An Assessment of Indoor Air Quality, Lost Work Time, and Perceived Air Quality in a Winnipeg School Division

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ABSTRACT

Indoor air quality measurements and staff absentee data were collected from elementary schools in a Winnipeg school division. Data was collected measuring carbon dioxide, carbon monoxide, temperature, relative humidity, particulate matter, and in some schools, radon. It was found that nearly all schools were experiencing some measure of IAQ problems. The most common issues measured were low levels of relative humidity and high concentrations of carbon dioxide. No significant relationships between staff absenteeism and IAQ parameters were identified in Pearson product-moment correlations and multiple regression analyses. Survey results found that 96% of respondents found IAQ problems in the workplace, and 79% of respondents show 'sick building syndrome'-like symptoms. Recommendations have been provided to improve IAQ and establish an IAQ management program in order to improve the indoor environment in the school division.

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1.0 CHAPTER 1: INTRODUCTION AND SCOPE

1.1 Background

During the energy crisis of the 1970s society demanded for a more energy efficient building design. Buildings became more tightly constructed in order to reduce the amount of energy lost through the building envelope. Not coincidentally, it was also at this time that the documentation of public concerns on the adverse effects of indoor air began on record (Mendell and Heath, 2005).

Indoor air quality (IAQ) problems are an indirect consequence of tight building design. IAQ problems are caused by chemical or biological contaminants that accumulate to levels that can adversely affect some occupants (CCOHS, 2008). Tight building designs rely more heavily on mechanical ventilation for the input and distribution of fresh air and also for the removal and dilution of pollutants. Air quality is often sacrificed for a lower operational cost of the ventilation system; for example, a lack of fresh air is introduced to the building in order to lower the costs associated with heating and conditioning the outdoor air. Therefore, one method of lowering the concentrations of indoor air pollutants is to increase the amount of outdoor air (EPA, 2012).

Source control can also improve IAQ by eliminating sources of pollution (EPA, 2012). There are many sources of indoor air pollution including:

- Mould,
- Smoke,

- Household products, such as cleaning products and pesticides,
- Gases, such as radon and carbon monoxide,
- And materials used in building, such as formaldehyde, asbestos, and lead (CCOHS, 2008).

Source control is achieved when the pollution can be removed, enclosed, or reduced in emissions (EPA, 2012). For example, off-gassing from finishes can be mitigated by choosing water based finishes and adhesives, which have a lower concentration of hazardous chemicals than other conventional products.

1.2 Health Effects of Indoor Air

Indoor air quality (IAQ) is a recognized health and safety concern (CCOHS, 2008). Common reported symptoms of poor IAQ include: headache, nausea, fatigue, dizziness, respiratory problems, chest tightness, dry throat, skin rashes, irritated eyes, nose, and throat, loss of concentration, and general discomfort (CCOHS, 2008; Health Canada, 1995). Many of these symptoms can also be caused by the common cold or flu, understandably leading to frequent misdiagnoses.

Although most symptoms are not life threatening, some pollutants at high concentrations can cause cancer or even death. For example, carbon monoxide poisoning may be the cause of more than 50% of fatal poisonings in many industrial countries (Omaye, 2002). Poisoning occurs when an individual has inhaled a toxic amount (concentrations above 1,200 ppm) of carbon monoxide (CCOHS, 2008). The American Society of Heating Refrigerating and Air Conditioning Engineers (ASHRAE) suggest that the 8-hour average exposure limit for carbon monoxide should not exceed 9 ppm.

Buildings with poor IAQ are often diagnosed with Sick Building Syndrome (SBS) or Building Related Illness (BRI). SBS occurs when:

1. A building's occupants have exhibited such symptoms for more than two weeks;

2. The symptoms are onset a few hours into occupancy and disappear when away from the building; and

3. The complaints and symptoms are associated with building occupancy, but no casual agent can be identified (Burroughs and Hansen, 2008).

BRI is often less frequent and more serious than SBS. BRI occurs when:

1. Symptoms of a diagnosable illness are identified; and
2. Symptoms can be directly attributed airborne contaminants in the building (Burroughs and Hansen, 2008).

SBS and BRI are diagnosed, in part, by an IAQ investigation that determines the IAQ conditions of the building.

1.3 Indoor Air Quality (IAQ) Assessments

When there is an IAQ problem, people may experience the symptoms discussed in the previous section. An IAQ assessment is then performed to determine if indoor air is the cause of complaints. Although reactive IAQ assessments are more common, proactive assessments are also conducted to confirm satisfactory IAQ in a building. Assessments generally follow a solution-oriented approach by narrowing the range of possibilities to find the most likely cause (Burroughs and Hansen, 2008). Organizations such as the

National Institute for Occupational Safety and Health (NIOSH) and Health Canada have recommended similar approaches when conducting an IAQ assessment. Atypical IAQ assessment includes the following steps (Health Canada, 1995; EPA and NIOSH 1998, Burroughs and Hansen, 2008):

- Problem description: Define the IAQ problem. Building occupants are interviewed and descriptions of complaints are documented. This step is used to formulate the testing methods.

- Potential source inspection: Explore different sources of contaminants in the building. This includes a walkthrough of the building and adjacent outdoor locations as well as a visual inspection of the ventilation system.

- Ventilation system inspection: Evaluate the HVAC (heating ventilation and air conditioning) system maintenance and operation.

- Air sampling/contaminant measurements: Conduct air testing for parameters based on the previous information gathered.

