | 0% |
| Spring | 25% | 20% | 38% | 11% | 2% | 2% | 2% |

Approximately 27% of teachers were satisfied with the cleanliness of the school during the fall season, while in other seasons like the winter and spring, their satisfaction level significantly dropped. Concerning school maintenance, the votes related to the fall, winter, and spring seasons were consistent throughout the observed period. Respondents showed the same level of satisfaction with maintenance across all seasons. Teacher's perception of the ventilation system was more negative as many of them (~80%) were ‘slightly dissatisfied’ to ‘very dissatisfied’ with it in the fall, winter, and spring seasons. Less than 10% of respondents were satisfied with the ventilation system. 60% of teachers opened their windows in the classroom. Over 45% opened their windows in the fall and 74% in the spring for more than three hours during a typical school day. Due to the low outdoor temperature in the winter season, half of the teachers opened their windows for less than one hour; 24% of them kept the windows open for less than three hours, and only 15% for longer, thus resulting in low air change rates.

A Spearman Rho test was conducted to examine the relationships between satisfaction with indoor air quality responses and classroom characteristics. As seen in Table 13, the test revealed a statistically significant, weak positive correlation between indoor air quality and school cleanliness in the fall and a statistically significant, moderate positive correlation in the winter. There was no correlation between indoor air quality and cleanliness in the spring season.

Table 13 Spearman rank correlation coefficients between satisfaction with indoor air quality and the classroom characteristics

| | | IAQ | | |
|---|---|---|---|---|
| | | Fall | Winter | Spring |
| Cleanliness | R | 0.274* | 0.442** | 0.219 |
| | p-value | 0.041 | 0.001 | 0.108 |
| Maintenance | R | 0.327* | 0.395** | 0.350** |
| | p-value | 0.014 | 0.003 | 0.009 |
| Ventilation | R | 0.373** | 0.625** | 0.591** |
| | p-value | 0.005 | 0.000 | 0.000 |

*. Correlation is significant at the 0.05 level (2-tailed)

**. Correlation is significant at the 0.01 level (2-tailed)

There are statistically significant, weak positive correlations between indoor air quality and maintenance in the fall, winter, and spring seasons. There are statistically significant, moderate positive correlations between indoor air quality and the ventilation system in the winter and spring seasons, while the correlation was statistically significant weak in the fall season.

Cleaning and maintenance operations contribute to the source management of particles, chemicals, and bio pollutants (Franke 1997). According to Kielb et al. (2015), the quality of classroom housekeeping is associated with exposure to allergens and irritants. At the same time, Allermann et al. (2003) found that the potency of the floor dust samples correlated significantly with the prevalence of building-related symptoms. Intense cleaning contributes to the consistent decrease in particulate matter contamination (Heudorf, Neitzert, and Spark 2009). Previous studies (e.g., Franke 1997) also found that cleaning programs contributed to measurable improvements in IAQ by reducing airborne dust mass, TVOC's, bacteria, and fungi.

Maintenance is a mounting challenge for school authorities as the US Department of Education has claimed that poor building conditions are mainly due to poor maintenance by school maintenance departments (Lavy and Bilbo 2009). Due to financial restrictions that the schools face, one of the reasons for having poor IAQ is the lack of maintenance and cleaning (Ekren et al. 2017). In this case, the ventilation system becomes a source of contamination. Previous studies showed that a higher ventilation rate reduced the proportion of people dissatisfied with perceived indoor air quality (Bluyssen et al., 1996). Inadequate ventilation, which consists of existing indoor pollutants, was found in many classrooms (Daisey et al. 2003; Tortolero et al. 2002; Hou et al. 2015). Hou et al. (2015) asserted that $CO_2$ levels above 3,000 ppm were not unusual in classrooms. The current study's results of objective measurements showed that 30 to 60% of CO2 values were above 1,000 ppm in classrooms in the fall, winter, and spring seasons. Moreover, teachers left comments related to the ventilation system such as: "*There must be an outside vent at classroom area because you can smell auto exhaust*", "*Need to change furnace filters*", "*Air filters and vents need cleaning*", "*The heating & ventilation systems aren't running properly, this needs to be addressed*". Maintenance and cleanliness of ducts and air filters is critical to avoid the development of bad odours, microorganism’s growth, and chemical reactions that can result in the poor quality of supply air (Ianniello 2011).

The Institute of Medicine (2000) discovered that odour from allergens and irritants could worsen or cause asthma or allergies (cited Kielb et al. 2015). The current study asked teachers to determine the extent to which allergens, irritants, and different odours as primary sources of poor IAQ (Table 14).

Table 14 Reported school characteristics related to sources of poor IAQ

| Sources of poor air quality | Number | Percent (%) |
|---|---|---|
| Furniture smell | 11 | 20% |
| Smoking smell | 5 | 9% |
| Art supplies and equipment like printer | 5 | 9% |
| Outdoor pollution like dust which enters the building | 32 | 57% |
| Washrooms smell | 45 | 80% |
| Cooking | 19 | 34% |
| Chemical substances smell (like cleaners) | 16 | 29% |
| Visible signs of moisture damage | 27 | 48% |
| Mold or cellar-like odour | 34 | 61% |

The vast majority of respondents (80%) found washroom smell to be the primary source of poor IAQ in the classrooms they used the most. Next, 61% of respondents reported mold and cellar-like odour, while 48% of them noticed visible signs of moisture damage in the school. Respondents commented on moisture problems as “*Floors and base of wall had damp darkened areas*” or “*There is often the water in the crawl space that opens in the classroom which contributes to the moldy smell*”. The possible reason for these findings is the failure of the somp-pump system a couple of years ago, which caused the infiltration of water into the building. Although the somp-pumps have been replaced, the consequences of water infiltration were still present, adversely affecting the building's performance. A study by Kielb et al. (2015) found that moisture problems were reported only by over 20% of teachers, while previous studies found relationships between mold and excess moisture and building-related health symptoms in the school facilities (Smedje et al. 1996; Kielb et al. 2015; Ebbehoj et al. 2005).

Additionally, the participants who noticed moldy/earthy/cellar-like odours were asked to specify the location of that unpleasant smell. Table 15 summarizes the respondents' answers to this question.

Table 15 Reported school places with moldy/earthy odour

| Location | Number | Percent (%) |
|---|---|---|
| Classrooms | 20 | 59% |
| Gym | 9 | 26% |
| Bathrooms | 26 | 76% |
| Kitchen | 1 | 3% |
| Canteen | 1 | 3% |
| Offices | 7 | 21% |
| Basement | 5 | 15% |
| None | 1 | 3% |

The most commonly reported places with moldy/earthy odour were bathrooms (76%) and classrooms (59%). Gyms and offices were reported by over 20% of teachers whereas 15% of them said this odour came from the basement.

Furthermore, 57% of the participants marked outdoor pollution to be a significant source of poor indoor air quality. Teachers commented on outdoor pollution as follows: "*The air smells bad only when buses and tractors smell comes in the vent*" or "*There must be an outside vent at the classroom area because you can smell auto exhaust*". These results are not surprising considering overall dissatisfaction with the ventilation system and cleanliness of the school. Lin et al. (2017) showed that one-third of surveyed teachers were quite disturbed by outdoor pollution (traffic), and 37% of them perceived air quality outside their school as not satisfactory. Kielb et al. (2015) found that over 10% of teachers complained about diesel exhaust. This exhaust contained a complex mixture of pollutants that can affect health.

Chemical substances smell (e.g., cleaners) and furniture smell were identified by 29% and 20% of participants, respectively, as the reason for poor IAQ. The odour from cleaners was reported by over 10% of respondents in the teacher survey by Kielb et al. (2015). Cleaning chemicals often contain VOCs and can thus have adverse health effects (U.S. Environmental Protection Agency, 2012).

Approximately 9% of respondents complained about irritant smells related to art supplies. This is in line with the teacher's survey by Kielb et al. (2015), who showed that over 10% of teachers reported odours from art supplies. Moreover, teachers were asked about the frequency of using art supplies such as glue, paints, and other products with irritant smell by season (as per Table 16).

Table 16 Frequency of using art supplies such as glue, paint, and enamels with irritant odour

| | Never | Once to 5 times a month | 5 times to 10 times a month | More than 10 times a month |
|---|---|---|---|---|
| Fall | 20% | 59% | 13% | 6% |
| Winter | 17% | 49% | 22% | 7% |
| Spring | 17% | 54% | 19% | 6% |

Around half of respondents used art supplies once to five times per month. Only a few of them used it more than 10 times per month.

Approximately a third of the participants identified cooking as the source of inadequate IAQ. This may be because of the proximity of the kitchen to the classrooms, and because of poor ventilation. A very small percentage of respondents (~9%) reported allergens/irritants such as smoking to be a source of unpleasant smell in the school. This was consistent with Kielb et al. (2015) who found that less than 10% of teachers reported the same issue.

Furthermore, the results of the survey showed that IAQ affected occupants' performance. In this regard, about 27% of school staff answered "yes" to a question enquiring about whether IAQ issues were affecting their ability to do work at school. Consequently, Table 17 demonstrates the relationship between satisfaction with indoor air quality conditions and teacher's self-reported performance.

Table 17 Association between satisfaction with indoor air quality and the teacher's performance

| | | Performance | | |
|---|---|---|---|---|
| | | Fall | Winter | Spring |
| Satisfaction with IAQ | R | -0.663** | -0.640** | -0.561** |
| | p-value | 0.000 | 0.000 | 0.000 |

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

As can be seen from Table 17, there are statistically significant, moderate negative associations between satisfaction with IAQ and the ability of teachers to do their work in the fall, winter, and spring seasons. This may mean that teachers' dissatisfaction with indoor air quality in the classroom profoundly influences their motivation to perform their work. Previous studies asserted that raised levels of indoor air pollution can reduce productivity and can have adverse effects on comfort and health (Wyon 2004). Lin et al. (2017) showed that about10% of teachers declared that poor IAQ reduced their ability to do schoolwork. Wyon (2004) found that inadequate indoor air quality could reduce the performance of office work by 6-9%.

Ventilation plays an essential role in reducing air pollution by exchanging indoor polluted air with outdoor clean and fresh air. Even though teachers kept windows open in the current study, approximately 80% of them found the work of the ventilation system to be problematic (see Table 12), thus the need to improve ventilation rates. Wargocky et al. (2000) observed that the doubling of ventilation rate increased the office worker's performance on average by 1.7%. Similarly, Seppanen, Fisk, and Lei (2006) found an increase in performance by approximately 1.5% for each doubling of the outdoor air supply rate. At the same time, Wargocki and Wyon (2013) suggested using energy-efficient technologies (e.g., hybrid ventilation systems, installing energy-recovering and air-cleaning technologies to avoid increases in energy consumption).

### *4.2.3 Thermal Comfort*

The subjective evaluation of thermal comfort perception was conducted through survey questions such as satisfaction with thermal comfort in the classroom and the impact of thermal comfort perception on teacher's performance. The commonly reported problem was linked to either cold or hot indoor environments. Approximately 10% of respondents simultaneously indicated both answers ‘hot’ and ‘cold’ when they were asked to describe their thermal perception. More than 30% of teachers expressed their thermal feelings as: “*Always too hot or too cold*”; “*Sometimes it's too cold in the classroom*”; “*It's very extreme - never consistent*”; “*Most days hot/very warm, rarely too cold*”; “*Sometimes it can be so hot you can't breathe, sometimes can be so cold your nose is cold*”. Hence, some classrooms had sharp thermal comfort changes – from cold to hot. Furthermore, the physical measurements provided evidence that some other classes remained hot or cold continuously.

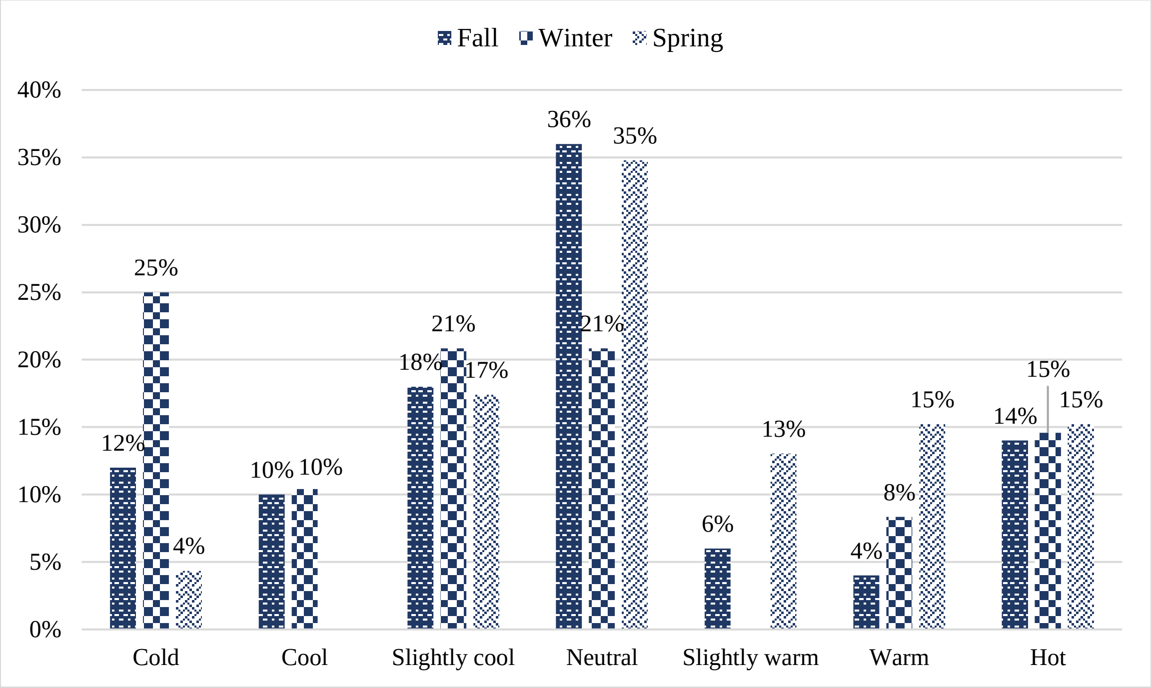

Figure 23 Satisfaction with thermal comfort

As illustrated, 36% of participants felt neutral, 40% of them felt ‘slightly cool’, ‘cool’, or ‘cold’, and 24% were either ‘slightly warm’, ‘warm’, or ‘hot’ during the fall season. Their satisfaction with thermal comfort significantly dropped during the winter. Thus, over half of the teachers felt ‘slightly cool’ or ‘cool/cold’ during the winter, while 23% of them felt ‘warm’ or ‘hot’. The questionnaire results were consistent with field measurements which showed that most surveyed classrooms experienced underheating. The relative humidity level was too low as about 90% of RH values were less than 30% during the winter. The reduced temperature, combined with a relative humidity that is too low, gives occupants the feeling of discomfort. At the same time, two classrooms: 171 or 178, experienced a combination of increased temperatures and low relative humidity, thus worsening the feeling of dry air. These large fluctuations in the indoor air temperatures during the winter season suggest issues with the operation of the heating system and its inability to maintain comfortable indoor air temperatures. These findings support information provided by the building manager about problems with the sensors that control the heating setpoints in the east and west wings as well as the oversized electric boilers that frequently short-cycle (i.e., stop and start multiple times during an hour). Thermal comfort somewhat improved during the spring season. As expected, participants felt the warmest during the spring when approximately a third of occupants had ‘neutral’ feelings, while 21% felt ‘cold’ or ‘cool’, and 43% felt either ‘warm’ or ‘hot’.

These results are consistent with the findings of previous studies (e.g., Lin et al. 2019; Karjalainen 2009; Katafygiotou and Serghides 2014). Lin et al. (2019) found that 19 of the surveyed schools reported unsatisfactory heating while teachers reported extreme cold and excessive heat in the classrooms during the year. A quarter of surveyed teachers complained about dry air in the classrooms. Katafygiotou and Serghides (2014) reported that a few occupants felt ‘hot’ (~7%) during the winter, while 70% of respondents felt ‘cool’ or ‘slightly cool’. 28% of respondents felt uncomfortably ‘cold’ while 11% of them felt ‘hot’ in the study by Karjalainen (2009). Spring was the most comfortable season for the occupants in the study by Katafygiotou and Serghides (2014) as more than half of them had ‘neutral’ feelings about thermal comfort, while 36% felt ‘slightly warm’ to ‘very hot’. Around 40% of occupants felt ‘neutral’, and a similar percentage had feelings from ‘somewhat warm’ to ‘hot’ in the fall season. Although the results of the current study are consistent with the previous studies, it is important to notice that every study has its factors, circumstances, or implications so previous studies do not necessarily validate the current research.

Additionally, the study presents differences in the sense of thermal comfort between the two genders (Table 18).

Table 18 Cross-tabulation of thermal comfort with gender

| Season | Gender | Satisfaction with thermal comfort | | | | | | | U (value) | p-value | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Cold | Cool | Slightly cool | Neutral | Slightly warm | Warm | Hot | | | |
| Fall | Male | 0 | 1 | 0 | 8 | 1 | 0 | 1 | 148.5 | 0.214 | 4.18 |
| | Female | 6 | 4 | 9 | 10 | 2 | 2 | 6 | | | 3.72 |
| Winter | Male | 2 | 1 | 1 | 5 | 0 | 2 | 0 | 163.0 | 0.574 | 3.55 |
| | Female | 10 | 4 | 9 | 5 | 0 | 2 | 7 | | | 3.41 |
| Spring | Male | 0 | 0 | 2 | 8 | 0 | 0 | 0 | 181.0* | 0.043 | 3.80 |
| | Female | 2 | 0 | 6 | 8 | 6 | 7 | 7 | | | 4.81 |

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

As seen in Table 17, the statistical analysis of thermal satisfaction shows statistically significant results for males and females in the spring season (p = 0.043). The female’s mean satisfaction level is 4.81, which is closer to ”slightly warm”, and the male’s mean satisfaction level is 3.80, which is almost ”neutral”. The survey showed that females were affected by the hot environment in the spring season more than males. There are no statistically significant associations between gender and thermal comfort perception in the fall and winter seasons (p=0.214 and p=0.574 accordingly). The frequency distribution of thermal comfort perception between females and males by seasons is shown in Figure 24.

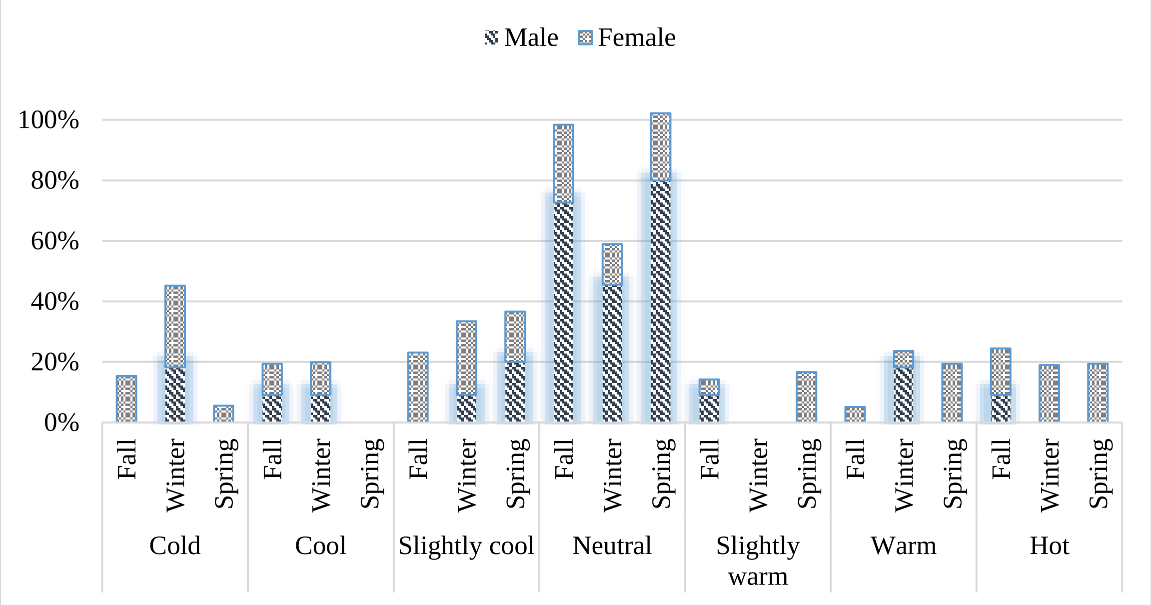

Figure 24 Perception of thermal comfort by seasons

As illustrated in Figure 25, spring is the most comfortable season for males as 80% of them felt neutral, while more than half of females had feelings from hot to slightly warm, which was likely not comfortable for them. The fall was comfortable for males as the majority of them (~73%) voted “neutral” while only a quarter of females had the same feelings. Approximately half of the females felt cold or cool in the fall season, while 25% of them felt hot or warm. In the winter, the prevailing low temperatures affected mainly females. Neutral feelings were expressed by 45% of males and only by 14% of females. Thus, 62% of females and 36% of males complained about feeling cold to slightly cool while 24% of females felt warm or hot versus 18% of males.