- Data interpretation: The data collected from air sampling is compared to relevant regulations, guidelines, and standards in the industry. The choice depends on location, parameters tested, etc.

- Mitigation: Mitigation plan of hypothesized problem. Re-testing the building to confirm the effectiveness of mitigation.

1.4 Regulations, Standards, and Guidelines

There are currently no regulations that set exposure limits specific to IAQ (CCOHS, 2008). The ACGIH (American Conference of Governmental Industrial Hygienists) TLVs (Threshold Limit Values) are often applied in industrial environments. However, in these situations industrial workers are generally exposed to larger concentrations of contaminants, and worker exposure is controlled by using personal protective equipment and other protective methods. In non-industrial settings such as offices and schools, workers are more commonly exposed to low levels of many contaminants at the same time.

Guidelines and standards for IAQ are generally used for non-industrial environments. ASHRAE (American Society of Heating, Refrigerating, and Air-conditioning Engineers) is one of, if not the most widely used organization. The most applicable standards include ANSI/ASHRAE Standard 62.1 *Ventilation for Acceptable Air Quality* and ANSI/ASHRAE Standard 55 *Thermal Environmental Conditions for Human Occupancy*.

1.5 Rationale

Reduced productivity, decreased performance, and absenteeism are other published effects of poor IAQ (Daisey, Angell, Apte, 2003; Mendell and Health, 2005). It is unclear if these effects are independent of the health effects. Although lost work time is commonly cited as an effect of poor IAQ, the association between the variables has yet to be sufficiently proven. Much of the research in the area is sparse, outdated, and/or poorly designed (Mendell and Health, 2005).

1.6 Study Objectives

This thesis involves the study of the IAQ of elementary schools in Winnipeg, Manitoba. IAQ assessments were conducted from January 10 to February 23, 2012. The objectives of this study were to:

1. Determine the present IAQ conditions and provide relevant recommendations in order to improve IAQ if necessary;
2. Determine levels of staff absenteeism and if these were associated with poor IAQ;
3. Measure the perceived air quality (PAQ) of staff in the schools; and
4. Recommend measures to enhance IAQ and staff attendance.

1.7 Study Area

There are six school divisions in Winnipeg, Manitoba. The school division that participated in this study encompasses 33 schools in the Southern portion of the city. The school's construction dates range from 1926 to 1998. The division is made up of 23 elementary schools, 6 junior high schools, and 4 high schools. The total student population is approximately 12,500. The schools that participated in the study are anonymous at the request of the school division.

Manitoba's cold and dry winter climate causes some specific challenges for IAQ. For instance, Manitoba's average outdoor temperature in winter is approximately -20°C (Environment Canada, 2013). These temperatures are costly to heat in the winter. Low relative humidity is also common for the same reason, as outdoor temperatures of -10°C limit indoor relative humidity to about 30% (Manitoba Hydro, n.d.). Dry conditions are a common wintertime condition in Canadian buildings (Hutcheon, 1960).

2.0 CHAPTER 2: IAQ AND STAFF ABSENTEEISM

2.1 Introduction

There are concerns that health problems caused by poor indoor air quality (IAQ) may impair performance and reduce attendance of building occupants (Mendell and Heath, 2005). The direct and indirect associations of this hypothesis, as well as a critical review of the literature, are summarized by Mendell and Heath (2005). The objective of this chapter is to review and summarize the scientific data on the relationship between selected IAQ parameters and lost work time. This will include much of the previously reviewed literature by Mendell and Heath but also adjoin more recently published works through 2012.

2.2 Methods

I reviewed the existing published literature on the IAQ parameters that were to be measured in the IAQ assessment of my study (carbon dioxide, carbon monoxide, temperature, relative humidity, and particulate matter) and their association with lost work time. Although schools were the buildings assessed in this study, the literature reviewed an extensive range of indoor environments (offices, daycares, etc.) in order to include more studies. Although absenteeism was the only form of lost work time measured in my study, the literature reviewed also included other forms of lost work time, such as reduced productivity.

I searched a number of electronic databases of scientific publications through 2012. A range of search terms related to the chosen IAQ parameters and to work time, productivity, and attendance were used (i.e. carbon dioxide and absenteeism). The studies chosen for review had a direct association between IAQ and performance and/or attendance. Additional articles and books were also reviewed to provide appropriate background information on the topic. Thirty-four publications are reviewed in the sections below. Twenty-three additional articles are referenced for further background purposes.

2.3 Literature Review Results

The following results are categorized by IAQ parameter. Some reviewed articles discuss multiple parameters. In that case, the articles are listed under the primary parameter of the study, but are also noted in the other relevant sections. Parameters that do not have a respective sub-section for either absenteeism or performance are due to the fact that no articles were identified on that subject.

2.3.1 Carbon Dioxide

Indoor carbon dioxide (CO_2) concentrations can indirectly indicate the amount of fresh air being provided to a space (CCOHS, 2008). The primary source of indoor carbon dioxide concentrations is the respiration of the building occupants (EPA, 2000). Elevated carbon dioxide concentrations indicate that an inadequate amount of fresh air is being provided to the area. It should be noted that carbon dioxide is not linked to SBS and its symptoms, but "rather CO_2 is approximately correlated with other indoor pollutants that may cause SBS symptoms" (Erdmann et al., 2002).

ASHRAE 62.1 recommends an upper limit of carbon dioxide concentrations 700 ppm above outdoor concentrations. Outdoor concentrations are typically 350 to 400 ppm, equating to an upper limit of about 1,050 to 1,100 ppm (ASHRAE, 2010).

However, concentrations of carbon dioxide below the ASHRAE 2010-62.1 recommendation do not always guarantee that the ventilation rate is adequate for removal of air pollutants from other indoor sources (Apte et al., 2000; Seppanen et al., 1999; Daisey, Angell, Apte, 2002). The findings from Daisey et al. (2003) as well as other literature reviewed (Godwin & Batterman, 2007; Lee & Chang, 2000; Shaughnessey et al., 2006; Shendell et al., 2004; Smedje, Norback, Edling, 1997) have found a majority of classrooms do not meet ASHRAE 2010-62.1's minimum ventilation standards. Although there is still limited research on the topic, there is evidence that portable classrooms may have more elevated concentrations of carbon dioxide compared to normal classrooms (Daisey et al., 2003). Because carbon dioxide can indicate the amount of fresh air provided to a space, articles in relation to fresh air and/or ventilation and performance and absenteeism were also reviewed.

Carbon Dioxide and Performance

Seppanen, Fisk, & Lei (2006) analyzed the literature relating to work performance and ventilation. Their review concluded that almost all studies found increases in performance with higher ventilation rates. By using statistical analysis the authors found a 1-3% improvement in performance per 10 litres per second per person increase in outdoor air ventilation rate. Performance improved the most when initial ventilation rates were below 20 litres per second per person. This study was strong in that it analyzed the results of the existing literature; however as the authors mentioned there is a bias in that a majority of published literature has found results (Seppanen, Fisk, & Lei, 2006).

Kajtar et al. (2003) studied the mental performance and well-being of subjects in various carbon dioxide concentrations (600, 1,500, 3,000, 4,000 ppm). The study concluded that well-being and attention decline when concentrations increase up to 3,000 ppm. The findings are extremely high compared to ASHRAE 2010-62.1's carbon dioxide standard (≈1,100 ppm). However, the study is significant as much of the literature has consistently found that classrooms exceed the recommended levels of carbon dioxide concentrations (Daisey et al., 2003; Godwin & Batterman, 2007; Lee & Chang, 2000; Shaughnessey et al., 2006; Shendell et al., 2004; Smedje, Norback, Edling, 1997). The study was strong in that it controlled for other constant factors such as temperature and relative humidity.

Myhrvold et al. (1996) reported from their study of five Norwegian schools that higher indoor carbon dioxide concentrations were associated with lower scores from students on a computerized test for reaction time. Carbon dioxide levels of 0 to 999, 1,000 to 1,499, and 1,500 to 4,000 ppm indicated gradually reduced performance of -0.08, 0.02, and 0.13 respectively (the positive scores relating to reduced performance). Also notable, a statistically significant partial correlation ($p<0.001$) was found between symptoms of headaches, dizziness, heavy headed, tiredness, difficulty concentrating, and unpleasant odour, and high carbon dioxide levels (1,500 to 4,000 ppm). The study controlled for confounding factors (age), but only had a brief description of its methodology and was not peer reviewed.

Wargocki et al. (2000) found increased performance of four office tasks improved with increasing ventilation rates (temperature and relative humidity were unchanged).

Typing was the least improved task, ($p<0.03$), and proof reading was the most, ($p<0.16$). Overall, work on office tasks increased by 1.1 to 2.1% for each doubling of ventilation rate (in the range of 3-30 litres per second per person). The associated decreasing levels of carbon dioxide with increasing ventilation rates were not reported. This study was well designed as it controlled for temperature and relative humidity when increasing the ventilation rate.

Shaughnessey et al. (2006) found a significant association ($p<0.10$) between student performance in math on standardized tests and classroom ventilation rates. Reading test scores did not reach statistical significance. The study was strongly statistically designed as it included adjustment for observed confounding factors (male/female classroom ratio, attendance rate, indication of family income, % gifted enrolment, % limited English, % mobility rate). Further analysis was also conducted after the preliminary results suggested that the association may be non-linear. Fifty four classrooms were observed in this study. The authors suggest a larger sample size is needed in order to draw conclusions based on the large number of confounding factors and possible non-linear association.

Kacamarczyk et al. (2004) found improved performance in text typing and addition in subjects provided with increased fresh air. The experiment provided subjects with personal ventilation systems (PVS) under four conditions (conventional mixing ventilation, placebo, outdoor air at room temperature, outdoor air at 20^{o}C). Performance improved in text typing ($p<0.01$) and addition ($p<0.04$), but the effects could not fully be measured because of the variability each individual used with their own PVS. Perceived air quality (PAQ) was also affected by the use of the PVS, but the subjects reported physical symptoms were not. Headache, difficulty thinking clearly, ability to concentrate, feeling bad/good improved monotonically from conditions 1 through 4.

Fisk et al. (2002) measured the association of productivity and ventilation rates in a call center. Subjects were measured on their call handling time per call for 30 minute intervals. No effect was found over most of the ventilation range. There was a possible 2% improvement of worker performance at the highest ventilation rate (<75ppm difference between indoor and outdoor carbon dioxide concentrations). Overwhelmingly, there was no association found with increased ventilation. The workers monitored were registered nurses (RNs) providing medical advice to callers. I question if the use of call time is an effective indicator of productivity as the effects of the caller cannot be controlled (i.e. the caller may extend the call time by asking questions, etc.).