Our findings are consistent with the results of the earlier studies where females expressed more dissatisfaction than males with the same thermal environment (Karjalainen 2012; Cena and de Dear, 2001) though Wyon, Andersen, and Lundqvist (1972) found that males were more dissatisfied with thermal conditions than females. Karjalainen (2007) found that females felt cold and hot more often than males, while Beshir and Ramsey (1981) reported that females expressed more dissatisfaction with warmer conditions than males (cited in Djongyang et al. 2010). Karjalainen (2007) reported a statistically significant difference ($p <0.005$) that 40% of females and 16% of males felt cold in the winter season while in the same season, 19% of females against 12% of males voted for "thermally unacceptable" in the study by Cena and de Dear (2001). An earlier study (Muzi et al. 1998)  also concluded that more females (29%) than males (12%) complained about feeling too hot in air-conditioned office buildings (cited Karjalainen 2012).

The differences in the thermal comfort responses of males versus females may be due to clothing differences (Cena and de Dear 2001; Andersson et al. 2002)). To determine the influence of clothing adjustment on their comfort, respondents were asked to provide answers to the question, "Which of the **a** to **k** clothing ensembles do you typically wear in the classroom that you use the most " (see Figure 25). Multiple answers were accepted.

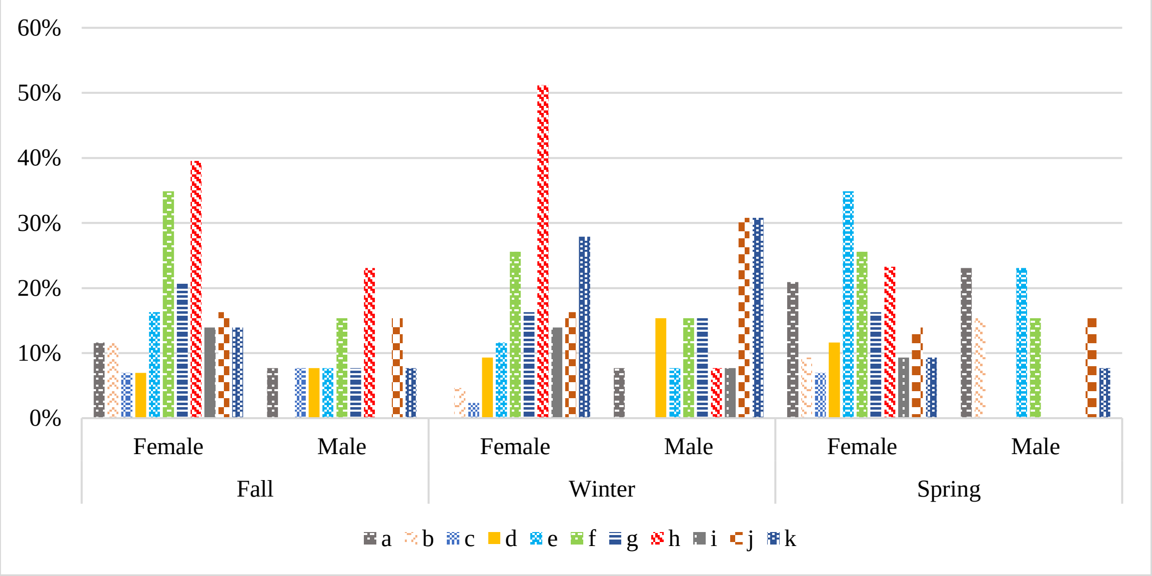

Figure 25 Clothing ensembles (*) the teachers typically wear during the fall, winter and spring seasons

| | |
|---|---|
| *a | shorts or knee-length skirt, short-sleeve shirt |
| b | shorts or knee-length skirt, short-sleeve shirt, sweater or jacket |
| c | shorts or knee-length skirt, long-sleeve top |
| d | shorts or knee-length skirt, long-sleeve shirt, long-sleeve sweater or jacket |
| e | trousers or ankle-length skirt, short-sleeve shirt |
| f | trousers or ankle-length skirt, short-sleeve shirt, sweater |
| g | trousers or ankle-length skirt, long-sleeve shirt |
| h | trousers or ankle-length skirt, long-sleeve shirt, sweater |
| **i** | trousers or ankle-length skirt, long-sleeve shirt, suit jacket |
| j | trousers or ankle-length skirt, long-sleeve shirt, suit jacket, vest or T-shirt |
| k | trousers or ankle-length skirt, long-sleeve shirt, suit jacket, sweater, vest or T-shirt |

During the winter, 51% of females wear trousers or ankle-length skirts, long-sleeve shirts, and sweaters (*h*) while around 60% of males wear trousers, long-sleeved shirts, suit jackets, sweaters, or vest (*j* and *k*). Males appeared to wear more clothing garments than females in the winter. This is in line with Erlandson et al. (2005), who found that females wore approximately 0.1 less closing insulation level than males in the winter (cited Karjalainen 2012). In the spring, more than half of the females and less than half of the males preferred to wear short-sleeve shirts (*a* and *e*). This could be because half of the females felt from ‘hot’ to ‘slightly warm’, while 80% of males had neutral feelings related to the thermal comfort in the spring (as seen in Figure 25). The majority of females (~75%) chose options *f* and *h* during the fall as 48% of females voted to feel from ‘cold’ to ‘slightly cool’.

Thermal comfort could be achievable for all occupants if they have effective control over the thermal environment (Van Hoof 2008). Adjustments related to thermal sensations such as changing clothing; opening/closing windows; and consuming hot or cold beverages play a significant role in defining thermal acceptability in classrooms. Thermal discomfort leads occupants to take active responses to adapt to the thermal environment. In this study, respondents were asked if they needed to control or adjust the temperature in the classroom, and if yes, what actions they needed to undertake (as shown in Figure 26).

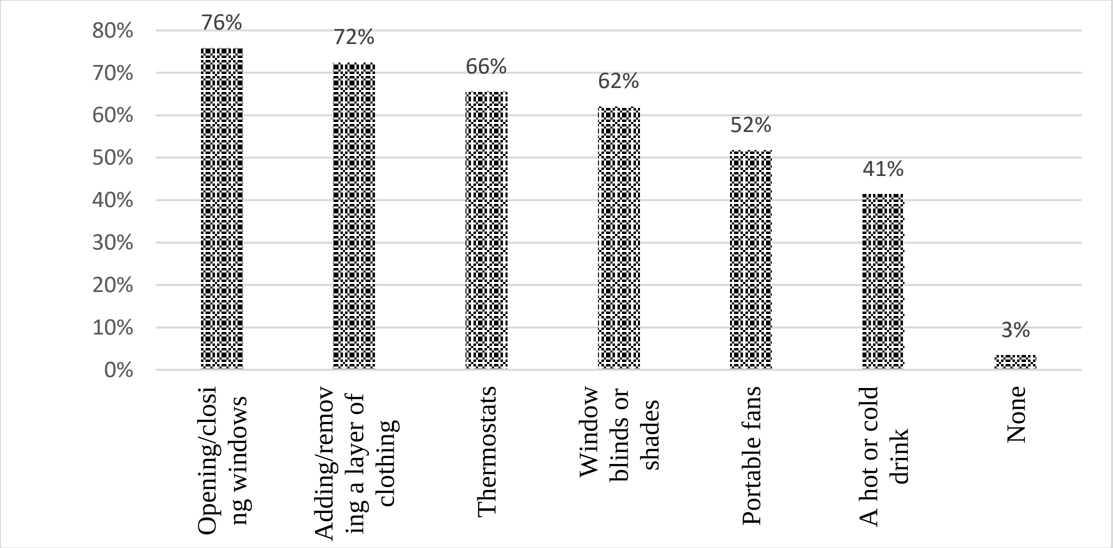

Figure 26 Options to control or adjust the temperature

Approximately half of the respondents wanted to control or adjust the temperature of the classroom. The majority of them used strategies such as opening or closing windows, changing clothing insulation, or adding or removing a clothing garment at the same time to do so. The current study showed that about 60% of teachers used window blinds or shades and thermostats as adaptive opportunities in the classrooms. One teacher expressed the concern that: "*I do not touch the thermostat, if turn it up it gets too hot*". This further reinforces the suggestion that a problem with the operation of the heating system and the placement of thermal sensors may exist in the school.

Table 19 depicts respondents' answers to the question: "Which of these options are not available to yourself/students or cannot be controlled by yourself/themselves in the classroom".

Table 19 Options that are not available to adjust the thermal sensation

| | Window blinds or shades | Thermostats | A hot or cold drink | Opening/closing windows | Portable fans | Other (please specify) | Adding/removing a layer of clothing | None |
|---|---|---|---|---|---|---|---|---|
| Teachers | 34% | 57% | 13% | 27% | 43% | 0% | 5% | 13% |

More than half of the teachers (57%) were unable to use the thermostats, while 27% of pedagogical staff did not have the option to open or close windows to adjust the thermal environment. The reasons for why respondents did not open the windows are illustrated by season in Table 20.

Table 20 Reasons for not opening windows

| | Fall | Winter | Spring |
|---|---|---|---|
| It is not needed | 30% | 7% | 15% |
| It is noisy outside | 0% | 0% | 0% |
| It is cold outside | 7% | 56% | 0% |
| It is dusty/smelly outside | 15% | 0% | 15% |
| None | 33% | 26% | 41% |

As seen in Table 19, during the mid-season, 15% of teachers did not open the windows because of dusty odours outside, while in the winter, the cold temperature was the main reason why they did not do so.

These results were in line with the results by Lin et al. (2020), who reported that about 78% of teachers were unable to control classroom temperature via the thermostats. A few of them (13.4%) also reported being unable to open classroom windows to adjust the temperature. Huizenga et al. (2006) found that occupant's dissatisfaction with thermal comfort was due to the absence of thermostats and operable windows. These two studies' results showed that personal control over environmental conditions had a significant positive impact on occupant satisfaction.

Thermal comfort has a significant impact on productivity and performance. If occupants are dissatisfied with the thermal environment, their level of productivity decreases (Al horr et al. 2016). Approximately 41% of respondents complained that thermal conditions affected their ability to do their work negatively. Table 21 demonstrated the association between the level of satisfaction with thermal comfort and teachers' performance.

Table 21 Association between satisfaction with thermal comfort and teachers' performance

| | | Performance | | |
|---|---|---|---|---|
| | | Fall | Winter | Spring |
| Perception of thermal comfort | R | 0.222 | -0.119 | 0.173 |
| | p-value | 0.122 | 0.421 | 0.251 |

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

As can be seen from Table 20, the Spearman Rho test did not reveal a statistically significant association between teachers' performance and their perception of thermal comfort. This could be due to the small sample of teachers surveyed. A bigger sample could provide different results. However, respondents reported the negative impact of thermal environment on performance: "*Heat gives way to laziness and less movement*"; "*Uncomfortable*"; "*On warmer days it is too hot to be in the class, students do not want to be in there either*"; "*Either too hot or too cold*"; "*Students feel sluggish*"; "*Cold in the winter, humid in the fall and spring*"; "*Creates tiredness, sluggishness, headaches, rashes, sneezing*"; "*Sometimes when they can't regulate the temperature in class, it is too hot or too cold; the heating system doesn't seem to work properly*".

In contrast to the results of the current study, previous studies found a relationship between thermal discomfort and occupants' productivity (Lan et al. 2010; Zeiler and Boxem 2009;

Seppanen et al. 2006; Al-horr et al. 2016). Lan et al. (2010) found that occupants' motivation to work was significantly affected by the air temperature. The authors added that occupants had significantly higher motivation to work in neutral conditions than in warm conditions. High air temperature substantially reduces participants' motivation to do their work (Zeiler and Boxem 2009; Lan et al. 2010). Seppanen et al. (2006) found a reduction in performance of about 1% for every 1°C change. The optimal range of temperature for the highest level of productivity should be between 20°C and 25°C (Al-horr et al. 2016). Some researchers (e.g., Bauman et al., 1998; Seppanen et al. 2006) provided evidence that personal control over thermal conditioning systems would improve productivity.

Hence, IEQ management requires the awareness and involvement of students, teachers, and school management (Ekren et al. 2017). Over half of the school staff complained about the thermal conditions of the classroom to the manager/supervisor, and 19% of them reported that the school management had addressed the problem.

### *4.2.4 Lighting comfort*

In this research, the teacher's perceptions of lighting quality were evaluated using survey questions inquiring about teachers' satisfaction with overall lighting and reflection/glare in the classroom. It also included inquiring about teachers' satisfaction with daylighting, their control of lighting in the school, and about the impact of lighting on performance. Teachers' satisfaction with lighting comfort is represented in Figure 27.

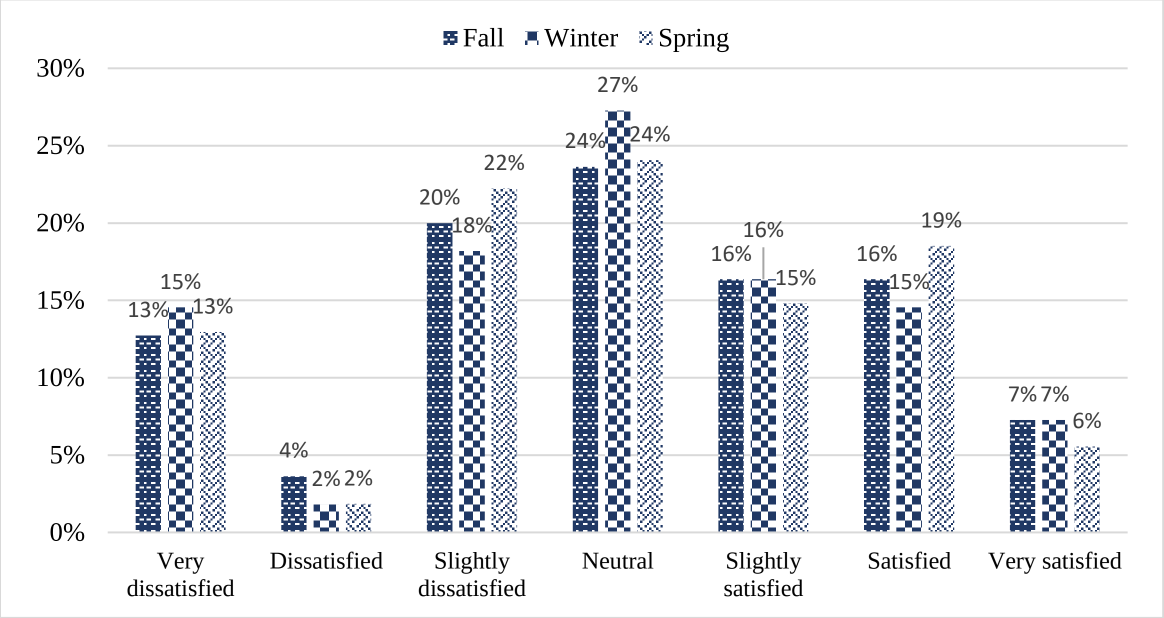

Figure 27 Satisfaction with lighting comfort

Figure 28 illustrated the diversity in opinions related to lighting quality. Approximately 40% of respondents reported feeling 'slightly satisfied' to 'very satisfied'; about a quarter of them had 'neutral' feelings about lighting across the seasons while the percentage of very dissatisfied respondents was about 15%.

Table 22 summarizes respondents' satisfaction with lighting quality by gender and season. The results of the Mann-Whitney U test did not reveal any statistically significant associations between gender and satisfaction with lighting comfort across the seasons ($p>0.05$).

Table 22 Cross-tabulation of lighting comfort with gender

| Season | Gender | Satisfaction with lighting comfort: Very dissatisfied | Moderately dissatisfied | Slightly dissatisfied | Neutral | Slightly satisfied | Moderately satisfied | Very Satisfied | U (value) | p-value |
|---|---|---|---|---|---|---|---|---|---|---|
| Fall | Male | 2 | 0 | 1 | 4 | 2 | 1 | 3 | 222.5 | 0.309 |
| | Female | 5 | 2 | 10 | 9 | 7 | 8 | 1 | | |
| Winter | Male | 2 | 0 | 1 | 4 | 2 | 1 | 3 | 219.5 | 0.280 |
| | Female | 6 | 1 | 9 | 11 | 7 | 7 | 1 | | |
| Spring | Male | 2 | 0 | 1 | 4 | 2 | 1 | 2 | 224.0 | 0.553 |
| | Female | 5 | 1 | 11 | 9 | 6 | 9 | 1 | | |

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

These findings are in agreement with the study by Xue et al. (2014), who reported a lack of statistically significant difference between genders with respect to satisfaction with lighting comfort. In contrast, Knez (2001) found that females were more perceptive of lighting conditions than males, while Duijnhoven (2020) found male participants to be statistically less satisfied with lighting than female participants.

Previous studies showed that people believed that daylight was superior to electric light in its effect on people (Galasiu and Veitch 2006; Xue et al. 2014). The current study showed that ~96% of respondents had windows. There were no windows in the gym and one of the offices in the school. Lin et al. (2020) showed that over 95% of respondents had windows in the classrooms, while 86% considered daylighting to be their preferred source of lighting (Galasiu and Veitch 2006). Xue et al. (2014) found that occupants' satisfaction with lighting comfort would be reduced if artificial lighting needed to be used. The current study showed that approximately 44% of teachers reported that they used natural lighting during the school day. Table 23 demonstrates how long on average, respondents used natural light for:

Table 23 Daily distribution of using natural light

| Season | Less than 1 hour | 1 to 3 hours | More than 3 hours |
|---|---|---|---|
| Fall | 21% | 29% | 58% |
| Winter | 21% | 33% | 58% |
| Spring | 17% | 21% | 71% |

The majority of occupants (~70%) used natural light in the spring as the duration of sunlight hours increased during the spring and decreased from summer to winter so that participants would have had fewer sunlight hours in the winter. More than half of the respondents used daylighting more than 3 hours per day in the fall and winter seasons.

Occupants were also asked to evaluate their satisfaction with glare and reflection (as seen in Figure 28).

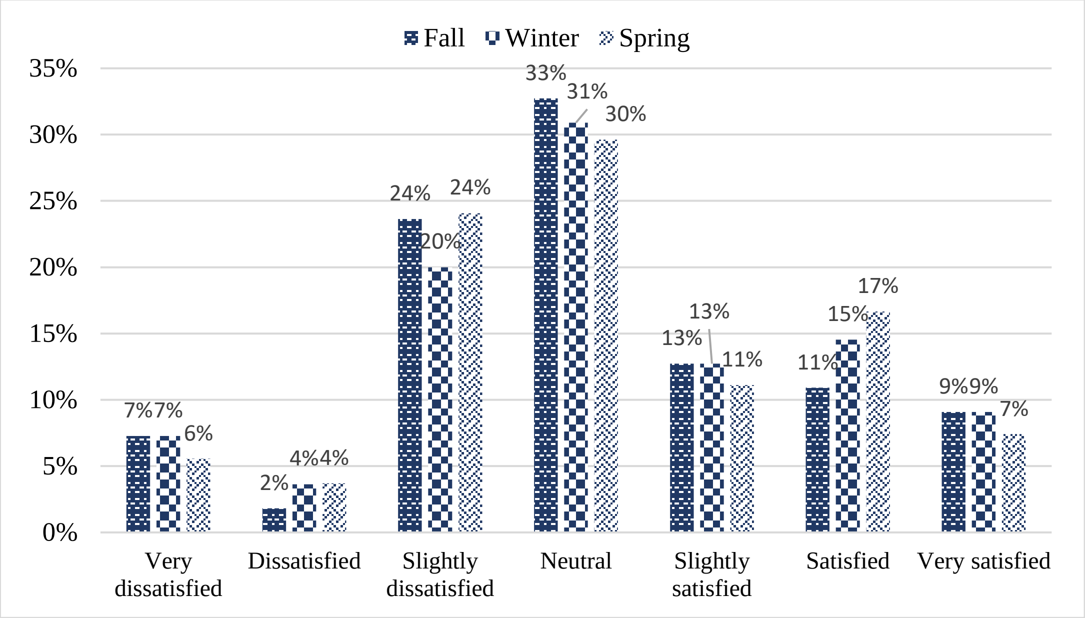

Figure 28 Satisfaction with glare/reflection

The results were divided into three parts: approximately one-third of respondents were ‘satisfied’ with lighting comfort while the other third part had ‘neutral’ feelings. The last third was uncomfortable with lighting. Some participants appreciated the possibility of dimming down illuminance: “Lighting may be too bright/glare at times”, or “Bright - irritates my eyes”. This is in line with the study by Lin et al. (2020), who reported that approximately 6% of school occupants complained that the classroom light was too bright. De Giuli et al. (2012) found that the primary source of glare in several surveyed schools was natural light. This was also the case in this study. To prevent glare, teachers “*added cellophane to the window to tone downlight*”. This is in line with Lin et al. (2020), where more than 7% of respondents controlled window glare by papers taped to the windows.

Winterbottom and Wilkins (2009) suggested that classrooms with excessive lighting should be equipped with adequate means of control. Boyce et al. (2006) concluded that lighting conditions that could be controlled individually were rated as more comfortable while Veitch et al. (2008) added that people with perceived good lighting conditions showed improved mood and higher ratings of lighting satisfaction. Approximately 64% of surveyed respondents needed to be able to control or adjust their lighting. This is consistent with Lang (2002), who reported that teachers preferred to have control of lighting levels (cited in Winterbbotom and Wilkins 2009). Table 24 presents the results with respect to options that were available and not available to teachers to control or adjust the lighting in the current study.