Macferran (2010) concluded that “there is no need to over ventilate a school”. The results found no difference in carbon dioxide, absenteeism, or performance in standardized testing at different levels of fresh air per student (15 cfm, 7.5 cfm, and 5 cfm). Results found that even levels of 5 cfm had adequate IAQ. The paper is a brief summary of the study, only a page, and does not include full explanations of the methodology, results, etc. A full report was not located in a search of scholarly electronic databases. Even if better understanding of the study is provided in a full report, the study is still flawed by the small sample size (eight schools).

Wargocki & Wyon (2007) and Tham et al. (2003) found an association between increased ventilation and performance and temperature and performance. Please see temperature and performance (section 2.6.1) for more details.

Carbon Dioxide and Absenteeism

Milton et al. (2000) found that increased ventilation rates were associated with decreases of approximately one third of short term sick leave. The research compared the sick leave of office workers at low and moderate ventilation rates, 25 cfm/person and 50 cfm/person. The authors propose that raising the ventilation rates could decrease short term sick leave up to 35%. It is suggested that respiratory illness or irritant/allergic reactions are likely to be the cause of sick leave related to ventilation. The study included a cost analysis estimating that the cost of sick leave attributed to inadequate ventilation is $480 USD/employee/year. Increasing the ventilation would therefore suggest a net savings of $400 USD/employee/year. The study was strongly designed in its methodology as it accounted for many employee features (race, age, gender, company seniority, etc.) and carefully analyzed sick leave (excluding any disability, pregnancy, or long term leave).

Shendell et al. (2004) also found an association of student absence with measures of dCO_2 (indoor carbon dioxide-outdoor carbon dioxide). Absentee and dCO_2 data were collected from 22 schools, 409 traditional classrooms and 25 portable classrooms were tested. The major results of the study found that a 1,000 ppm increase in indoor carbon dioxide above the outdoor concentration was associated ($p<.05$) with a 0.5 to 0.9% decrease in yearly attendance, corresponding to a relative 10 to 20% relative increase in student absence. Also notable, was that attendance was 2% higher in traditional classrooms as opposed to portable. The study used multivariate modelling to include factors of school level, ethnicity, gender, and socioeconomic status.

Myatt et al. (2002) did not find an association of increased absences with increased levels of carbon dioxide. This study was based on Milton et al.'s (2000) research however, Myatt et al. found no association between carbon dioxide and sick leave. The studies differences may have attributed to the contrary findings. For instance, Milton's study used a larger number of work areas and had areas with lower ventilation and higher carbon dioxide levels and only included a small number of carbon dioxide measurements that were estimated from outdoor air supply rates. Myatt's study had very low levels of carbon dioxide concentrations (the maximum outdoor differential only being 250 ppm). Based on their chosen study areas in the office, Milton seems biased towards finding an association of sick leave and carbon dioxide; while Myatt seems inclined towards not finding a relationship. Because the studies were conducted in the same office, an investigation of the entire building may have found a non-biased conclusion. Myatt does acknowledge the low carbon dioxide concentrations, and states that it is unlikely that respiratory infection in adults would be transmitted via an airbourne route with carbon dioxide concentrations below 450 ppm above background concentrations.

2.3.2 Carbon Monoxide

Carbon monoxide (CO) is a colourless, odourless gas. Common sources include tobacco smoking, automobile exhaust, and poorly vented combustion appliances (CCOHS, 2008). At low concentrations exposure to carbon monoxide may cause headaches, nausea, dizziness and tiredness (Health Canada, 1995). At high concentrations (greater than 1,200 ppm) carbon monoxide can cause poisoning or death (CCOHS, 2008).

Carbon monoxide should not be present in any significant concentration in any indoor environment. ASHRAE Standard 62.1 suggests that the 8-hour average exposure limit for carbon monoxide should not exceed 9 ppm (2010).

Little research on carbon monoxide levels in schools has been conducted. However one study by Chaloulakou et al. (2003) found carbon monoxide concentrations in schools had an average indoor concentration of 1.17 ppm during the summer and 3.96 ppm in the winter.

Carbon Monoxide and Absenteeism

Three studies were found that measured the effects of carbon monoxide and absenteeism (Chen, Jennison, Yang, & Omaye, 2000; Currie et al., 2009; Park et al., 2002). However, all of the studies measured outdoor levels related to absenteeism. Because the studies measured the outdoor environment rather than the indoor air quality of the buildings, they will not be included in this review.

A study by Chaloulakou and Mavroidis (2003) measured the relationship of indoor and outdoor carbon monoxide concentrations in a school and office. The authors found a clear positive relationship between outdoor and indoor carbon monoxide concentrations, possibly suggesting that the previously mentioned studies on ambient carbon monoxide and absenteeism should not be discounted. The lack of research on the subject is likely due to the human health risks associated with exposure to carbon monoxide (as discussed in section 1.2).

2.3.3 Thermal Comfort

Temperature and relative humidity are issues of thermal comfort and not IAQ; however they are important factors of indoor environmental quality that can also impact lost work time. If a room is too warm occupants may feel sluggish or tired; if a room is too cold occupants may feel restless or easily distracted (CCOHS, 2008). Temperature preferences are very individual, and there is no temperature that can satisfy everyone (CCOHS, 2008). Therefore, ASHRAE standard 55-2010 suggests thermal requirements are designed to satisfy at least 80% of occupants. This standard determines acceptable operating temperatures based on a combination of temperature, relative humidity, air movement, type of dress, and the level of occupant activity. ASHRAE recommends a temperature range of 20.5 to 25.5°C for winter attire, 30% relative humidity, and primarily sedentary activity. The same assumptions (attire and activity) based on 60% relative humidity has a recommended temperature range of 20 to 24°C.

High temperatures are a common condition in classrooms, even in cold countries (Wargocki & Wyon, 2007). Thermal loading is caused by heat produced by individuals and equipment in the building. A large survey in Sweden documented classroom temperatures typically between 23-25°C from April-September. In some classrooms temperatures were as high as 30°C (Eriksson, Mandorff, & Boysen, 1967).

ASHRAE 62.1-2010 recommends relative humidity remain below 65% to prevent microbial growth. ASHRAE does not set a lower limit for humidity levels, however they do acknowledge that levels below 30% may cause dry nasal passages, itchy eyes and coughing and exacerbation of cold and flu symptoms. A range of 30-65% relative humidity was chosen for comparison in this study, despite ASHRAE only citing an upper limit.

Relative humidity is said to have adverse impacts at both low and high levels. Low levels have been found to be associated with SBS symptoms (Wyon et al., 2003), and high levels are associated with the growth of mould, bacteria, and increased dust mites (Sepannen & Fisk, 2004b).

Like temperature, there were very few studies found that measured relative humidity in schools with cold climates. In the study conducted by Mors et al. (2011) they found that classroom relative humidity levels ranged from 20 to 50% year round.

Temperature and Performance

Wargocki & Wyon (2007) measured the effects of moderately raised classroom temperature and ventilation on performance of students. Student's performance in two numerical and two language based tests significantly improved when the temperature was reduced from 25°C to 20°C. Performance also significantly improved in four numerical exercises when ventilation was increased from 5.2 litres per second per person to 9.6 litres per second per person. In both scenarios speed improved with almost no effect on errors. The study was extremely persuasive in its statistical methods as well as its design. The authors collected strong data on the other IAQ parameters at the time of testing.

Wyon, Anderson, and Lundqvist (1979) tested the effects of moderate heat stress on students. The results found that heat stress negatively impacts tasks that demand concentration and clear thinking, but memory and utilization can improve. Specifically, sentence comprehension and multiplication tasks decreased with increased temperature, and recognition memory (maximum at 26°C, decrease at temperatures above and below) and degree of certainty (maximum at 27°C) increased with temperature. They also found that men are more strongly affected. Students were exposed to rooms with air temperatures rising from 20-29°C. The study was strongly designed as it used statistical analysis and mirrored typical classroom temperature increases. The findings of the study show that the effects of temperature on performance are not straightforward. The findings suggest that further research is needed on the effects of temperature on a variety of tasks.

Sepannen et al. (2004a) performed a cost benefit analysis of the potential benefits of thermal control. The results concluded that productivity improvements were 32 to 120 times greater than the cost of running fans overnight. The authors reviewed current research on thermal conditions and productivity to develop a model. The results of several studies were consistent, with about a 2% decrease in productivity for every 1˚C increase over 25˚C. However, productivity was unaffected by temperature in the 21 to 25˚C range. Although the studies used to generate the cost benefit analysis found consistent results, a stronger study would have measured productivity in its own analysis. All of the studies varied in productivity measurements, temperature, etc. These inconsistencies may reflect a false estimate for the cost benefit analysis.

Tham et al. (2003) found that temperature and outdoor air supply had a significant relationship on performance in a Singapore call center. Outdoor air supply and temperature were manipulated over an eight week period, each manipulation lasting one week. Outdoor air supply (5 litres per second per person or 10 litres per second per person) and temperature (22.5˚C or 24.5˚C) were interchanged for the manipulations. Temperature and outdoor air supply had a significant relationship to performance ($p<0.001$), indicating that variables are not independent of each other. This could likely be due to the relative humidity in the Singapore climate. Decreasing temperature from 24.5˚C to 22.5˚C at 10 litres per second per person significantly increased performance by 15.5% ($p<0.01$). Also notable were SBS symptoms, headaches and difficulty concentrating were reduced by 19% ($p<0.03$) and 13% ($p<0 .02$) with each respective level of increased supply rate.

Fang et al. (2002) studied thirty female subjects exposed to combinations of temperature and relative humidity (20˚C/40%, 23˚C/50%, 26˚C/60%). Perceived air quality (PAQ) improved at lower indoor air temperature and humidity, but performance results were unaffected as this level. Subjects experienced more intense SBS symptoms when exposed to raised temperature and humidity that reflected a poorer measure of PAQ at higher temperatures. However, productivity did not reduce at these levels. Subjects were encouraged to adjust their clothing to keep comfortable; this may not reflect actual office conditions as employees may not always be prepared to adjust their clothing or may be restricted by a dress code.

Witterseh et al. (2002) tested subject's performance on standardized tasks at three temperature levels, 22, 26, and 30˚C. Relative humidity and other IAQ factors remained constant. Decreased self-estimated performance ($p<0.001$) increased with temperature, however, no change in actual performance was measured. Higher temperatures increased eyes/nose/throat irritations, headache intensity ($p<0.05$), and difficulty concentrating ($p<0.05$). Subjects may have thought they performed more poorly as their SBS symptoms increased, however these symptoms did not actually decrease performance.