Table 24 Options to control or adjust the lighting comfort

| Options to control or adjust lighting | Options teachers use to control the lighting | Options are not available to teachers to control the lighting |
|---|---|---|
| Window blinds or shades | 64% | 23% |
| Light dimmer | 14% | 54% |
| Light switch | 100% | 7% |
| None | 0% | 29% |

The study also showed that 100% of respondents who wanted the ability to control or adjust lighting did so by switching on or off electric lighting. More than 60% used window blinds or shades, and only 14% had access to the light dimmer. Maniccia et al. (1999) surveyed occupants of 43 offices and found that 74% of them used dimmers to adjust their lights. More than half of the teachers in the current study did not have access to the light dimmer, while 23% of them could not prevent glare or reflection by window blinds or shades. Furthermore, the study showed that lighting that was “too bright” was associated with an increased risk of work-related symptoms. Approximately 7% of teachers complained about the bright light and its impact on health: “*The lights give me a headache and blurry vision afte*r”; “*I get headaches and often have to turn a few of the lights off*”; “*Headaches-fluorescent lighting sucks; it is way too bright*”. In general, previous studies (e.g. De Giuli et al. 2012) showed that school buildings were not equipped with adjustable lighting, and in many cases, shades were broken or missed thus creating visual discomfort that, in turn, significantly affected the health of school occupants. The use of lighting controls is essential to achieve an optimal level of lighting and reduce related energy consumption (Galasiu and Veitch 2006). Maniccia et al. (1999) also found that dimmers' ability to adjust lights along with motion sensors could maximize occupant satisfaction and minimize wasted energy.

Approximately 14 % of respondents indicated that lighting quality affected their ability to do the work. Teachers emphasized that this effect is connected with light and glare that were too bright, which in turn, led to eye irritation and headaches. The glare that is the result of excessive direct sunlight and artificial light can result in visual discomfort (Al-horr et al. 2016). The results of Spearman’s Rho test of correlation between the level of satisfaction with lighting quality and teachers’ performance are presented in Table 25.

Table 25 Association between satisfaction with lighting comfort and performance

| | | Performance | | |
|---|---|---|---|---|
| | | Fall | Winter | Spring |
| Satisfaction with lighting quality | R | -0.267* | -0.258 | -0.268 |
| | p-value | 0.05 | 0.06 | 0.06 |

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 24 shows that the Spearman Rho test revealed a statistically significant, weak association between satisfaction with lighting quality and teacher's performance, at the 0.05 level in the fall season. The test did not find statistically significant associations between lighting comfort and performance in the winter and spring seasons. This is in line with Knez (1995) who suggested that indoor lighting influenced mood and cognition and might then affect performance. In contrast, Veitch (1997) argued that lighting did not affect performance.

### *4.2.5 Acoustics comfort*

The subjective evaluations of acoustics perceptions were conducted using questions that enquired about teachers' satisfaction with noise levels in the classroom they used the most, the source of noises, the quality of speech communication between teachers and students, and the impact of acoustics quality on teachers' ability to do work.

Teacher satisfaction with acoustics quality is represented in Figure 29.

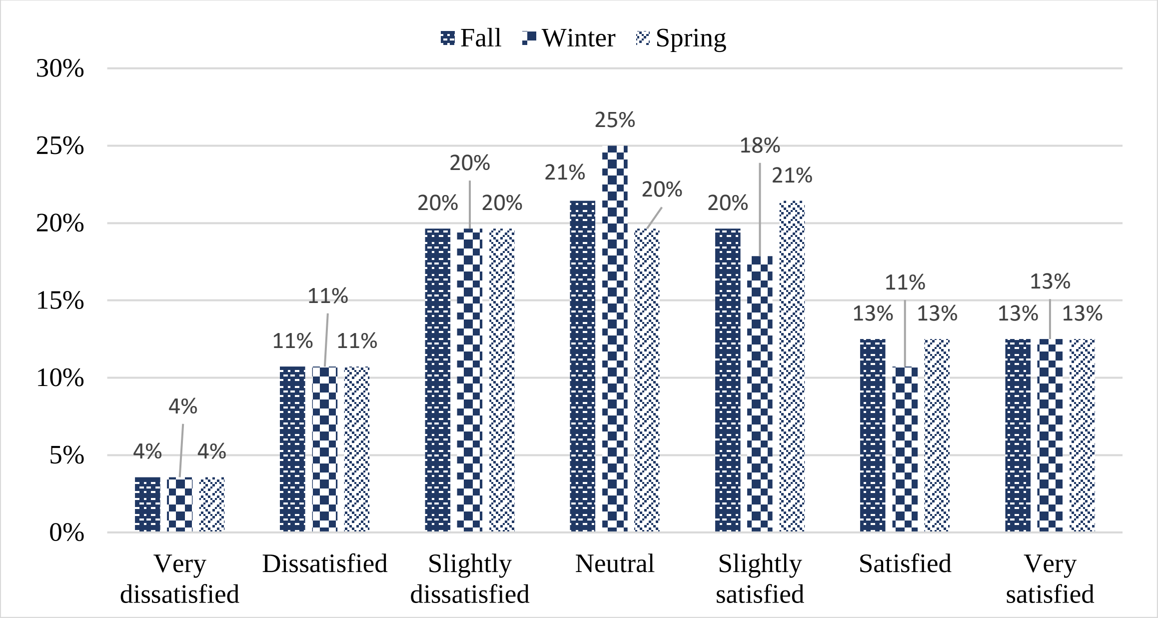

Figure 29 Satisfaction with acoustics comfort

Over 40% of school staff stated feeling from ‘slightly satisfied’ to ‘very satisfied’ with noise in the three seasons. Approximately 20% of occupants had “neutral feelings” while a third feel discomfort with noise. Over half of the teachers in the study by Lin et al. (2020) reported excessive noise, and about 3% reported excessive echo. Raymond, Truchon-Gagnon, and Bilodeau (1990) conducted a study in Quebec on noise problems in schools and found that “a majority of respondents (61%) reported that sound levels were ‘uncomfortable’ or ‘detrimental to their work’ and either a frequent or a permanent feature of their workplace”.

Table 26 shows that the results of the Mann-Whitney U test did not detect a statistically significant association between gender and satisfaction with acoustics comfort in the three seasons ($p > 0.05$).

Table 26 Cross-tabulation of acoustics comfort with gender

| | | Satisfaction with acoustics quality | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Seasons | Gender | Very dissatisfied | Moderately dissatisfied | Slightly dissatisfied | Neutral | Slightly satisfied | Moderately satisfied | Very Satisfied | U (value) | p-value |
| Fall | Male | 1 | 0 | 2 | 5 | 2 | 2 | 1 | 274 | 0.914 |
| | Female | 1 | 6 | 9 | 7 | 9 | 5 | 6 | | |
| Winter | Male | 1 | 0 | 2 | 5 | 3 | 1 | 1 | 273 | 0.898 |
| | Female | 1 | 6 | 9 | 9 | 7 | 5 | 6 | | |
| Spring | Male | 1 | 0 | 2 | 5 | 3 | 1 | 1 | 272 | 0.883 |
| | Female | 1 | 6 | 9 | 6 | 9 | 6 | 6 | | |

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Ellermeier and Zimmer (1997) reported that there was no significant difference between genders in the response to the effect of noise on performance. In contrast, Yang et al. (2012) found significant interactions between noise, task performance, and gender (cited Kim et al. 2013).

Speech communication includes two primary modes: speaking and hearing, so Sala and Viljanen (1995) suggested that "a classroom's acoustic design should be constructed so that the highest possible degree of speech intelligibility is achieved for teachers and pupils".

School teachers explained they experienced echoing (reverberation): “*There is an echo effect (I think) where the normal sound is amplified. It sounds like I'm yelling when I'm not*” or *“Echo when talking”*. This negatively affected the quality of speech communication between teachers and students and created a worse acoustic environment in the classroom. Table 27 shows the Spearman Rho test revealed statistically significant, moderate positive correlations between satisfaction with acoustics quality and satisfaction with speech communication in the three seasons. We can suggest that, as long as teachers are satisfied with the quality of verbal communication between them and students, their satisfaction with the acoustics quality will generally be higher.

Table 27 Spearman’s Rho coefficient between satisfaction with acoustics and satisfaction with speech communication

| | | Satisfaction with acoustics | | |
|---|---|---|---|---|
| | | Fall | Winter | Spring |
| Satisfaction with speech communication | R | $0.627^{**}$ | $0.611^{**}$ | $0.667^{**}$ |
| | p-value | 0.000 | 0.000 | 0.000 |

The results of the current study are consistent with the study by Lin et al. (2019), who found that due to noise or echo, about12% of teachers had to raise their voices to be heard, and they do not hear students. More than half of the teachers surveyed considered noise at work as an essential reason for communication problems (Raymond et al. 1990). Raymond et al. (1990) suggested that the acoustic environment of some Quebec classrooms is not optimal for teachers' well-being and their work performance.

The questionnaire demonstrated that teachers were sensitive to the acoustic environment and able to identify which acoustic conditions (i.e., sources of noise) interfered with the learning process and affected them most. Teachers were asked to rate their satisfaction with various sources of noise in the school, including 1) noise intrusion from outside the school; 2) noise from corridors and neighboring classrooms; 3) background noise within the room generated by HVAC; 4) noise caused by equipment like printers, projectors, or computers; as well as 5) noise from washrooms or other plumbing noise. As depicted in Figure 30, on average, teachers seemed to find noise from the outside (external) and from other areas (classrooms and halls) to be the most problematic.

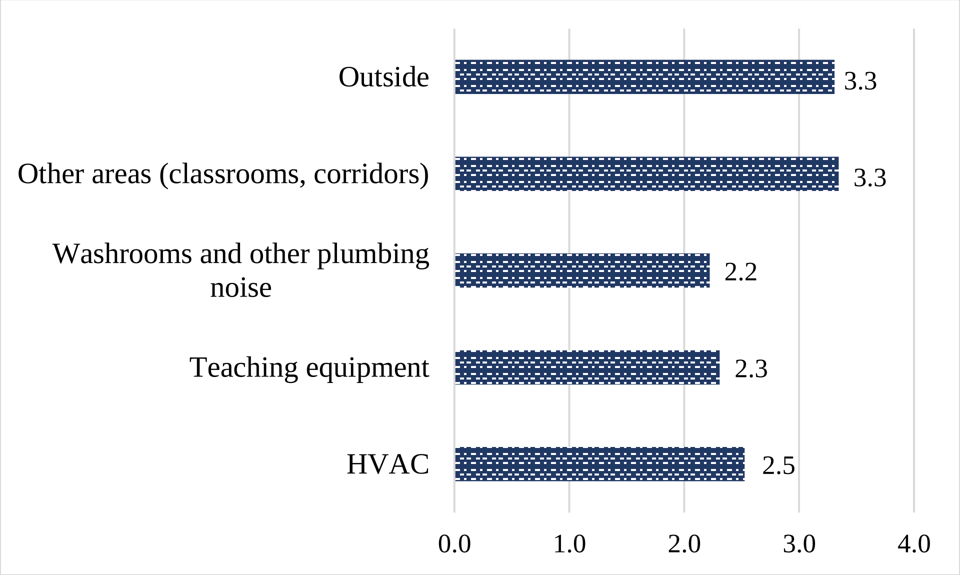

Figure 30 Teacher’s rating of various sources of noise

These results suggest that teachers were more satisfied with noise levels the lower the external noise, the noise from other areas (e.g., corridors, nearby classrooms), and the heating and ventilation background noise.

The Spearman Rho test was used to find associations between satisfaction with the quality of acoustics and noise sources such as HVAC, teaching equipment, washrooms (other plumbing areas), other areas (classrooms, corridors), and outside noise (as shown in Table 28).

Table 28 Spearman Rho coefficients between satisfaction with the acoustics quality and different sources of noise

| | | Satisfaction with acoustics | | |
|---|---|---|---|---|
| | | Fall | Winter | Spring |
| HVAC | R | -0.278* | -0.296* | -0.267* |
| | p-value | 0.040 | 0.028 | 0.049 |
| Teaching equipment | R | -0.243 | -0.253 | -0.235 |
| | p-value | 0.074 | 0.062 | 0.085 |
| Washrooms | R | -0.317* | -0.321* | -0.310* |
| | p-value | 0.020 | 0.018 | 0.022 |
| Other areas | R | -0.381** | -0.398** | -0.379** |
| | p-value | 0.004 | 0.003 | 0.004 |
| Outside | R | -0.281* | -0.289* | -0.274* |
| | p-value | 0.038 | 0.032 | 0.043 |

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed)

Table 28 showed that statistically significant, weak negative correlations existed between satisfaction with acoustics quality and other areas (nearby classrooms and corridors), washrooms, and outside areas across the seasons. Due to its location, the school was exposed to external noise as high traffic noise. Teachers highlighted that they were affected by noise from neighboring classrooms, corridors, and outside environments, and this kind of noise distracted them: “*Kids are noisy in the halls or when the next-door classroom has music or video (movie) on and the base vibrates too loudly*”; “*Outside, hallway noise is distracting*”; “*You can hear everything in the hall/neighboring classrooms*”; “*Noise by high traffic area, close to outside doors, kitchen, office, hall and bathrooms*”; “*The children that go outside from other classes can be heard even when my door is shut*”; “*Even when my class door is shut, I can still hear grades going out for recess; the acoustics is pretty awful*”.

The results partly mirrored the findings by Lin et al. (2020), who found that the most commonly reported sources of excessive noise were from nearby classrooms or hallways (~57% of respondents). Some studies (e.g., Woolner and Hall 2010; Dockrell and Shield 2004) investigated the effects of external noise on work in the classroom. Another study by Eysel-Gosepath (2012) found that 48% of teachers reported noise in the corridors as high, whereas external noise (e.g., construction, traffic) was not a disturbing problem for surveyed teachers (cited Winterbottom and Wilkins 2009)

These results raise concerns that have been raised in the literature in the past (e.g., Sadick and Issa 2017; Vilcekova et al. 2017; Astolfi and Pellerey 2008; Zannin & Marcon 2007; Woolner and Hall 2010). A survey of teachers by Vilcekova et al. (2017) showed that among pedagogical staff, 100% were concerned with sound discomfort,  identifying noisy students as the primary source of the problem. Astolfi and Perelly (2008) found a close correlation between noise disturbance and students talking or shuffling in neighboring classrooms. Teachers also preferred "an indoor environment that minimizes distractions from outside, and from nearby classrooms" (Sadick and Issa 2017). Astolfi et al. (2012) attributed the excessive noise and reverberation in schools to the poor sound insulation of windows that allowed external noise. Zannin and Marcon (2007) explained that the low acoustic insulation between classrooms and the corridor caused high levels of background noise in the classrooms. Noise leaking between rooms in schools can be due to design and construction issues, while HVAC noise reinforces the need for quieter HVAC systems (Woolner and Hall 2010).

Furthermore, approximately 14% of teachers believed that acoustical quality influenced their performance. Al-horr et al. (2016) suggested that both external and internal noise affected occupant’s performance and led to stress, anxiety, and possibly long-term health issues for occupants. Table 29 showed statistically significant, weak negative correlations between acoustics qualities and performance in the three seasons.

Table 29 Association between satisfaction with acoustics quality and teacher's performance

| | | Performance | | |
|---|---|---|---|---|
| | | Fall | Winter | Spring |
| Satisfaction with acoustics | R | -0.319* | -0.347** | -0.293* |
| | p-value | 0.017 | 0.009 | 0.028 |

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

The results of the current study are in line with those in the literature (Klatte and Hellbroock 2010; Lin et al. 2020; Raymond et al. 1990). About 11% of teachers reported that noise or echo affected their teaching ability (Lin et al. 2020). Moreover, MacKenzie and Airey

(1999) found that teachers working in classes with a high level of reverberation were absent more often than teachers in classes with no reverberation (cited Klatte and Hellbroock 2010). The reduced quality of speech communication caused teachers' fatigue and decreased students’ performance (Astolfi and Perelley 2008). Klatte and Hellbroock (2010) suggested that "poor interior acoustics negatively affect the social-emotional class atmosphere". This assumption was based on prior studies that concluded that noise and reverberation influenced teachers’ health. Raymond et al. (1990) also highlighted the negative impact of uncomfortable acoustic conditions on teachers' well-being and performance. These teachers had communication troubles, voice problems, less patience, and were less effective than they would like. They also suffered from stress and malaise.

### *4.2.6 Teacher's self-reported health symptoms and their influence on the performance*

#### *4.2.6.1 Teacher's self-reported symptoms*

A poor indoor environment may lead to health problems. The current study examined the relationship between indoor environmental quality and building-related health symptoms. Teachers were asked about building-related health symptoms and their impact on their ability to do their work across the seasons. They were also asked whether they had been diagnosed with asthma and their smoking habits or if they were subjected to environmental tobacco smoke (ETS).

In the current study, 41% of respondents were smokers, while 36% of teachers were subjected to environmental tobacco smoke. The results were higher than the one by Kielb et al. (2015), who showed that only 9.6% of teachers smoked or were exposed to second-hand smoke. The high rate of environmental tobacco smoke exposure in this study is not surprising given the high prevalence of smoking in many Aboriginal Canadian Communities (Daniel et al. 2004). (Reinikainen, Aunela-Tapola, and Jaakkola 1997) found no statistically significant difference in IAQ perception (odour and stuffiness) between smokers and non-smokers, while the study by Reijula and Sundman-Digert (2004) demonstrated that smokers complained more often about environmental problems (e.g., dry/stuffy air, dust or draught) and reported more SBS symptoms than non-smokers.

Approximately 16% of the participants were diagnosed with asthma. This is consistent with the survey by Kielb et al. (2015), who found that 12% of teachers had asthma. Nevertheless, another study (Vilcekova et al. 2017) had found that 60% of school staff had health concerns with asthma and 40% of them reported asthma within one year. Due to limited asthma data for Aboriginal communities, the prevalence of asthma among the Aboriginal population is contradictory. Gao et al. (2008) reported that the prevalence of asthma appears to be lower in Aboriginal children than in non-Aboriginal children in the northern territories of Canada, while Latycheva et al. (2013) argued that childhood asthma rates were 40% higher in Aboriginal communities than in the general Canadian population. These results are significant considering the evidence that poor indoor air quality conditions such as indoor dampness and mold are strongly linked to the aggravation of asthma symptoms (e.g., Bornehag et al. 2004; Norbäck et al. 1999; Kielb et al. 2015). Teachers from schools exposed to mold and dampness reported more asthma symptoms, with the symptoms being stronger among teachers who had been working for more than five years than those who were employed for five years and less (Zock et al. 2011). Asthmatic subjects are less sensitive to air pollution compared to non-asthmatic subjects because their odour intensity and sensory irritation ratings are generally lower than non-asthmatic subjects (Wolkoff 2018).

Figure 31 summarized the prevalence of self-reported health symptoms among teachers in the fall, winter, and spring seasons.

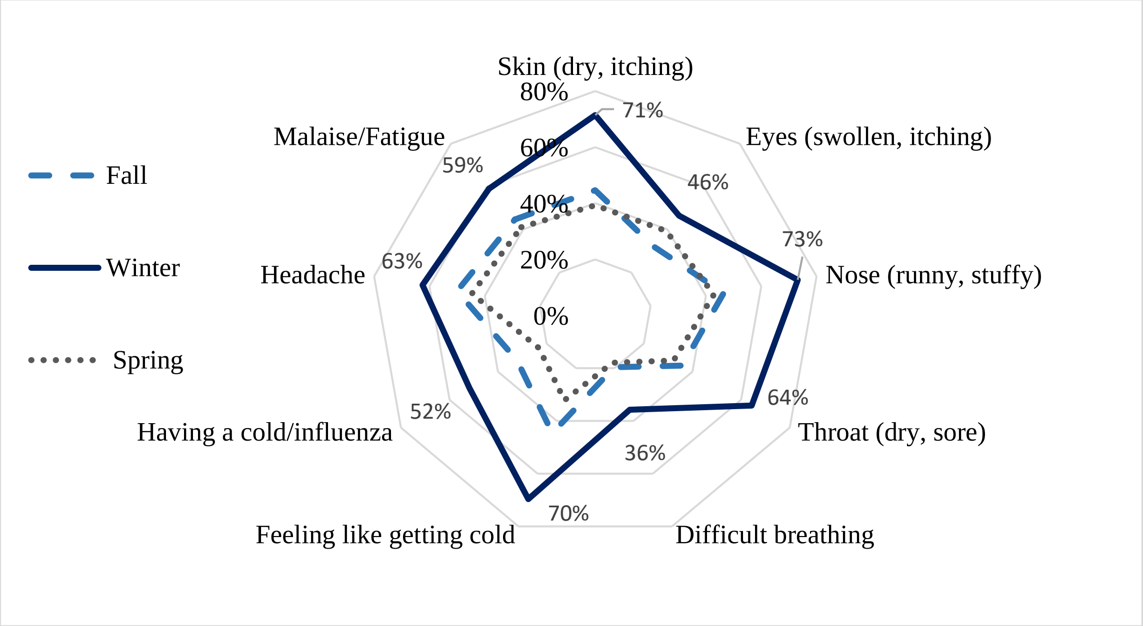

Figure 31 Prevalence of SBS symptoms among the teachers

The lowest number of health complaints was made in the spring season. The most frequently reported symptoms (~40%) were nose and eye irritation, headaches, fatigue, and skin problems in the spring. During the fall season, approximately 45% of the teachers surveyed reported headaches, nose irritation, skin problems, and feeling like getting a cold. Respondents noticed that health symptoms worsened in the winter season. The most-reported building-related symptoms in the winter season were runny/stuffy nose (~73%), skin problems (~70%), feeling like getting cold (~70%), headache (~63%), and dry throat (~64%).