Relative Humidity and Performance

Wyon et al. (2003) studied five groups of subjects at various conditions of RH (35%, 25%, 15%, and 5%) at 22˚C. Subjects performed office work on the computer to measure performance. The humidity rate reduced performance on three simulated office tasks: Text typing (by 3%; p<0.0 .002), proofreading (by 7%; $p<0.03$), and addition of two digit numbers on a computer (by 5%; $p<0.04$). The authors attribute the dry air to the reduced performance, as it affects the eyes. Eye dryness (p<0 .028) and eye irritation (p<0 .005) increased at low humidity. Blink rate increased at the lowest level of humidity ($p<0.05$), but tear film still decreased below 25% RH (p<0 .05). Although an association was found, it should be noted that these levels of relative humidity are extremely low, probably much lower than any school or office setting.

Fang et al. (2002), mentioned previously in temperature and performance, found that productivity was unaffected at various levels of temperature and humidity combinations.

Relative Humidity and Absenteeism

Green (1974) performed a study that found a consistent relationship between indoor RH (20-40%) and decreased absenteeism (slopes of -0.03 to -0.09) in primary schools. Absenteeism decreased by 3 to 9% for each percentage point increase in RH. Humidified schools also had statistically significant lower rates of absenteeism compared to non-humidified schools (4.6% vs. 5.1%, $p<0.05$). Although there were many confounding factors (temperature, age of school, etc.), Green insists they did not relate to absenteeism rates. A criticism of the study is that multivariate adjustments were not used. Also, the testing was completed in winter which makes the data obscure without seasonal variation. However despite the criticisms and dated research, this study is extremely persuasive.

Sale (1972) also observed student absenteeism over three levels of humidification. Students were placed into three categories: 1. Students with humidification at home and school, 2. students with humidification at either school or home, and 3. students without humidification in either school or home. The results found that absenteeism was lowest with students who had humidification in both locations. Absenteeism was greatest with students who did not have humidification in school or home. Interestingly, when humidification was stopped at the study school, absenteeism rates rose to equal those in the non-humidified schools. This study is compelling as the results are very strong, however the sample size is extremely small (only one humidified school measured) and the study did not use any statistical analysis.

2.3.4 Particulate Matter

Environmental Protection Agency (EPA) studies indicate that indoor levels of pollutants may be two to five times higher than outdoor levels (American Lung Association, 2000). Common indoor particulate can include numerous materials us as bits of building materials, mould spores, and skin cells (Health Canada, 1995). Elevated levels of airborne particulates can cause allergic reactions, dry eyes, contact lens irritation, nose, throat and skin irritation, coughing, sneezing and adverse respiratory reactions (CCOHS, 2008).

Particulate in the size range of 0.1 to 10 micrometres (PM_{10}) is the most concerning to human health (Environmental Protection Agency, 1998). Particulate smaller than 0.1 micrometres is usually exhaled (Environmental Protection Agency, 1998). Particulate larger than 10 micrometres is filtered through the respiratory tract (Environmental Protection Agency, 1998). Health Canada's "Indoor Air Quality in Office Buildings: A Technical Guide," 1995 indicates that the average particulate concentration in an office environment is about 10 micrograms per cubic metre of air per building ($\mu g/m^3$).

High concentrations of particulate matter in schools is a common occurrence documented in several studies (Branis et al., 2005; HESE, 2006; ODPM, 2006; Fromme et al., 2007; Heudorf et l., 2007). Chatzidiakou, Mumovic, and Summerfield (2012) reviewed the existing literature on particulate matter in European classrooms and found the daily mean concentrations of PM_{10} ranged from 43 to 169 $\mu g/m^3$. Dybendal & Elsayed (1992) found that dust allergens are about 11 times higher in carpeted floors than smooth floors in schools.

Particulate Matter and Performance

Mendell et al. (2002) performed a blinded intervention study of enhanced HVAC particle filtration on adult office workers. The intervention reduced concentration of small particles between 0.3 to 0.5µm by 95%. Productivity improved (2.1%) but was not statistically significant. Also notable was the effect of SBS symptoms. Symptoms did not decrease, but mental confusion, fatigue, and productivity improved. Confusion improved by 3.7%. Fatigue improved but was not statistically significant (2.1%). Increased temperature worsened all of the outcomes, including all of the symptoms. Productivity did improve with a lesser amount of PM; however the results were not statistically significant.

Nilsen et al. (2002) did not find an association between reduced particulate matter and improved performance. The research conducted an intervention study of improved office cleaning on two floors of an office building. The study observed before and after effects of the intervention. The results showed reduced visual dust, but no significant improvements in SBS symptoms or performance (measured by performance tests). Interestingly, absence due to sickness improved, mostly in short term sick leave.

The following studies conducted by Wargocki et al. (1999a, 1999b, 2002) have generated findings in the area of indoor pollution and diminished productivity. In a laboratory, a pollution source (36 m^2 of 20 year old carpet) was placed behind a 2 m high partition without the subject's knowledge. This carpet was used as a generalized form of odour/pollution/particulate matter. In Wargocki's 1999 study the results found that subjects typed 6.5% slower ($p<0.003$) and reported more headaches ($p<0.04$) when the carpet was present. The study was reanalyzed in 2002, where Wargocki indicated that the presence of the carpet caused subjects to type more slowly and type more errors ($p<0.005$). Subjects also experienced more headaches ($p<0.05$), odour intensity ($p<0.05$), and irritation of throat ($p<0.07$), and nose ($p<0.004$). Interestingly, although the elevated amount of SBS symptoms were experienced, PAQ did not diminish for subjects.