In general, these results are consistent with other studies (e.g., Turunen et al. 2014; Vilcekova et al. 2017; Kielb et al. 2015). Vilcekova et al. (2017) reported that the most frequently reported health symptoms by school occupants were fatigue (80%), cough (100%), nose irritation (80%), sore/dry throat (60%), and headaches (80%). In another study that addressed teacher health (Kielb et al. 2015) the most prevalent symptoms were frequent colds (60%), sinus problems (~46%), allergies/congestion (~33%), headaches (~37%), throat irritation (~38%), and nausea (~37%). Vilcekova et al. (2017) found that such symptoms were very common in schools, with many respondents reporting health problems they thought were caused by the school environment (Schneider 2003).

The risk of having adverse health symptoms is greater with increasing numbers of reported adverse classroom characteristics (Kielb et al. 2015). Spearman Rho test was run to assess the relationships between the environmental conditions of the school and reported health symptoms (as shown in Table 30). Table 30 depicts only statistically significant associations between variables so statistically insignificant relationships were excluded from the table.

Table 30 Relationships between health symptoms and environmental exposure at the school

| | Season | | Satisfaction with IAQ | Satisfaction with thermal comfort | Air temperature | Air humidity | Satisfaction with acoustics |
|---|---|---|---|---|---|---|---|
| Eyes irritation | Fall | R | -0.347** | | | | |
| | | p-value | 0.009 | | | | |
| | Spring | R | -0.360** | | | | |
| | | p-value | 0.006 | | | | |
| Nose irritation | Fall | R | -0.283* | | | | |
| | | p-value | 0.034 | | | | |
| | Winter | R | | | -0.315* | | |
| | | p-value | | | 0.019 | | |
| | Spring | R | -0.488** | 0.486** | -0.289* | | |
| | | p-value | 0.000 | 0.001 | 0.032 | | |
| Throat problems | Fall | R | -0.455** | | -0.311* | -0.303* | |
| | | p-value | 0.000 | | 0.020 | 0.027 | |
| | Winter | R | | | -0.367** | -0.326* | |
| | | p-value | | | 0.006 | 0.016 | |
| | Spring | R | -0.401** | | -0.342* | | |
| | | p-value | 0.002 | | 0.011 | | |
| Headache | Winter | R | -0.324* | -0.298* | -0.421** | -0.332* | -0.301* |
| | | p-value | 0.015 | 0.040 | 0.001 | 0.015 | 0.024 |
| Fatigue | Fall | R | -0.378** | | -0.287* | -0.355** | |
| | | p-value | 0.004 | | 0.034 | 0.008 | |
| | Winter | | -0.406** | | -0.324* | -0.279* | |
| | | | 0.002 | | 0.016 | 0.043 | |
| | Spring | | -0.587** | 0.366* | -0.329* | -0.298* | |
| | | | 0.000 | 0.012 | 0.014 | 0.029 | |
| Difficult breathing | Fall | R | | | -0.292* | | |
| | | p-value | | | 0.029 | | |
| Felling like getting cold | Winter | R | | | -0.306* | | |
| | | p-value | | | 0.023 | | |

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

The Spearman Rho test did not detect any statistically significant associations between satisfaction with lighting quality and health symptoms (p>0.005), as well as between satisfaction with lighting quality and ‘skin problems’(p>0.005). Statistically significant negative associations between satisfaction with IAQ and health symptoms such as eyes (fall, spring) and nose irritation (fall, spring), throat problems (fall, spring), headache (winter), and fatigue (fall, winter, spring) were found during the study.

Kreiss (1989) reported that concerns about the adverse effects of poor IAQ had increased since the late sixties when occupants of residential, commercial, and institutional buildings started reporting health problems associated with their environments, such as eye and upper respiratory tract irritation, headache, and fatigue (cited Wolkoff et al. 1993). The reporting of similar incidents has continued unabated, particularly in schools. The few studies conducted on the effectiveness of remedial measures in Europe and North America showed that poor ventilation, building characteristics, building use, maintenance, and cleaning were causal agents of poor IAQ in schools (EPA 2014; Daisey et al. 2003). The current study showed that approximately 70% of teachers were dissatisfied with indoor air quality, complaining about stuffy air (~35%) and improper work of the ventilation system (~80%). These results are consistent with studies that found associations between ventilation, building-related health symptoms, and perceived IAQ (Seppänen 1999; Schneider 2003; Smedje et al. 1996; Kielb et al. 2015). Schneider (2003) reported that the school environment caused health problems such as asthma and respiratory problems. Stenberg and Wall (1995) found that high $CO_2$ levels caused building-related symptoms such as allergy, discomfort, poorer perceived air quality, and reduced performance and productivity. High $CO_2$ concentrations were associated with health symptoms such as fatigue, headaches, dizziness, respiratory problems, and difficulties concentrating (Myhrvold et al. 1996; Daysey et al. 2003; Annesi-Maesano et al. 2013). Similarly, Kielb et al. (2015) reported ventilation inadequacy and teacher health symptoms. Kovesi et al. (2007) found a strong association between indoor $CO_2$ levels and the risk of lower respiratory tract infection among Inuit infants and young children. They suggested that inadequate home ventilation and overcrowding contributed to a high rate of lower respiratory diseases among Innuit children.

Statistically significant negative associations were detected between air humidity and adverse health symptoms such as throat problems in the fall and winter, headache in the winter, and fatigue in the fall, winter, and spring. Average relative humidity in the current study recorded values between 32-43% in the fall season, less than 30% in the winter, and close to the lowest recommended level in the spring. Previous studies reported that too high and too low relative humidity has direct and indirect effects on SBS symptoms (Wolkoff 2018; Angelon-Gaetz et al. 2016). Furthermore, dry indoor air is known to cause adverse health effects (Fang et al. 2004). For example, Amouei et al. (2019) found a significant relationship between ‘dry air’ and SBS symptoms in the winter (p=0.011) and a substantial connection between humidity and SBS symptoms in the spring (p=0.003).

It is possible in our study that dry air explained the prevalence of the symptoms indicated by teachers in the questionnaire. The mechanical ventilation system desiccated indoor air, and relative humidity was low in the surveyed classrooms. If the air is too dry, respiratory problems coupled with skin and eye irritation could occur (Wolkoff 2018). At the same time, dry air alone does not explain the symptoms as these are most probably due to the interaction of different factors together (Jarvi et al. 2018). Aboriginal school occupants are exposed to low humidity health effects not only in school buildings but also in their homes. Kovesi et al. (2007) reported that houses for Innuit people had very low humidity, increasing the risk of lower respiratory tract infections.

Furthermore, 61% of respondents reported mold and cellar-like odour, while 48% of them noticed visible signs of moisture damage in the school. It is well-known that indoor dampness and mold increase the risk of respiratory symptoms, such as asthma development, the aggravation of asthma symptoms, wheeze, and cough (Bornehag et al. 2004). Moisture damage may adversely impact teachers' respiratory health (Claudio et al. 2016). Meklin et al. (2002) investigated the effects of building frame and moisture damage on microbial IAQ in 17 wooden and 15 masonry schools. They found that while mean concentrations of viable airborne fungi were significantly higher in wooden than in concrete schools, the effect of moisture damage led to higher levels of viable airborne fungi in masonry than wooden schools.

The Spearman Rho test revealed a statistically significant, weak association between satisfaction with acoustics and headache in the spring season. These results are partly consistent with the results by Amouei et al. (2019), who reported that excessive noise led to headaches. They found a statistically significant relationship between acoustics and headaches in the winter (p=0.026) but not in the spring (p=0.600). Similarly, Walinder et al. (2007)

related noise to headache and fatigue among students (cited Turunen et al. 2013).

The results of the Spearman Rho test detected statistically significant associations between air temperature and adverse health symptoms such as fatigue in the fall, winter, and spring seasons, breathing difficulties in the fall, nose irritation in the winter, and spring, throat problems in the fall, winter, and spring, headache in the winter, and feeling like getting cold in the winter. Increased reporting of adverse health symptoms could be explained partly by the indoor temperature fluctuations. The current study provided evidence that classrooms experienced underheating or overheating during the school day. Two south-oriented classrooms were exposed to overheating while other classrooms experienced highly fluctuating temperature changes during the year, with some of these temperatures being very low. High temperature is known to cause dissatisfaction with indoor air quality and may negatively affect health (Fang et al. 2004; Lan et al. 2011). Palumbo et al. (2018) found that high temperature is associated with an increased risk of flu-like symptoms.

Linear regression models were run to investigate the associations between adverse health symptoms and potential predictor variables such as physical records of T, RH, and $CO_2$ during the winter season (Table 31). For the test, the results were considered statistically significant at $p < 0.05$. Linear regression allows direct interpretation between predictors and outputs (Cheung et al. 2017). The linear regression models used 9 independent variables: 1) maximum T, 2) minimum T, 3) mean T; 4) maximum RH, 5) minimum RH, 6) mean relative RH; 7) maximum $CO_2$, 8) minimum $CO_2$, and 9) mean $CO_2$. The dependent variable “score” was presented in the numerical form: from 0 - “no symptoms” to 9 -“maximum number of health symptoms”. The questionnaire data on the health of the teachers was aggregated to have a score: the more symptoms, the higher the score. Approximately 98% of teachers had one and more symptoms during winter.

Table 31 Regression with physical parameters as predictors of the score of having adverse health symptoms

| | B | $R^2$ | p-value |
|---|---|---|---|
| Tmax | -0.256 | 0.156 | 0.293 |
| Tmin | -1.002 | 0.246 | 0.175 |
| **T mean** | **-1.163** | **0.549** | **0.022** |
| RH max | 0.257 | 0.079 | 0.463 |
| RH min | 0.727 | 0.203 | 0.223 |
| **RH mean** | **0.783** | **0.447** | **0.049** |
| $CO_2$ max | 0.002 | 0.075 | 0.477 |
| $CO_2$ min | -0.040 | 0.203 | 0.454 |
| $CO_2$ mean | 0.013 | 0.082 | 0.190 |

The linear regression found that the mean indoor air temperature was statistically significantly associated with the score of adverse health symptoms, Beta= -1.163, CI [-2.104; -0.221] p<0.05 (as seen in Tables 32, 33, 34).

Table 32 Statistical significance of the model

**ANOVA**[a]

| Model | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Regression | 37.108 | 1 | 37.108 | 8.531 | 0.022[b] |
| Residual | 30.448 | 7 | 4.350 | | |
| Total | 67.556 | 8 | | | |

a. Dependent Variable: score

b. Predictors: (Constant), Tmean

Table 33 Model summary

**Model Summary[b]**

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate | Durbin-Watson |
|---|---|---|---|---|---|
| 1 | 0.741[a] | 0.549 | 0.485 | 2.086 | 2.407 |

a. Dependent Variable: score

Table 34 Coefficients Table

**Coefficients[a]**

| Model | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. | 95.0% Confidence Interval for B | |
|---|---|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | | Lower Bound | Upper Bound |
| 1 | (Constant) | 30.939 | 8.491 | | 3.644 | 0.008 | 10.861 | 51.017 |
| | Tmean | -1.163 | 0.398 | -0.741 | -2.921 | 0.022 | -2.104 | -0.221 |

a. Dependent Variable: score

A linear regression established that a decrease in mean indoor air temperature was statistically significantly associated with an increase in the score of having health symptoms. The mean indoor air temperature accounted for 54.9% of the explained variability in the score of SBS symptoms. The physical measurements of the temperature showed that the average temperature values were close to the lower reference values stipulated by ASHRAE in most classrooms during the winter. This is in line with Jaakkola, Heinonen, and Seppänen

(1989), who found that if the indoor air is too cold or warm, it increases health symptoms perceptions. The other statistically significant result was related to the mean relative humidity (Tables 35, 36, 37).

Table 35 Statistical significance of the model

| Model | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | 30.222 | 1 | 30.222 | 5.667 | 0.049[b] |
| | Residual | 37.333 | 7 | 5.333 | | |
| | Total | 67.556 | 8 | | | |

a. Dependent Variable: score
b. Predictors: (Constant), RHmean

Table 36 Model summary

**Model Summary[b]**

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate | Durbin-Watson |
|---|---|---|---|---|---|
| 1 | .669[a] | 0.447 | 0.368 | 2.309 | 2.441 |

a. Predictors: (Constant), RHmean
b. Dependent Variable: score

Table 37 Coefficients Table

**Coefficients**$^a$

| Model | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. | 95.0% Confidence Interval for B | |
|---|---|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | | Lower Bound | Upper Bound |
| 1 | (Constant) | -5.992 | 5.188 | | -1.155 | 0.286 | -18.261 | 6.277 |
| | RHmean | 0.783 | 0.329 | 0.669 | 2.380 | 0.049 | 0.005 | 1.561 |

a. Dependent Variable: score

The increase of mean relative humidity was statistically significantly associated with the rise in the score of adverse health symptoms, Beta= 0.783, CI [1.561; 0.005] $p<0.05$. The variable of mean relative humidity accounted for 44.7% of the explained variability in the score of SBS symptoms. The univariate linear multiple regression model analysis has some limitations. As the sampling data was limited, it was only possible to conduct this type of regression. This limitation also affected the veracity of the resulting findings. Low statistical power (because of the small sample size of the study) negatively affected the likelihood that a nominally statistically significant finding reflected a true effect (Button et al. 2013).

### *4.2.6.2 Teacher's health and performance*

The current study showed that a substantial proportion of respondents (41%) explained that health problems affected their ability to perform their school responsibilities. Approximately 2% of respondents stated they were unaware that SBS symptoms affected their ability to perform their responsibilities. Spearman's Rho test examined relationships between health responses and the performance of teachers. However, only statistically significant results are shown in Table 38. The results of the test provided quantitative and robust evidence for the link between SBS symptoms and performance.

Table 38 Relationships between health responses and the performance of teachers

| | | Performance | |
|---|---|---|---|
| | Season | R | p-value |
| Skin | Spring | 0.310* | 0.023 |
| Stuffy nose | Winter | 0.436** | 0.001 |
| | Spring | 0.295* | 0.029 |
| Dry throat | Spring | 0.430** | 0.001 |
| Feeling like getting cold | Fall | 0.336* | 0.012 |
| | Spring | 0.273* | 0.044 |
| Having a cold/influenza | Spring | 0.415** | 0.002 |
| Headache | Fall | 0.421** | 0.001 |
| | Winter | 0.439** | 0.001 |
| | Spring | 0.443** | 0.001 |
| Fatigue | Winter | 0.391** | 0.003 |

*. Correlation is significant at the 0.05 level (2-tailed)
**. Correlation is significant at the 0.01 level (2-tailed)

The test demonstrated that there were no statistically significant associations between teacher's performance and health symptoms such as eye irritation and breathing difficulties.

There is compelling evidence in the literature that SBS symptoms could influence building occupants' performance (Wargocki 1999; Nunes et al. 1993; Wyon and Wargocki 2006; Kielb et al. 2015; Raw et al. 1990). However, most of the studies relating SBS symptoms to productivity were focused on office workers rather on students than teachers (Kielb et al. 2015). Wargocki (1999) assessed perceived air quality and SBS symptoms while performing simulated office work, and found the significantly increased prevalence of headaches (p=0.04) and considerably lower levels of productivity. In the study of Canadian offices (Nunes et al. 1993), workers reporting SBS symptoms were found to be working 7.2% more slowly on one standardized computer task and to be making 30% more errors on another task. Self-reported productivity was linked to the prevalence of SBS symptoms in the questionnaire survey in office buildings in the UK (Raw et al. 1990). Raw et al. (1990) showed that while two SBS symptoms were relatively typical, six other SBS symptoms were associated with a 10% decrease in self-estimated efficiency. Kielb et al. (2015) found that a substantial proportion of respondents reported that having adverse health symptoms affected their teaching ability or attendance; this ranged from 16.7% for wheezing to 46.4% for sinus problems. Any factor which reduces SBS will increase performance and reduce absenteeism, both of which affect productivity (Wyon 1996).

## 4.3 Thermal imaging

The infrared thermography technique employs an infrared detector and an imaging system that allows converting the surface's emissive power into a temperature pattern (Balaras and Argiriou 2002). Surface temperature distributions can be used to identify thermal irregularities due to structural features, building materials, thermal insulation defects, moisture contents, energy problems, and air leakages in the building components (Nardi et al. 2018). The thermal imaging was conducted at the end of November to capture the difference between internal and external temperatures. It allowed revealing air leakage that can be observed internally when the building is depressurized (Taylor, Counsell, and Gill 2013).

Thermal imaging showed that the school building envelope had poor thermal performance (i.e., thermal bridges, cold surfaces, and air leakage). Thermal bridges created by the discontinuity of thermal insulations as parts of the building envelope have major effects on the thermal performance, e.g. increased heat loss in the winter (Ge and Baba 2015). Thermal bridges can be due to geometry or due to neighboring materials with different thermal properties (Vollmer and Möllmann 2010). Since thermal bridges lead to temperature differences, they are naturally present in infrared thermography (Vollmer and Möllmann 2010). Figure 33 captured the school entrance glass doors. Exterior doors and school entrances are the sources of heat and energy losses. Figures 34 and 35 show the appearance of heat loss due to the air leakage defects through the bottom and top of the entrance door. Gaps could be seen between the bottom of the frame and the door itself, which is also slightly loose.

Figure 32 Entrance school door

Figure 33 Air leakage below a door cools the surface of the surrounding floor

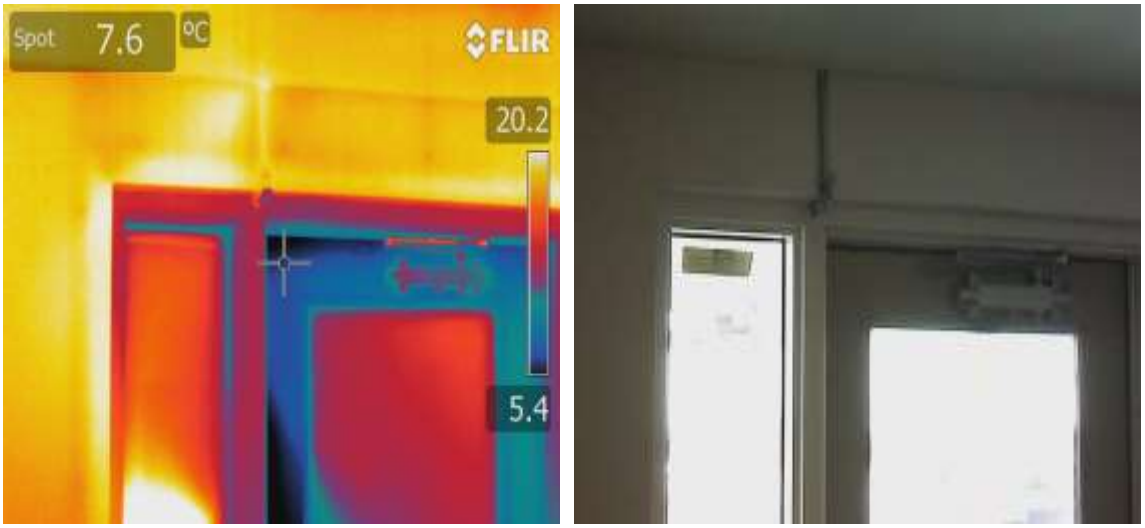

Figure 34 Air leakage through the top of the door

Figures 33 and 34 include thermal images. The thermal image is made of a number of pixels while an individual pixel represents a specific temperature data point (Your Perfect Palette). Figure 34 shows the thermal palette based on heat energy  (Your Perfect Palette). These data points are assigned a unique color or shade based on their value, meaning that as the thermal sensor detects changes in heat energy, it expresses this change by adjusting the color or shade of a pixel (Your Perfect Palette). Red and yellow colors in the thermal palette indicate higher temperatures while yellow refers to lower temperatures than red ones (Vollmer and Möllmann 2010). In Figures 33 and 34, the cross sign indicates the spot on the door frame with a temperature of -1.6°C and 5.4 °C accordingly. It is observed that the door frame has a much lower temperature than the walls. The airflow movement through high-use front entrance doors of a school building with large flows of people is responsible for the resulting heat and energy losses. There is an air heat fan operating in the entrance area designed to counteract cold air entering the building. During the heating season, cold air flows through the entrance doors mixing with warm air from an air fan installed in the entrance area, separating external doors and internal swinging doors. Air infiltration or exfiltration due to the frequent use of doors, coupled with pressure differences across each entry, created by the wind or ventilation systems contributes to this phenomenon (Maxwell, Durrani, and Eftekhari 2016). Wind pressures can provide a driving force for infiltration through cracks or gaps in the building structure (Maxwell et al. 2016). Yan (2010) and Chen (2011) investigated the heavy traffic of staff and students entering or leaving a college building through the building’s sliding doors entrance and assumed the occurrence of subsequent heat and energy losses. The study found that the discomfort of the occupants working near the front entrance or reception areas was not offset by the air curtain fan operating in the entrance area to deal with the cold air.

The current study recommends potential improvements that can be obtained through improved design and replacement of old school entrance doors to avoid thermal comfort dissatisfaction and reduce energy consumption.

The windows themselves represent thermal bridges, with a lower interior temperature than the rest of the building envelope. School windows are wooden-framed and double-glazed. Most of the school window frames visually have cracks, increasing radiated heat loss and air leakage (as seen in Figure 35).

Figure 35 Classroom window

As evident from Figure 35, due to multiple cracks, the window frame represents the thermal bridge with a temperature as low as approximately 14.9˚C (the cross sign indicates the spot with the measured temperature). In the winter, radiant heat loss toward a cold window surface, drafts induced by cold air drainage off the window surface, and temperature asymmetry between the room and the window can make an occupant feel uncomfortable (Lyons, Arasteh, and Huizenga 2000). Occupants’ discomfort can often be compensated with the heating system. This increases the classrooms’ energy needs which still does not guarantee comfort for the occupants.