As mentioned in the carbon dioxide and performance section, Kacamarczyk et al. (2004) used the same laboratory and methodology as Wargocki (1999a, 1999b) with the addition of a PVS for each subject. Performance improved with the increased amount of fresh air from the PVS. However, this study possibly better shows the effects of increased ventilation and not pollution.

Largercrantz et al. (2000) replicated Wargocki's studies (1999a, 1999b) in a Swedish office building using the same carpet and partition scenario. Results were similar as subjects typed more slowly ($p<0.04$) and made more errors in additions ($p<0.05$) when the carpet was present. These reactions are possibly explained by the reported SBS symptoms. Subjects experienced difficulty thinking clearly ($p<0.05$), more dizziness ($p<0.05$), and fatigue ($p<0.05$). Unlike Wargocki, the subjects in this study did have diminished PAQ when the carpet was present. This is a short, non peer reviewed study. Although strongly designed, the emissions from the carpet (in this and Wargocki's study) were not defined. Meaning, it may not generalize for other carpets in indoor environments.

Particulate Matter and Absenteeism

Park et al. (2002) and Ransom & Pope (1992) found an association of air pollution and school absenteeism due to illness. However, the studies measured ambient air pollution, rather than indoor, so it will not be discussed at length in this review. As mentioned in the particulate matter and performance section, Nilsen et al. (2002) did find improved absentee rates when particulate matter was diminished.

Niemela et al. (2006) performed an intervention study, by cleaning and balancing the ventilation system and replacing the duct lining in an insurance company. The prevalence of SBS symptoms before the intervention was 8.8% and 4.3% after. Fatigue, heavy headedness, and irritated/stuffy noses declined. The absenteeism before the intervention was 1.2% and was 0.9% after. A reduction was possibly caused by the decreased amount of SBS symptoms experienced. The study did not measure the IAQ conditions of the building before and after the intervention. Particulate matter was assumed to be improved by the cleaning of the ventilation system but was not measured. Furthermore, balancing of the system could have also improved other IAQ parameters leading to the reduction in SBS symptoms and absenteeism.

Rosen & Richardson (1999) found a correlation between fine particulate matter and absenteeism in daycares. Using electrostatic air cleaning technology (EAC), they reduced indoor particles caused by outdoor pollution by 78%, and fine particles produced indoors by 45%. Absenteeism in one of the daycares was reduced by 55%. The decrease in absenteeism is dramatic, however the other daycare center did not see as large of an absentee improvement.

2.4 Discussion

A review of the literature indicates that elevated levels of carbon dioxide (Daisey et al., 2003; Chatzidiakou et al., 2012) and particulate matter (Branis et al., 2005; HESE, 2006; ODPM, 2006; Fromme et al., 2007; Heudorf et al., 2007) are common IAQ pollutants in the schools. Chatzidiakou, Mumovic, and Summerfield (2012) reviewed the published literature and found approximately 30% of tested classrooms exceed 1,500 ppm of carbon dioxide and the daily mean concentrations of PM_{10} ranged from 43 to 169 $\mu g/m^3$. Very little research has reviewed the common concentrations of carbon monoxide in schools. Research on thermal comfort documents that high temperatures in classrooms are a common condition (Wargocki & Wyon, 2007), but little is discussed on the state of relative humidity in schools.

Most of the studies reviewed found a relationship between one or more IAQ parameters and lost work time. However, there is still a lack of statistical evidence confirming the relationship. Studies with negative findings are less likely to be published (Mendell & Heath, 2005). Therefore, the results of this review may be partial towards finding a relationship.

A majority of research reviewed found increased ventilation rates are associated with fewer SBS symptoms and higher performance. However, findings are inconsistent as some studies have found the opposite. Limited research has been conducted on the effects of ventilation and/or carbon dioxide on absenteeism, but some studies have identified a possible relationship.

The research reviewed on carbon monoxide has focused on outdoor levels. Outdoor pollutants should not be ignored as they can frequently enter indoors, but further research on indoor concentrations needs to be explored in order to develop any assumptions on lost work time. Indoor carbon monoxide concentrations may have had less research because indoor environments should have low/no concentrations. However, there may still be a relationship between lost work time and carbon monoxide, even at low levels.

A majority of the reviewed studies found that SBS symptoms and declined productivity were associated with higher temperatures. This may indicate that thermal comfort has a stronger impact than IAQ on lost work time. Slowed work rate was the primary effect of increased temperature, with little to no effects of accuracy. It is suspected that people slow their work rate until they can attain a low level of errors (Wyon & Wargocki, 2013). Much less information is known about low temperatures and lost work time. However, some authors do suppose that lower temperatures also have a negative effect. Seppanen et al. (2004a) suggest that a greater number of errors may be made as blood flow in hands is restricted at temperatures below 20 to 22˚C and therefore may impact office tasks such as typing.

Overall few studies have been found to measure the effects of lost work time and humidity. Studies reviewed found low relative humidity can increase absenteeism; however the studies are dated (Green, 1974; Sale, 1972). One experiment showed that low relative humidity has negative effects on productivity. This is mainly due to the effects of dry eyes, making it difficult to process visual information (Wyon &Wargocki, 2013).

There is no direct evidence that particulate matter impacts performance. In Wargocki's experiments and the subsequent replications, an old carpet was used as a general indicator of pollution. While this may be a measure of particulate matter, gases and odours may have also influenced the results of the studies. The relationship with SBS symptoms and particulate matter is also unclear as the reviewed studies found mixed results.