Not only is the window area in the building’s envelope emitting heat, but also so are structural connections such as the flat roof and weight-bearing columns in the walls. Figure 36 shows the thermal palette with the lowest temperature of 15.3˚C and the highest temperature of 30.4 ˚C. The low-temperature area is observed between the column and wall connection (the cross sign indicates the spot with 16.6˚C).

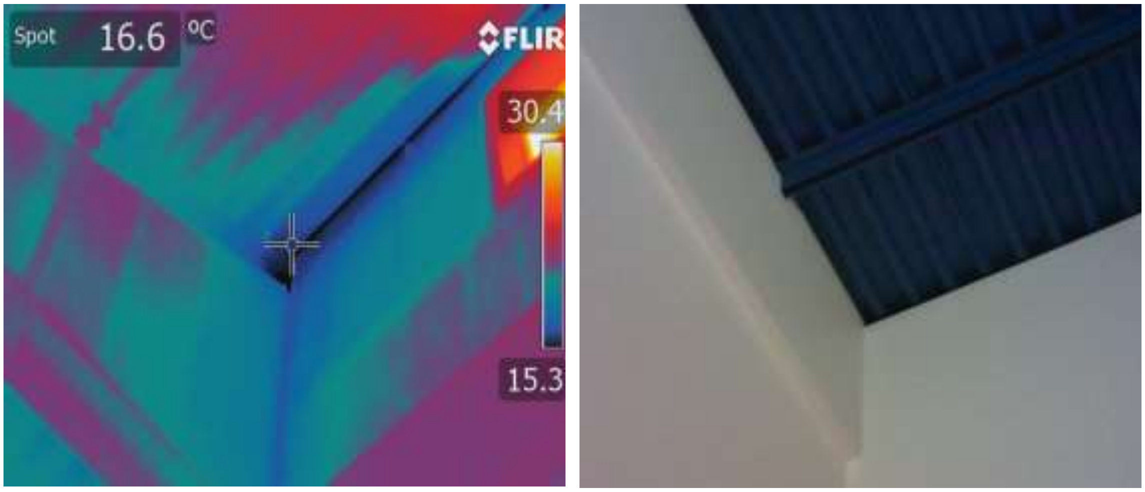

Figure 36 Connection between the roof and the weight-bearing columns

Several opportunities for improvements in the building envelope can be detected on the thermal images. The thermal bridge at the junction between the wall and ceiling affects both thermal comfort and energy use. Thermal imaging also discovered a heat loss of the poorly insulated metal roof. Figure 37 demonstrates the low temperature on the surfaces adjacent to the roof.

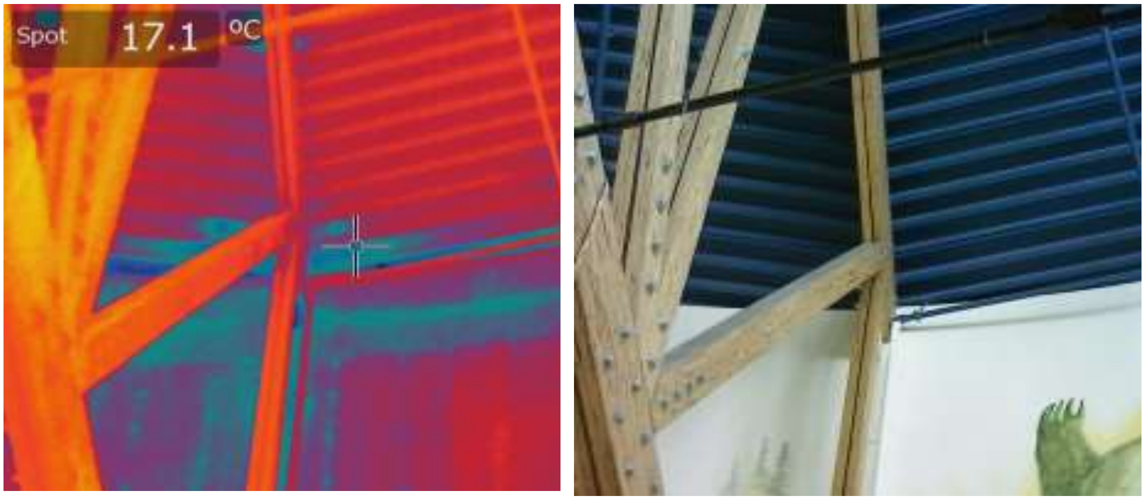

Figure 37 Thermal imaging of the roof

Furthermore, it is difficult to quantify the amount of heat loss through thermal bridges. However, the study by Ge and Baba (2015) used building energy simulations to find the effect of thermal bridges on energy performance. They found that the presence of thermal bridges increased the annual amount of heat energy by 18% in the cold climate of zone 7.

# 5 Conclusion and Recommendations

This research project advanced our knowledge of indoor environmental quality in First Nations schools through collecting data to improve the overall performance of the school and reduce or eliminate harmful health effects. This research revealed several important issues related to indoor environmental quality in the school.

- The biggest problem was the poor IAQ in the classrooms. The Mann-Whitney U test found statistically significant associations between gender and satisfaction with indoor air quality. Females, compared to males, were found to be less satisfied with indoor air quality during the fall, winter, and spring seasons. In the school’s case, the HVAC system experienced difficulties with providing cleaner air from the outside: washrooms smell, outdoor pollution, and mold or cellar-like odour were the most reported sources of poor IAQ. Statistically significant associations between satisfaction with IAQ, performance, and health symptoms were revealed during the study.
- Another significant issue was thermal discomfort. The HVAC system did not maintain a stable and comfortable level of temperature and humidity for occupants. The thermal discomfort was caused by high fluctuations of indoor air temperature and dry air especially during the winter and spring seasons. Statistically significant results showed that females were affected by the hot environment in the spring season more than males. The findings of the study suggested issues with the operation of the heating system and its inability to maintain comfortable indoor air temperatures. Records showed that spaces close to the center of the building had significantly higher temperatures compared to the spaces at the end of the wings. Approximately half of the respondents

expressed their need to control or adjust the temperature of the classroom. The results of the Spearman Rho test detected statistically significant associations between air temperature, relative humidity, and adverse health symptoms. A linear regression established that a decrease in mean T and an increase in mean RH were statistically significantly associated with the rise in the score of having adverse health symptoms.

- Thermal comfort was assessed by thermal imaging tests. Thermal imaging showed that the envelope had poor thermal performance. A few issues were identified such as heat losses through entrance doors, exterior doors, windows, and wall junctions with the roof.
- The current study showed that approximately 40% of teachers were satisfied with lighting comfort. More than 60% of teachers reported their need to control the light so the visual discomfort would not affect their health. The Spearman Rho test revealed a statistically significant association between satisfaction with lighting quality and teacher's performance in the fall season.
- Over 40% of teachers were satisfied with acoustics comfort while a third of respondents felt discomfort with noise. Echoing negatively influenced the quality of speech communication between teachers and students and contributed to a worse acoustic climate in the classroom. The Spearman Rho test found statistically significant correlations between satisfaction with acoustics quality and other areas (nearby classrooms and corridors), washrooms, and outside areas. Both external and internal noise affected school teacher’s performance and health. These facts were confirmed by statistically significant associations between acoustics, performance, and headaches.
- The results of teachers’ satisfaction with different aspects of the indoor environment

sometimes were found not significant and this fact is disappointing. At the same time, teachers left numerous comments about their dissatisfaction with indoor environment parameters. The lack of statistical significance could be due to the size of the sample studied but also due to the inaccurate filling of the questionnaires. Larger samples of several schools and teachers would improve the generalizability of the study.

The current study represents one of the few indoor environmental quality studies carried out in First Nations schools in Canada. Gathered information allowed us to understand the main issues that adversely affect both indoor environmental quality and the energy performance of the school. Therefore, we proposed to the school authorities the following recommendations composed of measures that can be immediately applied without significant investments and those that involve more intensive renovations through more substantial investments. There are two pathways for refurbishment measures. First is a low-cost and easy to implement pathway that includes the following measures:

1) Proper maintenance of the HVAC system

Cleaning of the air ducts, grilles, dampers, and changing of the filters is a low-cost measure that would have a positive effect on occupants' health and performance. Furthermore, local or central humidifiers should be introduced to improve air quality.

2) Planting of the trees and installing of interior landscape plants

The most cost-effective measure to increase the humidity of the indoor air is to install interior landscape plants, and particularly beneficial for indoor air quality are air-filtering plants recommended by NASA (NASA 1989). Additionally, rows of trees and bushes should be planted strategically (e.g. on the north side of the school) around the school to decrease the negative impact of the winds from Lake Winnipeg and to reduce solar gains in the summer (e.g. south-west side of the school).

3) Replacement of lights with LED lighting

Daylight could be used for energy savings and to improve teachers' health. In this case, automatic photoelectric or manual dimming strategies such as photosensors, occupancy sensors, and time switches will help to efficiently balance daylight and electric light. Another low-hanging fruit that can considerably improve lighting quality and reduce electricity consumption is the replacement of existing technically obsolete lighting with light-emitting diodes (LED) lighting.

4) Replacement of doors and windows, walls, and roof insulation.

Replacement of the leaky and poorly insulated external doors would significantly reduce the effect of undesirable local cooling of the human body that represents a severe thermal comfort problem. Consequently, it would reduce infiltration and exfiltration. Another useful measure that would result in overall performance improvement of the school includes the insulation of the east and west walls. It would increase the thermal comfort of the classrooms at the end of the wings that have the lowest indoor air temperatures and the most dissatisfied occupants. The moderately expensive measure should include roof insulation. All of the above-mentioned measures would reduce heating losses and improve the energy performance of the building.

5) Replacement of the existing HVAC sensor and introduction of a new sensor for better control of the system.

Replacement of the existing HVAC sensor and the introduction of new sensors for better control of the system represents a moderately expensive energy-efficiency measure. In particular, this measure would have a positive impact on the thermal comfort of the occupants and energy consumption through the introduction of adequate set point and set back temperatures.

The second pathway requires more substantial investments as it includes in-depth refurbishment measures:

1) Deep renovation of the building envelope.

When the building is sufficiently insulated, it will lead to an increase in energy efficiency, occupant’s comfort, and improving their quality of life. Deep renovation of the envelope should include optimal insulation of the external walls, floors, and ceiling/roof, as well as the replacement of all damaged and inefficient fenestration with more efficient ones.

2) Modification of the HVAC system.

The most economical solution would be the addition of a heat recovery system. Another viable solution is the addition of air-source heat pumps that will allow efficient conditioning during the favourable outdoor air temperatures. Furthermore, the heat pumps can transfer the air from one area to another to reduce considerable variation in the indoor air temperatures between different parts of the building.

3) Addition of renewable energy systems.

One of the effective and sustainable solutions includes the addition of the photovoltaic panels that will provide the electricity required by electrical appliances, lightings, and equipment.

The efficient school retrofit options should include all the advantages of the abovementioned solutions to achieve energy, environmental, and school occupant’s health benefits.

# 6 Limitations and Future Research

The limitations of this study that should be addressed by future research include:

- The most significant constraint of this study is its small sample size related to the number of schools and classrooms. Thus, its findings and conclusions cannot be generalized, and further research should provide additional evidence about IEQ in First Nations schools across Canada. In this respect, studies with more First Nation schools and larger classroom samples should either validate or not the results presented herein.
- The research involved conducting on-site physical measurements of IEQ, so resource limitations such as a small number of measurement devices precluded a more extensive sampling of classrooms for analysis. Furthermore, the remoteness of the communities requires a significantly larger team.
- Due to the small sample size, the surveyed population consisted of 56 teachers. Nevertheless, the response rate was high, allowing a comprehensive analysis of their responses and. Future research should include a larger population size.
- Due to the limited resources, this research measured only three IEQ parameters, including temperature, RH, and $CO_2$. Thus, future research should expand the number of investigated indoor environmental quality parameters to enable a more comprehensive assessment of the indoor environment.
- The questionnaire survey only included teachers. Consequently, the findings are limited to adults, and future research should consider students due to their higher sensitivity to environmental pollutants than adults. The students are excluded from the study for the following reasons. The content of the questionnaire might not be understandable

to students due to their young age. Furthermore, the length of the questionnaire could influence their ability to answer it correctly and reliably. Another reason for not surveying children is the difficulty of obtaining parents' consent and ethics approval.

- We did not collect noise and lighting comfort parameters, such as measurements of background noise or illuminance. Resource limitations, such as the lack of the needed equipment, precluded us from conducting measurements related to acoustics and lighting comfort. Noise measurements are essential, as many teachers often complain about noise during school hours. Future studies addressing the evaluation of noise in schools should include monitoring classroom reverberation time and background noise. Furthermore, given the frequent complaints from teachers about lighting brightness levels, there's a need to conduct a measurement of classroom illuminance levels to analyze the impact of lighting on the performance and health of school teachers and students.
- The questionnaire was paper-based. Teachers filled them by hand, and sometimes it was challenging to interpret the handwriting. Sometimes, respondents gave two answers to the same question or they marked the wrong section. In these cases, the responses were excluded from the analysis. Future research should include online questionnaires that would mandate the answering of all or specific questions.

# Bibliography

Akimoto, T., Tanabe, S.-I., Yanai, T. & Sasaki, M. 2010 "Thermal comfort and productivity - Evaluation of workplace environment in a task conditioned office." Building and Environment.. 45. 45-50.

Akom, J. Evaluation of Indoor Environmental Quality in Green Low-Income Housing, 2019.

Alborz, N., and Berardi U. A. 2015 "Post Occupancy Evaluation Framework for LEED Certified U.S. Higher Education Residence Halls. Procedia Engineering." 118:19–27.

Allab, Y., Pellegrino M., Guo X., Nefzaoui E., and Kindinis A. 2017. "Energy and Comfort Assessment in Educational Building: Case Study in a French University Campus." Energy and Buildings.. 143:202–19.

Allermann, L., Meyer, H.W., Poulsen, O.M., Nielsen, J.B. and Gyntelberg, F. 2003. "Inflammatory potential of dust from schools and building related symptoms.". Occupational and Environmental Medicine, 60, E5.

Almeida, Ricardo M. S. F. and Vasco Peixoto De Freitas. 2014. "Indoor Environmental Quality of Classrooms in Southern European Climate." Energy and Buildings.. 81:127–40.

Almeida, S.; Canha, N.; Silva, A.; Freitas, M.C.; Pegas, P.; Alves, C.; Evtyugina, M.; Pio, C.A. Children Exposure to Atmospheric Particles in Indoor of Lisbon Primary Schools. Atmos. Environ. (1994) 2011. 45. 7594–7599.

d'Ambrosio Alfano, Francesca R.; Bellia, Laura; Boerstra, Atze; Dijken, Froukje van; Ianniello, Elvira; Lopardo, Gino; Minichiello, Francesco; Romagnoni, Piercarlo; Gameiro da Silva, Manuel Carlos. n.d. "2 Indoor Environmental Comfort Aspects."

Amouei, Abdoliman, Zahra Aghalari, Ahmad Zarei, Mojtaba Afsharnia, Zahra Geraili, and Mehdi Qasemi. 2019. "Evaluating the Relationships between Air Pollution and Environmental Parameters with Sick Building Syndrome in Schools of Northern Iran." Indoor and Built Environment 28(10):1422–30.

Andersson, K., G. Stridh, I. Fagerlund, W. Aslaksen, and S. Rudblad. 2002. "Comparison of the Perceived Indoor Climate and Symptoms Reported By Students and Personnel in 16 Senior High Schools in Sweden." 3(January 2002):399–403.

Angelon-Gaetz, Kim A., David B. Richardson, Stephen W. Marshall, and Michelle L. Hernandez. 2016. "Exploration of the Effects of Classroom Humidity Levels on Teachers' Respiratory Symptoms." International Archives of Occupational and Environmental Health 89(5):729–37.

Angelon-Gaetz, K. A., D. B. Richardson, D. M. Lipton, S. W. Marshall, B. Lamb, and T. Lofrese. 2015. "The Effects of Building-Related Factors on Classroom Relative Humidity among North Carolina Schools Participating in the 'Free to Breathe, Free to Teach' Study." Indoor Air 25(6):620–30.

Annesi-Maesano, I., Baiz, N., Banerjee, S. (2013) Indoor air quality and sources in schools and related health effects. Journal of Toxicological Environmental Health Part B 16:491–550.

Aries, Myriam B. C., Jennifer A. Veitch, and Guy R. Newsham. 2010. "Windows, View, and Office Characteristics Predict Physical and Psychological Discomfort." Journal of Environmental Psychology 30(4):533–41.

Arundel, A., Sterling, E., Biggin, J., et al. Indirect health effects of relative humidity in indoor environments. Environment Health Perspectives 1986. 65. 351-361.

Asif, Ayesha, Muhammad Zeeshan, and Muhammad Jahanzaib. 2018. "Indoor Temperature, Relative Humidity, and CO2 Levels Assessment in Academic Buildings with Different Heating, Ventilation, and Air-Conditioning Systems." Building and Environment 133(December 2017):83–90.

ASHRAE Standards 62.1-2016. Ventilation for Acceptable Indoor Air Quality.

ASHRAE, 2013. Standard 55: Thermal Environmental Conditions for Human Occupancy. American Society of Heating Refrigerating and Air-conditioning Engineers.

ASHRAE Standard 62.1-2004 (2004) Ventilation for Acceptable Indoor Air Quality, Atlanta GA, American Society of Heating, Refrigerating and Air Conditioning Engineers.

ASHRAE 2001, "Humidity Control Design Guide" Chapter 18:277-285. ASHRAE Standard 62-1999, Atlanta.

ASHRAE Standard 55-2004. Thermal environmental conditions for human occupancy. Atlanta: American society of heating, refrigerating, and air- conditioning engineers; 2004.

ANSI/ASHRAE/IES Standard 90.1-2016, Energy Efficiency Standard for Buildings Except Low-Rise Residential Buildings.

ASHRAE Standard 62.1. Ventilation for acceptable indoor air quality. Atlanta: American society of heating, refrigerating, and air-conditioning engineers; 2007.

Assembly of First Nations Environmental Stewardship Unit, 2008. The Health of First Nations Children and the Environment. Discussion paper.

Astolfi, Arianna, Pasquale Bottalico, and Giulio Barbato. 2012. "Subjective and Objective Speech Intelligibility Investigations in Primary School Classrooms." The Journal of the Acoustical Society of America 131(1):247–57.

Astolfi, Arianna and Franco Pellerey. 2008. "Subjective and Objective Assessment of Acoustical and Overall Environmental Quality in Secondary School Classrooms." The Journal of the Acoustical Society of America 123(1):163–73.

Balaras, C. A. and A. A. Argiriou. 2002. "Infrared Thermography for Building Diagnostics." Energy and Buildings 34(2):171–83.

Bak-Biro, Z., Clements-Croome, D., Kochhar, N., Awbi, H., Williams, M.Ventilation rates in schools and pupils performance, Building Environment. 2012. 48. 215–223.

Bae, Suyeon, Caren S Martin, and Abimbola O Asojo. "Higher Education Students' Indoor Environmental Quality Satisfaction Benchmark." Building research and information : the international journal of research, development and demonstration (2020): 1–16.

Berghout, Joanne, J. David Miller, Roger Mazerolle, Len O'Neill, Craig Wakelin, Barbara Mackinnon, Kenneth Maybee, et al. "Indoor Environmental Quality in Homes of Asthmatic Children on the Elsipogtog Reserve (NB), Canada." International journal of circumpolar health 64, no. 1 (February 1, 2005): 77–85

Berquist, Justin, Mohamed M. Ouf, and William O'Brien. 2019. "A Method to Conduct Longitudinal Studies on Indoor Environmental Quality and Perceived Occupant

Comfort.” Building and Environment 150(October 2018):88–98.

Beshir MY, Ramsey JD. Heat stress indices: a review paper. International Journal of Industrial Ergonomics 1988;3:89–102.

Bhattacherjee, A. Social Science Research: Principles, Methods, and Practice, Version 2.0, 2011, Free download from Blackboard (my.usf.edu).

Bishara, Anthony J, and James B Hittner. “Testing the Significance of a Correlation With Nonnormal Data: Comparison of Pearson, Spearman, Transformation, and Resampling Approaches.” Psychological methods 17, no. 3 (2012): 399–417.

Bluyssen, Philomena M., Dadi Zhang, Stanley Kurvers, Marjolein Overtoom, and Marco Ortiz-Sanchez. 2018. “Self-Reported Health and Comfort of School Children in 54 Classrooms of 21 Dutch School Buildings.” Building and Environment 138(April):106–23.

Bornehag, C. G., J. Sundell, S. Bonini, A. Custovic, P. Malmberg, S. Skerfving, T. Sigsgaard, and A. Verhoeff. 2004. “Dampness in Buildings as a Risk Factor for Health Effects, EUROEXPO: A Multidisciplinary Review of the Literature (1998-2000) on Dampness and Mite Exposure in Buildings and Health Effects.” Indoor Air 14(4):243–57.

Boyce P., Veitch J., Newsham G., et al. Lighting quality and office work: two field simulation experiments. Lighting Research & Technology. 2006;38(3):191-223.

Brennan, T., Clarkin, M., Turner, W., Fisher, G. and Thompson, R. (1991) School buildings with air exchange rates that do not meet minimum professional guidelines or codes and implications for radon control. Proceedings of ASHRAE IAQ 91 Healthy Buildings, Atlanta, GA, ASHRAE, 228–229.

BS EN 15251:2007 “Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics”.

Button, Katherine S., John P. A. Ioannidis, Claire Mokrysz, Brian A. Nosek, Jonathan Flint, Emma S. J. Robinson, and Marcus R. Munafò. 2013. “Power Failure: Why Small Sample Size Undermines the Reliability of Neuroscience.” Nature Reviews Neuroscience 14(5):365–76.

Cena, K. & De Dear, R. 2001. « Thermal comfort and behavioural strategies in office buildings located in a hot-arid climate.” Journal of Thermal Biology. 26. 409-414.

Center for Disease Control and Prevention, Workplace safety and health topics: indoor environmental quality. http://www.cdc.gov/niosh/topics/ indoorenv/, 2013 (Accessed 4 June 2019).

Cerdeira, F., Vazquez, M. E., Collazo, J. and Granada, E. Applicability of infrared thermography to the study of the behaviour of stone panels as building envelopes. Energy and Buildings. 2011.

Chen, Y. (2011). Monitoring Thermal Comfort and Energy consumption in a college. MSc dissertation, Department of Civil and Building Engineering, Loughborough University

Cheung, Toby C. T., Stefano Schiavon, Elliott T. Gall, Ming Jin, and William W. Nazaroff. 2017. “Longitudinal Assessment of Thermal and Perceived Air Quality Acceptability in Relation to Temperature, Humidity, and CO2 Exposure in Singapore.” Building and Environment 115:80–90.

Chung, T. M. and John Burnett. 2000. "Lighting Quality Surveys in Office Premises." Indoor and Built Environment 9(6):335–41.

Claudio, Luz, Glory A. Rivera, and Olivia F. Ramirez. 2016. "Association Between Markers of Classroom Environmental Conditions and Teachers' Respiratory Health." Journal of School Health 86(6):444–51.

Clausen, T., Christensen, K. B., Lund, T., & Kristiansen, J. (2009). Self-reported noise exposure as a risk factor for long-term sickness absence. Noise Health, 11, 93-97.

Connolly, Daniel M., Julie E. Dockrell, Bridget M. Shield, Rob Conetta, and Trevor J. Cox. 2015. "Students' Perceptions of School Acoustics and the Impact of Noise on Teaching and Learning in Secondary Schools: Findings of a Questionnaire Survey." Energy Procedia 78:3114–19.

Corgnati, Stefano Paolo, Marco Filippi, and Sara Viazzo. 2007. "Perception of the Thermal Environment in High School and University Classrooms: Subjective Preferences and Thermal Comfort." Building and Environment 42(2):951–59.

Corsi, R. L., V. M. Torres, and M. Sanders. 2002. "Carbon Dioxide Levels and Dynamics in Elementary Schools : Results of the Tesias Study." 9th International Conference on Indoor Air Quality and Climate 74–79.

Creswell, J. Research Design: Qualitative, Quantitative, and Mixed Methods Approaches, fourth ed., Sage publications, Thousand Oaks, California, 2014.

Cui, Weilin, Guoguang Cao, Jung Ho Park, Qin Ouyang, and Yingxin Zhu. 2013. "Influence of Indoor Air Temperature on Human Thermal Comfort, Motivation and Performance." Building and Environment 68:114–22.

Daniel, Mark, Margaret D. Cargo, Julie Lifshay, and Lawrence W. Green. 2004. "Cigarette Smoking, Mental Health and Social Support." Canadian Journal of Public Health 95(1):45–49.

De Giuli, Valeria, Osvaldo Da Pos, and Michele De Carli. 2012. "Indoor Environmental Quality and Pupil Perception in Italian Primary Schools." Building and Environment 56:335–45.

Daisey, J. M., W. J. Angell, and M. G. Apte. 2003. "Indoor Air Quality, Ventilation and Health Symptoms in Schools: An Analysis of Existing Information." Indoor Air 13(1):53–64.

Dias Pereira, Luísa, Daniela Raimondo, Stefano Paolo Corgnati, and Manuel Gameiro da Silva. 2014. "Assessment of Indoor Air Quality and Thermal Comfort in Portuguese Secondary Classrooms: Methodology and Results." Building and Environment 81:69–80.

Djongyang, Noël, René Tchinda, and Donatien Njomo. 2010. "Thermal Comfort: A Review Paper." Renewable and Sustainable Energy Reviews 14(9):2626–40.

Dockrell, Julie E., and Bridget Shield. 2004. "Children's Perceptions of Their Acoustic Environment at School and Home." The Journal of the Acoustical Society of America 115(6):2964–73.

Dorizas, P., Assimakopoulos, M., Santamouris, M. 2015. "A holistic approach for the assessment of the indoor environmental quality, student productivity, and energy consumption in primary schools. Environmental Monitoring Assessment." 187-259.

Duijnhoven, Van. 2020. "Office Lighting Characteristics Determining Occupant ' s Satisfaction and Health (2017).

Dykes, Clare and George Baird. 2013. “A Review of Questionnaire-Based Methods Used for Assessing and Benchmarking Indoor Environmental Quality.” Intelligent Buildings International 5(3):135–49.

Ebbehoj, N., Meyer, H., Wurtz, H., Suadicani, P., Valbjorn, O., Sigsgaard, T. and Gyntelberg, F. (2005) Molds in floor dust, building-related symptoms, and lung function among male and female schoolteachers, Indoor Air, 15 (Suppl 10). 7–16.

Ekren, Orhan, Ziya Haktan Karadeniz, Ibrahim Atmaca, Tugba Ugranli-Cicek, Sait C. Sofuoglu, and Macit Toksoy. 2017. “Assessment and Improvement of Indoor Environmental Quality in a Primary School.” Science and Technology for the Built Environment 23(2):391–402.

Ellermeier W, Zimmer K. 1997. Individual differences in susceptibility to the ‘irrelevant speech effect’. Journal of Acoustics Society American.102: 2191-2199.

Enmarker, I., & Boman, E. (2004). Noise annoyance responses of middle school pupils and teachers. Journal of Environmental Psychology, 24, 527-536.

Environmental Defense, 2006. Polluted Children, Toxic Nations: A Report on Pollution in Canadian Families. Environmental Defense.

Environmental Protection Agency Energy Savings Plus Health. (n.d.). Retrieved October 17, 2020, fromhttps://www.epa.gov/sites/production/files/2014-10/documents/energy_savings_plus_health_guideline.pdf

Environmental Protection Agency (EPA), 2014. Energy Savings Plus Health: Indoor Air Quality Guidelines for School Building Upgrades. United States Environmental Protection Agency.

Environmental Protection Agency (EPA), 2014. Energy Savings Plus Health: Indoor Air Quality Guidelines for School Building Upgrades. United States Environmental Protection Agency.

Erlandson, T.M., Cena, K. and de Dear, R. (2005) Gender differences and non-thermal factors in thermal comfort of office occupants in a hot-arid climate, Elsevier Ergonomics Book Series, 3, 263–268.

European Commission, 2014. Schools Indoor Pollution & Health Observatory Network in Europe (SINPHONIE) – Final Report. Publications Office of the European Union.

Fadeyi, T. (2015). Impact of asthma, exposure period, and filters on human responses during exposures to ozone and its initiated chemistry products. Indoor Air, 25(5), 512–522.

Fang, L., Wyon, D.P., Clausen, G., Fanger, P.O., 2004. Impact of indoor air temperature and humidity in an office on perceived air quality, SBS symptoms and performance. Indoor Air 14, 74–81.

Fanger O. Thermal comfort. Danish Technical Press. Copenhagen. 1970.

Fischer, By John C. and Charlene W. Bayer. 2001. “Humidity Control in School Facilities.” Ashrae Standard no volume(no issue):1–7.

Fisk, William J., Ekaterina A. Eliseeva, and Mark J. Mendell. 2010. “Association of Residential Dampness and Mold with Respiratory Tract Infections and Bronchitis: A Meta-Analysis.” Environmental Health: A Global Access Science Source 9(1):72.

Fisk, J., Rosenfeld, A. Estimates of improved productivity and health from better indoor environments, Indoor Air. 1997. 7. 158–172.

Franke, Deborah L. 1997. “Cleaning for Improved Indoor Air Quality: An Initial Assessment of Effectiveness.” Indoor Air 7(1):41–54.

Franklin, Peter J. 2007. “Indoor Air Quality and Respiratory Health of Children.” Paediatric Respiratory Reviews 8(4):281–86.

Frontczak, Monika, Rune Vinther Andersen, and Pawel Wargocki. 2012. “Questionnaire Survey on Factors Influencing Comfort with Indoor Environmental Quality in Danish Housing.” Building and Environment 50:56–64.

Frontczak, M., Schiavon, S., Goins, J., Arens, E. A., Zhang, H. & Wargoski, P. Quantitative relationships between occupant satisfaction and satisfaction aspects of indoor environmental quality and building design. International journal of Indoor Environment and Health. 2012.

Frontczak, Monika and Pawel Wargocki. 2011. “Literature Survey on How Different Factors Influence Human Comfort in Indoor Environments.” Building and Environment 46(4):922–37.

Galasiu, Anca D. and Jennifer A. Veitch. 2006. “Occupant Preferences and Satisfaction with the Luminous Environment and Control Systems in Daylit Offices: A Literature Review.” Energy and Buildings 38(7):728–42.

Gao, Zhiwei, Brian H. Rowe, Carina Majaesic, Cindy O’Hara, and A. Senthilselvan. 2008. “Prevalence of Asthma and Risk Factors for Asthma-like Symptoms in Aboriginal and Non-Aboriginal Children in the Northern Territories of Canada.” Canadian Respiratory Journal 15(3):139–45.

Ge, Hua and Fuad Baba. 2015. “Dynamic Effect of Thermal Bridges on the Energy Performance of a Low-Rise Residential Building.” Energy and Buildings 105:106–18.

Godwin, Christopher, Batterman, Stuart. Indoor air quality in Michigan schools. Indoor Air. 2007. 17 (2), 109–121.

Gordon, D. E. (2010). Green Schools as High Performance Learning Facilities National Clearinghouse for Educational Facilities Washington, DC: National Institute of Building Sciences.

Griffiths, M., Eftekhari, M. Control of CO2 in a naturally ventilated classroom. Energy and Buildings. 2008. 40 (4). 556–560.

Guo, H., Morawska, L., He, C., Gilbert, D., 2008. Impact of ventilation scenario on air exchange rates and on indoor particle number concentrations in an air-conditioned classroom. Atmospheric Environment 42, 757-768.

Hancock, P., Vasmatzidis, I. Human occupational and performance limits under stress: thermal environment as a prototypical example, Ergonomics 41. 1998. 1169–1191.

Hathaway, W. Lights, windows, color: elements of the school environment. In 59th Annual meeting of the Council of Educational Facility Planners. 1983. Canada.

Havenith, G. 2007. “Metabolic Rate and Clothing Insulation Data of Children and Adolescents during Various School Activities.” Ergonomics 50(10):1689–1701.

Haverinen-Shaughnessy, Ulla and Richard J. Shaughnessy. 2015. “Effects of Classroom Ventilation Rate and Temperature on Students’ Test Scores.” PLoS ONE 10(8):1–14.

Haverinen-Shaughnessy, U., D. J. Moschandreas, and R. J. Shaughnessy. 2011. “Association between Substandard Classroom Ventilation Rates and Students’ Academic Achievement.” Indoor Air 21(2):121–31.

Heinzerling, David, Stefano Schiavon, Tom Webster, and Ed Arens. 2013. "Indoor Environmental Quality Assessment Models: A Literature Review and a Proposed Weighting and Classification Scheme." Building and Environment 70:210–22.

Health Canada, 2003. Indoor Air Quality Tools for Schools Action Kit. Health Canada.

Health Canada. Residential indoor air quality guidelines - Moulds. Ottawa, ON: Health Canada, Environmental and Workplace Health; 2007 Available from: http://www.hc-sc.gc.ca/ewh-semt/pubs/air/mouldmoisissure-eng.php.

Hemmers, J., Winkler, K., Kool, S. Virus survival as a seasonal factor in influenza and poliomyelitis. Nature 1960. 188. 430-431.

Heudorf, U., V. Neitzert, and J. Spark. 2009. "Particulate Matter and Carbon Dioxide in Classrooms - The Impact of Cleaning and Ventilation." International Journal of Hygiene and Environmental Health 212(1):45–55.

Hou, Yuefei, Junjie Liu, and Jiayu Li. 2015. "Investigation of Indoor Air Quality in Primary School Classrooms." Procedia Engineering 121:830–37.

Hodgson, Murray and Eva-Marie Nosal. 2002. "Effect of Noise and Occupancy on Optimal Reverberation Times for Speech Intelligibility in Classrooms." The Journal of the Acoustical Society of America 111(2):931–39.

Hodgson, M., Rempel, R. and Kennedy, S. Measurement and prediction of typical speech and background noise levels in university class- rooms during lectures. Acoustical Society of America. 1999. 105. 226–233.

Hui, X., Li, B., & Zheng, J. Evaluation of IEQ in Urban Residential Buildings in Chongqin China. Paper presented at the The 23rd Conference on Passive and Low Energy Architecture. 2006. Geneva, Switzerland.

Huizenga, C., S. Abbaszadeh, L. Zagreus, and E. Arens. 2006. "Air Quality and Thermal Comfort in Office Buildings: Results of a Large Indoor Environmental Quality Survey." HB 2006 - Healthy Buildings: Creating a Healthy Indoor Environment for People, Proceedings 3:393–97.

Hutcheon, N.B. Canadian Building Digest 1 Humidity Canadian Buildings. 1960. Ottawa, Ontario, Canada: National Research Council Canada.

Ianniello, Elvira. 2011. "Ventilation Systems and IAQ in School Buildings." Rehva Journal (march):26–29.

ISO. EN ISO 7730:2001 Ergonomics of the thermal environment. International Standardization Organization. 2001.

Jaakkola, J.J.K., Heinonen, O.P. and Seppanen, O. Sick Building Syndrome, sensation of dryness and thermal comfort in relation to room temperature in an office building: need for individual control of air temperature. Environmental Int. 1989.15. 163–168.

Järvi, Kati, Camilla Vornanen-Winqvist, Raimo Mikkola, Jarek Kurnitski, and Heidi Salonen. 2018. "Online Questionnaire as a Tool to Assess Symptoms and Perceived Indoor Air Quality in a School Environment." Atmosphere 9(7):1–20.

Jenkins, Alison L., Theresa W. Gyorkos, Kate N. Culman, Brian J. Ward, Gary S. Pekeles, and Elaine L. Mills. 2003. "An Overview of Factors Influencing the Health of Canadian Inuit Infants." International Journal of Circumpolar Health 62(1):17–39.

Jeon J. Y., Lee P. J., You J., Kang J. Perceptual assessment of quality of urban soundscapes with combined noise sources and water sounds. Acoustical Society of America.

2010. 127. 1357–1366.

Jiang, Jing, Dengjia Wang, Yanfeng Liu, Yanchao Xu, and Jiaping Liu. 2018. “A Study on Pupils’ Learning Performance and Thermal Comfort of Primary Schools in China.” Building and Environment 134(November 2017):102–13.

Johnson R., Christensen L. Educational Research. Quantitative, Qualitative and Mixed approaches. 2016. SAGE. USA.

Karjalainen, Sami. 2009. “Thermal Comfort and Use of Thermostats in Finnish Homes and Offices.” Building and Environment 44(6):1237–45.

Karjalainen, Sami. 2007. “Gender Differences in Thermal Comfort and Use of Thermostats in Everyday Thermal Environments.” Building and Environment 42(4):1594–1603.

Karjalainen, S. 2012. “Thermal Comfort and Gender: A Literature Review.” Indoor Air 22(2):96–109.

Katafygiotou, M., Serghides, D. Indoor comfort and energy performance of buildings in relation to occupants’ satisfaction: investigation in secondary schools of Cyprus, Advances in Building Energy Research (2014) 1–25.

Kennedy, Susan M., Murray Hodgson, Lisa Dillon Edgett, Noelle Lamb, and Rod Rempel. 2006. “Subjective Assessment of Listening Environments in University Classrooms: Perceptions of Students.” The Journal of the Acoustical Society of America 119(1):299–309.

Kephalopoulos, S., Csobod, C., Bruinen de Bruin, Y., de Oliveira Fernandes, E. Guidelines for Healthy Environments within European Schools, SINPHONIE Project, European Commission’s Directorates General for Health and Consumers and Joint Research Centre, EUR 26726 EN, Luxembourg, 2014 downloaded at September 9, 2020 from https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/guidelines-healthy-environments-within-european-schools

Kielb, C., S. Lin, N. Muscatiello, W. Hord, J. Rogers-Harrington, and J. Healy. 2015. “Building-Related Health Symptoms and Classroom Indoor Air Quality: A Survey of School Teachers in New York State.” Indoor Air 25(4):371–80.

Kim, J., Mi, L., Johansson, Y., Smedje, M., Nörback, G. Current asthma and respiratory symptoms among pupils in relation to dietary factors and allergens in the school environment. Indoor Air. 2005. 15. 170–182.

Kim, Jungsoo, Richard de Dear, Christhina Cândido, Hui Zhang, and Edward Arens. 2013. “Gender Differences in Office Occupant Perception of Indoor Environmental Quality (IEQ).” Building and Environment 70 (December):245–56.

Klatte, M. and J. Hellbroock. 2010. Effects of Classroom Acoustics on Performance and Wellbeing in Elementary School Children: A Field Study. Vol. 2.

mfort Assessment of Daylit and Sunlit Areas: A Longitudinal Field Survey in Classrooms in Kashan, Iran.” Energy and Buildings 128:305–18.

Knez, I. Effects of indoor lighting on mood and cognition. Journal of Environmental Psychology. 1995. 15(1). 39–51.

Knez, I. (2001) Effects of colour of light on nonvisual psychological processes, Journal of Environmental Psychology, 21(3), 201–208.

Knotsch, Cathleen, and Dianne Kinnon. If Not Now... When? Addressing the Ongoing Inuit Housing Crisis in Canada. If Not Now... When? Addressing the Ongoing Inuit Housing Crisis in Canada. National Aboriginal Health Organization, 2011.

Kovesi T. Respiratory disease in Canadian First Nations and Inuit children. Paediatr Child Health. 2012; 17(7):376-380.

Kovesi, Thomas, Nicolas L. Gilbert, Corinne Stocco, Don Fugler, Robert E. Dales, Mireille Guay, and J. David Miller. 2007. "Indoor Air Quality and the Risk of Lower Respiratory Tract Infections in Young Canadian Inuit Children." Cmaj 177(2):155–60.

Kovesi, T., D. Creery, N. L. Gilbert, R. Dales, D. Fugler, B. Thompson, N. Randhawa, and J. D. Miller. 2006. "Indoor Air Quality Risk Factors for Severe Lower Respiratory Tract Infections in Inuit Infants in Baffin Region, Nunavut: A Pilot Study." Indoor Air 16(4):266–75.

Kreiss K., 1989. The epidemiology of building-related complaints and illness. Occup. Med, 4, pp. 575-592.

Kristiansen, J. (2010). Is noise exposure in non-industrial work environments associated with increased sickness absence? Noise & Vibration Worldwide, 41, 9-16.

Kristiansen, Jesper, Roger Persson, Søren Peter Lund, Hitomi Shibuya, and Per Møberg Nielsen. 2013. "Effects of Classroom Acoustics and Self-Reported Noise Exposure on Teachers' Well-Being." Environment and Behavior 45(2):283–300.

Lan, Li, Zhiwei Lian, and Li Pan. 2010. "The Effects of Air Temperature on Office Workers' Well-Being, Workload and Productivity-Evaluated with Subjective Ratings." Applied Ergonomics 42(1):29–36.

Lan, Li, Pawel Wargocki, and Zhiwei Lian. 2011. "Quantitative Measurement of Productivity Loss Due to Thermal Discomfort." Energy and Buildings 43(5):1057–62.

Latycheva, O., R. Chera, C. Hampson, J. R. Masuda, M. Stewart, S. J. Elliott, and N. E. Fenton. 2013. "Engaging First Nation and Inuit Communities in Asthma Management and Control: Assessing Cultural Appropriateness of Educational Resources." Rural and Remote Health 13(1):1–11.

Lavy, Sarel and David L. Bilbo. 2009. "Facilities Maintenance Management Practices in Large Public Schools, Texas." Facilities 27(1–2):5–20.

Li, D. H. W., S. L. Wong, C. L. Tsang, and Gary H. W. Cheung. 2006. "A Study of the Daylighting Performance and Energy Use in Heavily Obstructed Residential Buildings via Computer Simulation Techniques." Energy and Buildings 38(11):1343–48.

Lin, Z., Deng S. A study on the thermal comfort in sleeping environments in the subtropics—developing a thermal comfort model for sleeping environments. Building and Environment. 2008. 43. 70–80.

Lin, Shao, Wayne R. Lawrence, Ziqiang Lin, Melissa Francois, Iulia A. Neamtiu, Qiaoxuan Lin, Eva Csobod, and Eugen S. Gurzau. 2017. "Teacher Respiratory Health Symptoms in Relation to School and Home Environment." International Archives of Occupational and Environmental Health 90(8):725–39.

Lin, Shao, Emily Lipton, Yi Lu, and Christine Kielb. 2020. "Are Classroom Thermal Conditions, Lighting, and Acoustics Related to Teacher Health Symptoms?" Indoor Air 30(3):544–52.

Lukcso, D., Guidotti, T.L., Franklin, D.E., Burt, A. Indoor environmental and air quality characteristics, building-related health symptoms, and worker productivity in a federal government building complex. Architecture Environment Occupational Health. 2016. 71. 85–101.

Lyons, Peter R., Dariush Arasteh, and Charlie Huizenga. 2000. "Window Performance for Human Thermal Comfort." ASHRAE Transactions 106(August 1999).

Madureira, J., Alvim-Ferraz, M., Rodrigues, S., Gonçalves, C., Azevedo, M., Pinto, E., Mayan, O. Indoor air quality in schools and health symptoms among Portuguese teachers, Human Ecological Risk Assessment. 2009. 15 (1). 159-169.

Maniccia, Dorene, Burr Rutledge, Mark S. Rea, and Wayne Morrow. 1999. "Occupant Use of Manual Lighting Controls in Private Offices." Journal of the Illuminating Engineering Society 28(2):42–56.

Matz, C.J., Stieb, D.M., Davis, K., Egyed, M., Rose, A., Chou, B. and Brion, O. (2014) Effects of age, season, gender and urban-rural status on time-activity: Canadian Human Activity Pattern Survey 2 (CHAPS 2). International Journal of Environmental Research and Public Health,11(2): 2108-2124.

Maxwell, Patrick, Faisal Durrani, and Mahroo Eftekhari. 2016. "Investigating Heat Loss through Vestibule Doors for a Non-Residential Building." Sustainability in Environment 1(1):25.

Meklin, T., T. Husman, A. Vepsäläinen, M. Vahteristo, J. Koivisto, J. Halla-Aho, A. Hyvärinen, D. Moschandreas, and A. Nevalainen. 2002. "Indoor Air Microbes and Respiratory Symptoms of Children in Moisture Damaged and Reference Schools." Indoor Air 12(3):175–83.

Mendell, Mark J. 1993. "Non-Specific Symptoms In Office Workers: A Review And Summary Of The Epidemiologic Literature." Indoor Air 3(4):227–36.

Mendell, M., Fisk, W., Kreiss, K., Levin, H., Alexander, D., Cain, W., Girman, J., Hines, C., Jensen, P., Milton, D., Rexroat, L., & Wallingford, K. Improving the health of workers in indoor environments: Priority research needs for a national occupational research agenda. American Journal of Public Health. 2002. 92. 1430–1440.

Mendell, M.J., and G.A. Heath. Do indoor pollutants and ther- mal conditions in schools influence student performance? A critical review of the literature. Indoor Air. 2005. 15. 27–52.

Miller, N., Pogue, D., Gough, Q. & Davis, S. Green Building and Productivity. Journal of Sustainable Real Estate. 2009. 1. 65.

Mishra, A. K., M. T. H. Derks, L. Kooi, M. G. L. C. Loomans, and H. S. M. Kort. 2017. "Analysing Thermal Comfort Perception of Students through the Class Hour, during Heating Season, in a University Classroom." Building and Environment 125:464–74.

Moezzi, Mithra. 2009. "Are Comfort Expectations of Building Occupants Too High?" Building Research and Information 37(1):79–83.

Montazami, Azadeh and Fergus Nicol. 2013. "Overheating in Schools: Comparing Existing and New Guidelines." Building Research and Information 41(3):317–29.

Montgomery D. & Kalman D. Indoor/Outdoor Air Quality: Reference Pollutant Concentrations in Complaint-Free Residences. Applied Industrial Hygiene.1989. 4:1, 17-20.

Mumovic, D., J. Palmer, M. Davies, M. Orme, I. Ridley, T. Oreszczyn, C. Judd, R. Critchlow, H. A. Medina, G. Pilmoor, C. Pearson, and P. Way. 2009. "Winter Indoor Air Quality, Thermal Comfort and Acoustic Performance of Newly Built Secondary Schools in England." Building and Environment 44(7):1466–77.

Myhrvold, A., Olsen, E., Lauridsen, O. Indoor environment in schools - pupils health and performance in regard to CO2 concentrations. Proceedings of Seventh International Conference on Indoor Air Quality and Climate, vol. 4. July 21-26, 1996, pp. 369-374. Nagoya, Japan.

Nardi, Iole, Elena Lucchi, Tullio de Rubeis, and Dario Ambrosini. 2018. “Quantification of Heat Energy Losses through the Building Envelope: A State-of-the-Art Analysis with Critical and Comprehensive Review on Infrared Thermography.” Building and Environment 146(September):190–205.

National Academy of Science. Clearing the air: asthma and indoor exposure. Washington DC, National Academy of Science Press. 2000.

Navai M, Veitch JA. Acoustic satisfaction in open-plan offices: review and recommendations. Research Report RR-151. Ottawa, Canada: Institute for Research in Construction, National Research Council Canada. Available at, http://www.nrc-cnrc.gc.ca/obj/irc/doc/pubs/rr/rr151/rr151.pdf; 2003.

Norbäck, Dan, E. Björnsson, C. Janson, U. Palmgren, and G. Boman. 1999. “Current Asthma and Biochemical Signs of Inflammation in Relation to Building Dampness in Dwellings.” International Journal of Tuberculosis and Lung Disease 3(5):368–76.

NRCan. 2014. “Natural Resources Canada.”

Nunes, F., Menzies, R., Tamblyn R.M., Boehm, E. and Letz, R. (1993) The effect of varying level of outdoor air supply on neurobehavioral performance function during a study of sick building syndrome (SBS). In: Saarela, K., Kalliokoski, P. and Seppanen, O. (eds) Proceedings of Indoor Air ’93, Helsinki, The 6th International Conference on Indoor Air Quality and Climate, Vol. 1, pp. 53–58.

Ogbonna, A. C. and D. J. Harris. 2008. “Thermal Comfort in Sub-Saharan Africa: Field Study Report in Jos-Nigeria.” Applied Energy 85(1):1–11.

Ogbonna, A., Harris D. Thermal comfort in sub-Saharan Africa: field study report in Jos–Nigeria. Applied Energy. 2008; 85:1–11.

Ouf, Mohamed. The Effect of Occupancy on School Buildings’ Energy Consumption in Manitoba. Energy and Buildings; Elsevier, 2016.

Pakulski, L., Glassman, J., Anderson, K., & Squires, E.. Noise Pollution ( Noise-Scape ) Among School Children. 2016.

Palumbo, J., Lin, S., Lin, Z., Neamtiu, I., Zhang, W., Csobod, E., and Gurzau. E. “Assessing Associations Between Indoor Environment and Health Symptoms in Romanian School Children: An Analysis of Data from the SINPHONIE Project.” Environmental Science and Pollution Research 25, no. 9 (March 2018): 9186–9193.

Parsons, K. C. 2002. “The Effects of Gender, Acclimation State, the Opportunity to Adjust Clothing and Physical Disability on Requirements for Thermal Comfort.” Energy and Buildings 34(6):593–99.

Pei, Z., Lin, B., Liu, Y., Zhu, Y. Comparative study on the indoor environment quality of green office buildings in China with a long- term field measurement and investigation. Building Environment. 2015; 84:80-88.

Polyzois D., Polyzoi E., Wells J., Koulis T., 2016. Poor Indoor Air Quality, Mold Exposure, and Upper Respiratory Tract Infections-Are We Placing Our Children at Risk? Environmental Health, 78(7), pp. 20-27.

Price, Edrs. 2002. “Schneider, Mark.”

Puglisi, G. E., L. C. Cantor Cutiva, L. Pavese, A. Castellana, M. Bona, S. Fasolis, V. Lorenzatti, A. Carullo, A. Burdor, F. Bronuzzi, and A. Astolfi. 2015. “Acoustic Comfort in High-School Classrooms for Students and Teachers.” Energy Procedia 78:3096–3101.

Radwan, Ahmed. An Evaluation of Indoor Environmental Quality and Occupant Well-Being in Three Southern Rural Manitoba School Buildings, 2015.

Ravindu S, Rameezdeen R, Zuo J, Zhou Z, Chandratilake R. Indoor environment quality of green buildings: case study of an LEED platinum certified factory in a warm humid tropical climate. Build Environ. 2015;84:105-113.

Raw, G.J., Roys, M.S. and Leaman, A. 1990. Further findings from the office environment survey: productivity. Indoor Air '90, Toronto, Proceedings Vol. 1, 231-236

Raysoni, Amit U., Thomas H. Stock, Jeremy A. Sarnat, Teresa Montoya Sosa, Stefanie Ebelt Sarnat, Fernando Holguin, Roby Greenwald, Brent Johnson, and Wen Whai Li. 2013. “Characterization of Traffic-Related Air Pollutant Metrics at Four Schools in El Paso, Texas, USA: Implications for Exposure Assessment and Siting Schools in Urban Areas.” Atmospheric Environment 80:140–51.

Raymond, Hetu, Claire Truchon-Gagnon, and Sylvie A. Bilodeau. 1990. “Problems of Noise in School Settings : A Review of Literature and the Results of an Exploratory Study Problemes de Bruit En Milieu Seo / Sire : Etst Des Eonnsisssnees et Etude Exp / Orstoire Eru.” Journal of Speech-Language Pathology and Audiology (1979):31–39.

Reijula, K. and C. Sundman-Digert. 2004. “Assessment of Indoor Air Problems at Work with a Questionnaire.” Occupational and Environmental Medicine 61(1):33–38.

Reinikainen, Leena M., Leena Aunela-Tapola, and Jouni J. K. Jaakkola. 1997. “Humidification and Perceived Indoor Air Quality in the Office Environment.” Occupational and Environmental Medicine 54(5):322–27.

Ricciardi, Paola and Cinzia Buratti. 2018. “Environmental Quality of University Classrooms: Subjective and Objective Evaluation of the Thermal, Acoustic, and Lighting Comfort Conditions.” Building and Environment 127(August 2017):23–36.

Rittner, H., & Robbin, M. Color and light in learning. School Planning & Management. 2002. 41(2), 57–58.

Roelofsen, Paul. 2016. “A Computer Model for the Assessment of Employee Performance Loss as a Function of Thermal Discomfort or Degree of Heat Stress.” Intelligent Buildings International 8(4):195–214.

Sadick, Abdul Manan and Mohamed H. Issa. 2017. “Occupants’ Indoor Environmental Quality Satisfaction Factors as Measures of School Teachers’ Well-Being.” Building and Environment 119:99–109.

Sadick, Abdul-Manan. Assessment of School Buildings’ Physical Conditions and Indoor Environmental Quality in Relation to Teachers’ Satisfaction and Well-Being, 2018.

Sala, E. and V. Viljanen. 1995. “Improvement of Acoustic Conditions for Speech Communication in Classrooms.” Applied Acoustics 45(1):81–91.

Sato, Mikiya, Shingo Fukayo, and Eiji Yano. 2003. “Adverse Environmental Health Effects of Ultra-Low Relative Humidity Indoor Air.” Journal of Occupational Health 45(2):133–36.

Schreiber, M. Lighting alternatives: considerations for child care centres. Young Children. 1996. 51(4). 11–13.

Schwartz, J. Air pollution and children's health. Pediatrics. 2004. 113. 1037-1043.

Seppänen, O. A. 1999. “Association of Ventilation Rates and CO2 Concentrations with Health and Other Responses in Commercial and Institutional Buildings.” Indoor Air 9(4):226–52.

Seppanen, O, W.J Fisk, and Q.H Lei. “Room Temperature and Productivity in Office Work”. United States, 2006.

Seppänen O, Vuolle M. Control of Temperature for productivity. Rehva journal. Federation of European Heating and Air-Conditioning Associations. 2003. 8-12.

Seppanen, O., Fisk, W. Some quantitative relations between indoor environmental quality and work performance or health. HVAC and R research. 2006. 12. 957-973.

Simons, Elinor, Syni An Hwang, Edward F. Fitzgerald, Christine Kielb, and Shao Lin. 2010. “The Impact of School Building Conditions on Student Absenteeism in Upstate New York.” American Journal of Public Health 100(9):1679–86.

Singh A., Syal M., Grady C., Korkmaz S. Effects of green buildings on employee’s health and productivity. American Pub Health 2010. 100(9): 1665–1668.

Smedje, G., M. Mattsson, and R. Wålinder. 2011. “Comparing Mixing and Displacement Ventilation in Classrooms: Pupils Perception and Health.” Indoor Air 21(6):454–61.

Smedje, Greta and Dan Norbäck. 2000. “New Ventilation Systems at Select Schools in Sweden—Effects on Asthma and Exposure.” Archives of Environmental Health 55(1):18–25.

Smedje, G., Norback, D., Wessen, B. and Edling, C. (1996) Asthma among school employees in relation to the school environment. In: Proceedings of Indoor Air ’96: The 7th International Conference on Indoor Air Quality and Climate, Nagoya, Japan, July, 1996, Vol. 1, 611–616.

Standards EN 12465-2011.Light and Lighting; Basic Terms and Criteria for Specifying Lighting Requirements; European Committee for Standardization: Brussels, Belgium, 2011 (18) (PDF) Visual Comfort Assessment in an Industrial Environment: A Case Study. Available from: https://www.researchgate.net/publication/333340927_Visual_Comfort_Assessment_in_an_Industrial_Environment_A_Case_Study [accessed Oct 17 2020].

Statistics Canada, 2010. Children and Youth. http://www.statcan.gc.ca/pub/11-402-x/2011000/chap/c-e/c-e-eng.htm (last visited Oct. 11, 2020)

Statistics Canada, 2010 Available: http://www. statcan.ca (Accessed 10 January 2020).

Stenberg, Berndt and Stig Wall. 1995. “Why Do Women Report ‘sick Building Symptoms’ More Often than Men?” Social Science and Medicine 40(4):491–502.

Sufar, Suhaila, Anuar Talib, and Haris Hambali. 2012. “Towards a Better Design: Physical Interior Environments of Public Libraries in Peninsular Malaysia.” Procedia - Social and Behavioral Sciences 42(July 2010):131–43.

Sundell, J., H. Levin, W. W. Nazaroff, W. S. Cain, W. J. Fisk, D. T. Grimsrud, F. Gyntelberg, Y. Li, A. K. Persily, A. C. Pickering, J. M. Samet, J. D. Spengler, S. T. Taylor, and C. J. Weschler. 2011. “Ventilation Rates and Health: Multidisciplinary Review of the Scientific Literature." Indoor Air 21(3):191–204.

Taylor, Tim, John Counsell, and Steve Gill. 2013. "Energy Efficiency Is More than Skin Deep: Improving Construction Quality Control in New-Build Housing Using Thermography." Energy and Buildings 66:222–31.

Teli, Despoina, Mark F. Jentsch, and Patrick A. B. James. 2014. "The Role of a Building's Thermal Properties on Pupils' Thermal Comfort in Junior School Classrooms as Determined in Field Studies." Building and Environment 82:640–54.

Theodosiou, T. G. and K. T. Ordoumpozanis. 2008. "Energy, Comfort and Indoor Air Quality in Nursery and Elementary School Buildings in the Cold Climatic Zone of Greece." Energy and Buildings 40(12):2207–14.

Tortolero, S.R., Bartholomew, L.K., Tyrrel, S., Abramson, S.L., Sockrider, M.M., Markham, C.M., Whitehead, L.W. and Parcel, G.S. (2002) Environmental allergens and irritants in schools: a focus on asthma, J. Sch. Health, 72,33–38.

Trebilcock, M. Soto-Munoz, J., Yanez, J., Figueroa-San Martin R. The right to comfort: a field study on adaptive thermal comfort in free – running schools in Chile, Building Environment. 2017. 114. 455–469.

Turanjanin, V., Vucicevic, B., Jovanovic, M., Mirkov, N., Lazovic, I. Indoor CO2 measurements in Serbian schools and ventilation rate calculation. Energy. 2014. 77. 290-296.

Turunen, Mari, Oluyemi Toyinbo, Tuula Putus, Aino Nevalainen, Richard Shaughnessy, and Ulla Haverinen-Shaughnessy. 2013. "Indoor Environmental Quality in School Buildings, and the Health and Wellbeing of Students." International Journal of Hygiene and Environmental Health 217(7):733–39.

Ung-Lanki, S., J. Lampi, and J. Pekkanen. 2017. "Analyzing Symptom Data in Indoor Air Questionnaires for Primary Schools." Indoor Air 27(5):900–908.

University of Manitoba 2014. University of Manitoba Strategic Research Plan 2015-2020. University of Manitoba 2014.

U.S. Environmental Protection Agency. An Introduction to Indoor Air Quality (IAQ) Volatile Organic Compounds (VOCs), 7-9-2012. Available at: http://www.epa.gov/iaq/voc.html

U.S. Department of Education, National Center for Education Statistics. Condition of America's Public School Facilities: 1999, NCES 2000-032, 2000, Washington, D.C.

U.S. Environmental Protection Agency. An Introduction to Indoor Air Quality (IAQ) Volatile Organic Compounds (VOCs), 7-9-2012a, Available at: http://www.epa.gov/iaq/voc.html.

Van Dijken, F., J. E. M. H. Van Bronswijk, and J. Sundell. 2006. "Indoor Environment and Pupils' Health in Primary Schools." Building Research and Information 34(5):437–46.

Van Hoof, J. 2008. "Forty Years of Fanger's Model of Thermal Comfort: Comfort for All?" Indoor Air 18(3):182–201.

Veitch, J. A. and G. R. Newsham. 1998. "Determinants of Lighting Quality i: State of the Science." Journal of the Illuminating Engineering Society 27(1):92–106.

Veitch, Jennifer A., G. R. Newsham, P. R. Boyce, and C. C. Jones. 2008. "Lighting Appraisal, Well-Being and Performance in Open-Plan Offices: A Linked Mechanisms

Approach.” Lighting Research and Technology 40(2):133–48.

Veitch, J., Gifford, R. Assessing beliefs about lighting effects on health, performance, mood, and social behavior, Environment and Behavior. 1996. 28 (4). 446–470.

Veitch, J. Revisiting The performance and mood effects of information about lighting and fluorescent lamp type. Journal of Environmental Psychology. 1997. 17(3). 253–262.

Vilcekova, Silvia, Ludmila Meciarova, Eva Kridlova Burdova, Jana Katunska, Danica Kosicanova, and Saeed Doroudiani. 2017. “Indoor Environmental Quality of Classrooms and Occupants’ Comfort in a Special Education School in Slovak Republic.” Building and Environment 120:29–40.

Vollmer, M., & Möllmann, K. (2010). Infrared thermal imaging fundamentals, research and applications . Wiley-VCH.

Wargocki, Pawel. 1999. “Perceived Air Quality, Sick Building Syndrome (SBS) Symptoms and Productivity in an Office with Two Different Pollution Loads.” Indoor Air 9(3):165–79.

Wargocki, Pawel and David P. Wyon. 2013. “Providing Better Thermal and Air Quality Conditions in School Classrooms Would Be Cost-Effective.” Building and Environment 59:581–89.

Wargocki, P., Wyon, D.P., Sundell, J., Clausen, G., Fanger, P. The effects of outdoor air supply rate in an office on perceived air quality, sick building syndrome (SBS) symptoms and productivity. Indoor Air. 2000. 10 (4). 222–236.

Wargocki, Pawel and David P. Wyon. 2007. “The Effects of Moderately Raised Classroom Temperatures and Classroom Ventilation Rate on the Performance of Schoolwork by Children (RP-1257).” HVAC and R Research 13(2):193–220.

Wargocki, Pavel, Wyon, D., Sundell, J. et al. ‘‘The effects of outdoor air supply rate in an office on perceived air quality, sick building syndrome (SBS) Symptoms and Productivity’’. Indoor Air. 2000. 222– 236.

Wargocki, P., Wyon, D.P., Sundell, J., Clausen, G. and Fanger, P.O. (2000) The effects of outdoor air supply rate in an office on perceived air quality, sick building syndrome (SBS) symptoms and productivity. Indoor Air, 10(4), 222–236.

Weinstein, C. The physical environment of the school: a review of the research. Review of Educational Research. 1979. 49(4). 577–610.

Wang, Z., Li, A., Ren, J., He, Y. Thermal adaptation and thermal environment in university classrooms and offices in Harbin, Energy and Buildings. 2014. 77 (7). 192-196.

Willers, S., Andersson, S., Andersson, R. et al. Sick Building Syndrome symptoms among the staff in schools and kindergartens: are the levels of volatile organic compounds and carbon dioxide responsible? Indoor Built Environment, 1996; 5:232-35.

Winterbottom, Mark and Arnold Wilkins. 2009. “Lighting and Discomfort in the Classroom.” Journal of Environmental Psychology 29(1):63–75.

Witterseh, T., Wyon, D., Clausen G. The effects of moderate heat stress and open-plan office noise distraction on SBS symptoms and on the performance of office work. Indoor Air. 2004. 30-40.

Wolkoff, Peder, Cornelius K. Wilkins, Per A. Clausen, and Kjeld Larsen. 1993. “Comparison Of Volatile Organic Compounds From Processed Paper And Toners From Office Copiers And Printers: Methods, Emission Rates, And Modeled Concentrations.” Indoor Air 3(2):113–23.

Wolkoff, Peder. 2018. “Indoor Air Humidity, Air Quality, and Health – An Overview.” International Journal of Hygiene and Environmental Health 221(3):376–90.

Wong N., Khoo S. Thermal comfort in classrooms in the tropics. Energy Building. 2003. 35. 337-351.

Woolner, Pamela and Elaine Hall. 2010. “Noise in Schools: A Holistic Approach to the Issue.” International Journal of Environmental Research and Public Health 7(8):3255–69.

Woolner, Pamela, Elaine Hall, Steve Higgins, Caroline McCaughey, and Kate Wall. 2007. “A Sound Foundation? What We Know about the Impact of Environments on Learning and the Implications for Building Schools for the Future.” Oxford Review of Education 33(1):47–70.

Wyon, D. and P. Wargocki. 2006. “Room Temperature Effects on Office Work: Creating the Productive Workplace.” (January 2006).

Wyon, D. The effects of indoor air quality on performance and productivity. Indoor air, 2004, 14, 92- 101.

Wyon, D.P., Andersen, I. and Lundqvist, G.R. (1972) Spontaneous magnitude estimation of thermal discomfort during changes in the ambient temperature, Journal of Hygiene, 70, 203–221.

Wyon, D. P. (1996). Indoor environmental effects on productivity. In Proceedings of IAQ. Vol. 96, pp. 5-15.

Xue, Peng, C. M. Mak, and H. D. Cheung. 2014. “The Effects of Daylighting and Human Behavior on Luminous Comfort in Residential Buildings: A Questionnaire Survey.” Building and Environment 81:51–59.

Yan, Z. (2010). Analysis and Comparison of a Dynamic Thermal Model Energy Analysis and the Monitored Energy Performance on an EPC A Rated Building. MSc dissertation, Department of Civil and Building Engineering, Loughborough University.

Your Perfect Palette. (n.d.). Retrieved January 14, 2021, from https://www.flir.ca/discover/ots/outdoor/your-perfect-palette/

Yousef Al Horr Amit Kaushik, Ahmed Mazroei, Mohammed Arif, Esam Elsarrag Martha Katafygiotou, Yousef Al horr, Mohammed Arif, Mazroei AK, Katafygiotou A, and Esam Elsarrag. 2016. “Occupant Productivity and Office Indoor Environment Quality : A Review of the Literature Occupant Productivity and Office Indoor Environment Quality : A Review of the Literature.” Building and Environment 105:45.

Zannin, Paulo Henrique Trombetta and Carolina Reich Marcon. 2007. “Objective and Subjective Evaluation of the Acoustic Comfort in Classrooms.” Applied Ergonomics 38(5):675–80.

Zannin, Paulo Henrique Trombetta and Daniele Petri Zanardo Zwirtes. 2009. “Evaluation of the Acoustic Performance of Classrooms in Public Schools.” Applied Acoustics 70(4):626–35.

Zeiler, Wim and Gert Boxem. 2009. “Effects of Thermal Activated Building Systems in Schools on Thermal Comfort in Winter.” Building and Environment 44(11):2308–17.

Zhao, Zhuohui, Zheng Zhang, Zhuanhua Wang, Martin Ferm, Yanling Liang, and Dan Norbäck. 2008. “Asthmatic Symptoms among Pupils in Relation to Winter Indoor and Outdoor Air Pollution in Schools in Taiyuan, China.” Environmental Health Perspectives 116(1):90–97.

Zhang, H., Arens, E., Pasut, W. Air temperature thresholds for indoor comfort and perceived air quality. Building Research and Information. 2011. 134–144.

Zock, J. P., A. Borras-Santos, J. Jacobs, E. Krop, A. Hyvarinen, M. Taubel, U. Haverinen-Shaughnessy, D. Heederik, J. Pekkanen, and A. Nevalainen. 2011. “Dampness and Mould in School Buildings and Respiratory Symptoms in Teachers: An International Study.” Occupational and Environmental Medicine 68(Suppl_1):A91–92.

Zomorodian, Zahra Sadat, Mohammad Tahsildoost, and Mohammadreza Hafezi. 2016. “Thermal Comfort in Educational Buildings: A Review Article.” Renewable and Sustainable Energy Reviews 59:895–906.

Zuo, Qun, and Eileen E MaloneBeach. “Assessing Staff Satisfaction with Indoor Environmental Quality in Assisted Living Facilities: ASSISTED LIVING STAFF SATISFACTION WITH IEQ.” Journal of interior design 42, no. 1 (2017): 67–84.

# Appendix 1

## Summary of survey responses

### Section 1 Demography

**1. What is your gender?**

| | |
|---|---|
| Female | 43 |
| Male | 13 |

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

| | |
|---|---|
| Less than 1 year | 3 |
| 1 to 3 years | 17 |
| More than 3 years | 36 |

**3. On average, how many hours per week do you spend in the classroom that you use the most?**

| | |
|---|---|
| 10 or less than 10 | 4 |
| 11 to 20 | 2 |
| 21 to 30 | 17 |
| More than 30 | 33 |

**4. On average, how many students do you have in the classroom that you use the most?**

| | |
|---|---|
| 10 or less than 10 | 8 |
| 11 to 15 | 7 |
| 16 to 20 | 25 |
| More than 20 | 15 |

**5. Please indicate in which classrooms you teach this school year**

**6. Please indicate which grades you teach in this school year**

## Section 2 General satisfaction or dissatisfaction with the school's condition

**1. On average, how satisfied or dissatisfied are you with the following conditions of your school?**

| | | Very dissatisfied | Moderately dissatisfied | Slightly dissatisfied | Neutral | Slightly satisfied | Moderately satisfied | Very Satisfied |
|---|---|---|---|---|---|---|---|---|
| Cleanliness | Fall | 8 | 8 | 13 | 12 | 9 | 4 | 2 |
| | Winter | 12 | 9 | 15 | 9 | 7 | 2 | 1 |
| | Spring | 10 | 12 | 15 | 10 | 6 | 1 | 1 |
| Maintenance | Fall | 6 | 5 | 12 | 17 | 7 | 6 | 3 |
| | Winter | 8 | 5 | 12 | 13 | 9 | 6 | 2 |
| | Spring | 7 | 5 | 12 | 14 | 9 | 6 | 2 |
| Ventilation system | Fall | 14 | 8 | 22 | 7 | 2 | 1 | 2 |
| | Winter | 18 | 8 | 19 | 7 | 2 | 1 | 0 |
| | Spring | 14 | 11 | 21 | 6 | 1 | 1 | 1 |

**2. Overall, how satisfied or dissatisfied are you with your school?**

| Very dissatisfied | Moderately dissatisfied | Slightly dissatisfied | Neutral | Slightly satisfied | Moderately satisfied | Very Satisfied |
|---|---|---|---|---|---|---|
| 4 | 5 | 19 | 15 | 8 | 4 | 1 |

## Section 3 Indoor Air Quality

**1. On average, how satisfied or dissatisfied are you with the air quality of the office that you use most?**

| | Very dissatisfied | Moderately dissatisfied | Slightly dissatisfied | Neutral | Slightly satisfied | Moderately satisfied | Very Satisfied |
|---|---|---|---|---|---|---|---|
| Fall | 9 | 13 | 15 | 11 | 6 | 2 | 0 |
| Winter | 8 | 15 | 16 | 11 | 5 | 1 | 0 |
| Spring | 8 | 12 | 19 | 10 | 5 | 1 | 1 |

**2. On average, how you rate below listed indoor air quality issues in the office that you use the most?**

Air smells bad

| | Not problem at all | 2 | 3 | Moderately | 5 | 6 | A major problem |
|---|---|---|---|---|---|---|---|
| Fall | 7 | 11 | 14 | 8 | 6 | 4 | 5 |
| Winter | 9 | 10 | 11 | 9 | 5 | 4 | 7 |
| Spring | 8 | 6 | 14 | 10 | 4 | 6 | 7 |

Ais is stuffy

| | Not problem at all | 2 | 3 | Moderately | 5 | 6 | A major problem |
|---|---|---|---|---|---|---|---|
| Fall | 10 | 5 | 11 | 9 | 8 | 7 | 5 |
| Winter | 8 | 5 | 15 | 7 | 5 | 9 | 7 |
| Spring | 9 | 5 | 13 | 10 | 5 | 7 | 6 |

Air is dusty

| | Not problem at all | 2 | 3 | Moder-ately | 5 | 6 | A major problem |
|---|---|---|---|---|---|---|---|
| Fall | 8 | 9 | 10 | 9 | 9 | 6 | 5 |
| Winter | 10 | 8 | 11 | 10 | 5 | 6 | 6 |
| Spring | 8 | 5 | 12 | 13 | 5 | 7 | 5 |

**3. On average, how frequently do your students use glue, paint, enamels, or other products for artwork with an irritant smell in the classroom that you use the most?**

| | Never | Once to 5 times a month | 5 times to 10 times a month | More than 10 times a month |
|---|---|---|---|---|
| Fall | 11 | 32 | 7 | 3 |
| Winter | 9 | 26 | 12 | 4 |
| Spring | 9 | 29 | 10 | 3 |

**4. Which do you recognize as the source of poor indoor air quality in the classroom that you use the most? Please check ALL that apply.**

| Sources of poor air quality | Number |
|---|---|
| Furniture smell | 11 |
| Smoking smell | 5 |
| Art supplies and equipment like printer | 5 |
| Outdoor pollution like dust which enters the building | 32 |
| Washrooms smell | 45 |
| Cooking | 19 |
| Chemical substances smell (like cleaners) | 16 |
| Visible signs of moisture damage | 27 |
| Mold or cellar-like odour | 34 |

**5. Have you ever noticed a moldy/earthy or cedar-like odour inside your school building?**

No - 22; Yes - 34

**6. If your answer in Question 5 is YES, please indicate the spaces in which you have noticed moldy/earthy or cedar-like odour. Please check ALL that apply.**

| Location | Number |
|---|---|
| Classrooms | 20 |
| Gym | 9 |
| Bathrooms | 26 |
| Kitchen | 1 |
| Canteen | 1 |
| Offices | 7 |
| Basement | 5 |
| None | 1 |

**7. Have there ever been visible signs of moisture damage such as damp stains or sports, deterioration or darkening of surface materials in the ceiling, walls, or floors, or signs of condensation of water on surfaces in the classroom that you use the most?**

No - 29; Yes - 27

**8. Does the indoor air quality of the office that you use the most affect your ability to do your work at school?**

No - 40; Yes - 15; one respondent gave two answers (Yes and No)

**9. If your answer in Question 8 is YES, how do you describe this effect?**

**10. Please indicate if you have any comments about the indoor air quality of the office that you use the most.**

## Section 4 Thermal Comfort

### 1. On average, how do you feel about the temperature of the office that you use the most?

| | Cold | Cool | Slightly cool | Neutral | Slightly warm | Warm | Hot |
|---|---|---|---|---|---|---|---|
| Fall | 6 | 5 | 9 | 18 | 3 | 2 | 7 |
| Winter | 12 | 5 | 10 | 10 | 0 | 4 | 7 |
| Spring | 2 | 0 | 8 | 16 | 6 | 7 | 7 |

### 2. On average, how satisfied or dissatisfied are you with the following parameters in the office that you use the most?

| | Air humidity | | | Air movement | | | Temperature | | |
|---|---|---|---|---|---|---|---|---|---|
| | Fall | Winter | Spring | Fall | Winter | Spring | Fall | Winter | Spring |
| Very dissatisfied | 10 | 10 | 9 | 10 | 14 | 9 | 9 | 11 | 10 |
| Moderately dissatisfied | 10 | 12 | 12 | 14 | 12 | 14 | 16 | 16 | 15 |
| Slightly dissatisfied | 16 | 14 | 14 | 13 | 11 | 13 | 13 | 13 | 12 |
| Neutral | 15 | 12 | 16 | 14 | 13 | 13 | 12 | 11 | 13 |
| Slightly satisfied | 2 | 3 | 1 | 2 | 3 | 2 | 3 | 1 | 3 |
| Moderately satisfied | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 1 |
| Very Satisfied | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

**3. During a usual school day, are the windows open in the office that you use the most?**

No 27 Yes 27

**4. If your answer in Question 3 is YES, on average how long are the windows opened during a usual school day?**

| Season | Less than 1 hour | 1 to 3 hours | More than 3 hours |
|---|---|---|---|
| Fall | 4 | 11 | 16 |
| Winter | 18 | 8 | 5 |
| Spring | 1 | 8 | 25 |

**5. If your answer for Question 3 is NO, what is the reason for not opening windows?**

| | Fall | Winter | Spring |
|---|---|---|---|
| It is not needed | 8 | 2 | 4 |
| It is noisy outside | 0 | 0 | 0 |
| It is cold outside | 2 | 15 | 0 |
| It is dusty/smelly outside | 4 | 0 | 4 |
| None | 9 | 7 | 11 |

**6. Which of the *a* to *k* clothing ensembles do you typically wear in the classroom that you use the most?**

| | a | b | c | d | e | f | g | h | i | j | k |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Fall | 5 | 5 | 3 | 3 | 7 | 15 | 9 | 17 | 6 | 7 | 6 |
| Winter | 0 | 2 | 1 | 4 | 5 | 11 | 7 | 22 | 6 | 7 | 12 |
| Spring | 9 | 4 | 3 | 5 | 15 | 11 | 7 | 10 | 4 | 6 | 4 |

**7. Have you ever complained to a manager/supervisor/staff at your school about the thermal conditions of the classroom that you use the most?**

No 23 Yes 30

**8. If your answer in Question 7 is YES, was the problem addressed by a manager/supervisor/staff after your complaint?**

No 18 Yes 19

**9. Do you need to control or adjust the temperature by yourself in the classroom that you use the most?**

No 27 Yes 29

**10. If you answer to Question 9 is YES, how do you do that? Please check ALL that apply.**

| Window blinds or shades | Thermostats | A hot or cold drink | Opening/closing windows | Portable fans | Adding/removing a layer of clothing | None |
|---|---|---|---|---|---|---|
| 18 | 19 | 12 | 22 | 15 | 21 | 1 |

**11. Which of these options are NOT available to you or you cannot control by yourself in the office that you use the most? Please check ALL that apply.**

| Window blinds or shades | Thermostats | A hot or cold drink | Opening/closing windows | Portable fans | Adding/removing a layer of clothing | None |
|---|---|---|---|---|---|---|
| 19 | 32 | 7 | 15 | 24 | 3 | 7 |

**12. Which of these options are NOT available to your students or they cannot control by themselves in the classroom that you use the most? Please check ALL that apply.**

| Window blinds or shades | Thermostats | A hot or cold drink | Opening/closing windows | Portable fans | Adding/removing a layer of clothing | None |
|---|---|---|---|---|---|---|
| 27 | 37 | 10 | 24 | 30 | 4 | 3 |

**13. Does the thermal condition of the office that you use the most affect your ability to do your work at school?**

No 32  Yes 23

**14. If your answer in Question 13 is YES, how do you describe this effect?**

**15. Please indicate if you have any comments about the thermal condition of the classroom that you use the most.**

# Section 5 Health Syndromes

## 1. Have you ever had any of the following symptoms?

| | | | | | |
|---|---|---|---|---|---|
| Skin (dry, itching, eczema, rash) | No | 10 | Feeling like getting a cold | No | 9 |
| | yes, in Fall | 25 | | yes, in Fall | 25 |
| | yes, in winter | 40 | | yes, in winter | 39 |
| | yes, in spring | 22 | | yes, in spring | 18 |
| Eyes: swollen/red/burning, itching, dry/teary | No | 21 | Having a cold/Influenza/Fever | No | 12 |
| | yes, in Fall | 18 | | yes, in Fall | 18 |
| | yes, in winter | 26 | | yes, in winter | 29 |
| | yes, in spring | 22 | | yes, in spring | 13 |
| Nose: Runny, itching, sneezing, stuffy, blocked | No | 9 | Headache | No | 13 |
| | yes, in Fall | 26 | | yes, in Fall | 28 |
| | yes, in winter | 41 | | yes, in winter | 35 |
| | yes, in spring | 24 | | yes, in spring | 25 |
| Throat: fry cough/dry/sore | No | 13 | Malaise/Fatigue | No | 14 |
| | yes, in Fall | 20 | | yes, in Fall | 25 |
| | yes, in winter | 36 | | yes, in winter | 33 |
| | yes, in spring | 18 | | yes, in spring | 23 |
| Wheezing the chest/difficult breathing | No | 24 | | | |
| | yes, in Fall | 11 | | | |
| | yes, in winter | 20 | | | |
| | yes, in spring | 10 | | | |

**2. Do you smoke tobacco?**

No 33 Yes 23

**3. Are you subjected to tobacco smoke at home?**

No 34 Yes 20

**4. Are you asthmatic?**

No 47 Yes 9

**5. To your knowledge, are there asthmatic students in the classroom that you use the most?**

No 16 Yes 15 I do not know 25

**6. If your answer in question 5 is YES, what percentage of students have asthma?**

| | |
|---|---|
| 10 or less than 10 | 11 |
| 11 to 20 | 4 |
| 21 to 30 | 0 |
| More than 30 | 0 |

**7. Do your health syndromes mention in Questions 1 in this section affect your ability to do your work at school?**

No 32 Yes 23 I do not know 1

**8. If your answer in Question 7 is YES, how do you describe this effect?**

**9. Please indicate if you have any comments about the health syndromes you have experienced.**

## Section 6 Lighting

**1. On average, how satisfied or dissatisfied are you with the overall lighting in the office that you use most?**

| | Fall | Winter | Spring |
|---|---|---|---|
| Very dissatisfied | 7 | 8 | 7 |
| Dissatisfied | 2 | 1 | 1 |
| Slightly dissatisfied | 11 | 10 | 12 |
| Neutral | 13 | 15 | 13 |
| Slightly satisfied | 9 | 9 | 8 |
| Satisfied | 9 | 8 | 10 |
| Very satisfied | 4 | 4 | 3 |

**2. On average, how satisfied or dissatisfied are you visually with reflection and glare in the classroom that you use most?**

| | Fall | Winter | Spring |
|---|---|---|---|
| Very dissatisfied | 4 | 4 | 3 |
| Dissatisfied | 1 | 2 | 2 |
| Slightly dissatisfied | 13 | 11 | 13 |
| Neutral | 18 | 17 | 16 |
| Slightly satisfied | 7 | 7 | 6 |
| Satisfied | 6 | 8 | 9 |
| Very satisfied | 5 | 5 | 4 |

**3. During a usual school day, is natural light used in the office that you use the most?**

No 32 Yes 24

**4. If your answer in Question 3 is YES, on average how long is the natural light used?**

| Season | Less than 1 hour | 1 to 3 hours | More than 3 hours |
|---|---|---|---|
| Fall | 5 | 7 | 14 |
| Winter | 5 | 8 | 14 |
| Spring | 4 | 5 | 17 |

**5. Do you need to control or adjust lighting by yourself in the office that you use the most?**

No 32 Yes 24

**6. If your answer in Question 5 is YES, how do you do that? Please check ALL that apply.**

| | |
|---|---|
| Window blinds or shades | 23 |
| Light dimmer | 5 |
| Light switch | 36 |
| None | 0 |

**7. Which of these options are not available to you or you cannot control by yourself in the office that you use the most. Please check ALL that apply.**

| | |
|---|---|
| Window blinds or shades | 13 |
| Light dimmer | 30 |
| Light switch | 4 |
| None | 16 |

**8. Which of these options are not available to your students or they cannot control by themselves in the classroom that you use the most. Please check ALL that apply.**

| | |
|---|---|
| Window blinds or shades | 20 |
| Light dimmer | 27 |
| Light switch | 9 |
| None | 13 |

**9. Does the lighting of the office that you use the most in this school year affect your ability to do your work at school?**

No 48 Yes 8

**10. If your answer in Question 9 is YES, how do you describe this effect?**

**11. Please indicate if you have any comments about the lighting quality of the classroom that you use the most**

## Sections 7 Acoustics

### 1. On average, how satisfied or dissatisfied are you with the noise level in the office that you use most?

| | Fall | Winter | Spring |
|---|---|---|---|
| Very dissatisfied | 2 | 2 | 2 |
| Dissatisfied | 6 | 6 | 6 |
| Slightly dissatisfied | 11 | 11 | 11 |
| Neutral | 12 | 14 | 11 |
| Slightly satisfied | 11 | 10 | 12 |
| Satisfied | 7 | 6 | 7 |
| Very satisfied | 7 | 7 | 7 |

### 2. On average, how satisfied or dissatisfied are you with the quality of speech communication between you and students in the classroom that you use most?

| | Fall | Winter | Spring |
|---|---|---|---|
| Very dissatisfied | 5 | 5 | 5 |
| Dissatisfied | 5 | 5 | 5 |
| Slightly dissatisfied | 14 | 14 | 14 |
| Neutral | 9 | 8 | 8 |
| Slightly satisfied | 10 | 12 | 12 |
| Satisfied | 9 | 8 | 8 |
| Very satisfied | 3 | 3 | 3 |

### 3. On average, how much does the noise from the following items disturb you in the classroom that you use the most?

| | HVAC | Teaching equipment | Washrooms and other plumbing noise | Other areas (classrooms, corridors) | Outside |
|---|---|---|---|---|---|
| Not at all | 23 | 25 | 26 | 11 | 17 |
| 2 | 9 | 10 | 11 | 13 | 6 |
| 3 | 6 | 7 | 6 | 6 | 7 |
| Moderately | 9 | 7 | 6 | 10 | 8 |
| 5 | 5 | 3 | 2 | 5 | 7 |
| 6 | 2 | 3 | 1 | 6 | 5 |
| Very disturbing | 1 | 0 | 2 | 4 | 5 |

**4. Does the acoustics quality of the office that you use the most in this school year affect your ability to do work at school?**

No 47  Yes 8

**5. If your answer in Question 4 is YES, how do you describe this effect?**

**6. Please indicate if you have any comments about the acoustics quality of the classroom that you use the most**