A large majority of the research was conducted on adults. Studies have found that the affect of IAQ and performance is stronger on children than adults (Wyon & Wargocki, 2013). It is suspected that adults are less affected because they are usually familiar with the work and more able to cope with negative environmental conditions (Wyon & Wargocki, 2013). This is important to note as school children will likely experience stronger effects of IAQ than adult staff members.

2.5 Conclusion

The intent of this review was to examine the current studies on indoor air quality and absenteeism in schools. Due to the little direct scientific research in the area the review was expanded to include a larger range of settings and measures of lost work time. Although a majority of the literature reviewed found a relationship between IAQ and lost work time, there is not enough evidence to draw significant conclusions. Some topics have inconsistent results, many studies are missing statistical data, and overall there is a lack of research on the topic.

Strongly designed statistical studies will add significant research to this field of work. More importantly, it may further awareness of the importance of adequate air quality in schools. The future research in this area should focus on strongly designed studies and include an interdisciplinary approach with health sciences, engineering, and statistics.

3.0 CHAPTER 3: IAQ IN WINNIPEG SCHOOLS

3.1 Introduction

Indoor air quality (IAQ) is a significant occupational and environmental health issue (CCOHS, 2008). Most commonly, poor IAQ leads to discomfort for building occupants, but in some cases can also be associated with a range of health concerns. The purpose of the IAQ assessment in a Winnipeg school division was to evaluate present conditions and provide recommendations to improve IAQ if necessary.

The following chapter provides the details on an indoor air quality assessment of elementary schools in Winnipeg, Manitoba in order to determine present conditions. Short- term spot measurements of carbon dioxide, carbon monoxide, temperature, relative humidity, and particulate matter (PM_{10}) were collected in all elementary schools in the division. The results found that nearly all schools did not meet the relevant ASHRAE and Health Canada guidelines for at least one parameter. The most common problems measured were areas of low relative humidity and high carbon dioxide. Based on the results, recommendations were made in order to improve IAQ.

3.2 Study Area

Indoor and outdoor samples were obtained from all elementary schools in a particular division. The school selection was based on a singular work area, as elementary school teachers only work in one assigned classroom. This selection more easily associates any experienced IAQ symptoms with the primary work location. The main office of each school was also selected under the same justification. Kindergarten classrooms were eliminated from analysis as multiple teachers in the division work half days.

The assessment was limited to a maximum of eleven locations per school. This included two classrooms from each grade level (1-5) and the main office. Seventy five percent of the schools had ≤ 2 classrooms for each grade level, satisfying that all grades 1-5 classrooms underwent analysis. Schools with ≥ 2 classrooms per grade level were chosen at random. Schools and classrooms were chosen at random prior to testing.

3.3 Methods

3.3.1 Field Procedures

The assessment involved a visual inspection of the building environment and measurement of indoor environmental parameters. The investigator interviewed building staff, usually the caretaker on site, during the assessment to discuss the history of the building, maintenance schedules, and any IAQ complaints.

Spot measurements of carbon dioxide, carbon monoxide, temperature, and relative humidity were collected using a Honeywell IAQ Probe. The concentration of dust was collected with a DustTrak (TSI) Aerosal Monitor. The sampling strategy followed the National Institute for Occupational Safety and Health (NIOSH) approved methodology, *Common IAQ Measurements – A General Guide* (1998). Spot measurements were collected as follows:

1. Prior to sampling, equipment was calibrated according to manufacture specifications and set to collect continuous measurements every ten seconds.

2. Once on site, the equipment was turned on outdoors to collect ambient readings. If accessible this was done by the fresh air intake(s). Both machines stabilized, showing little variation (a range of ≈ 50 ppm), before going indoors.
3. Indoor samples were collected based on the predetermined room order (see *3.2*). Inside each location short-term measurements were taken until the equipment stabilized, lasting approximately five minutes. First, indoor air was assessed near the center of the classroom at breathing zone height (approximately 1.5 m above floor level). Equipment remained at least 1 m from students and away from supply diffusers. Recordings were taken for carbon dioxide, carbon monoxide, temperature, humidity, and particulates.
4. Manual notes were taken, such as visual observations and estimated machine recording averages. The key visual observations noted include: Time, occupancy, water damage, mould, windows, and ventilation (number, size, and location of returns and fresh air), and any other factors that could degrade air quality. Photographs were also taken at this time.
5. The ventilation system of the room was examined. Wherever possible, the air diffusers or gratings covering the air ducts were removed for inspection. The investigator noted cleanliness and other factors impacting operation and maintenance.
6. The equipment stabilized in the hallway, a control area, before entering the next testing location where the previous steps were then repeated. This step ensures

that the previous location's recordings would not affect the readings for the upcoming classroom.

3.3.2 Data Analysis

ASHRAE and Health Canada were the primary references chosen to determine acceptable indoor air quality. The guidelines, standards, and references chosen for comparison were based on the purpose of their development, meaning the setting and purpose for which they were developed apply to the setting in which this study takes place. Relevant guidelines to this project used for diagnostic purposes are listed below in Table 1.

Table 1: IAQ guidelines.

Parameter	Reference	Acceptable Concentration
Carbon Dioxide	ASHRAE Standard 62.1-2010	< 1,100 ppm
Carbon Monoxide	Health Canada Indoor Air Quality in Office Buildings: A Technical Guide - 1995	< 5 ppm
Temperature	ASHRAE Standard 55 - 2010	20 to 25.5°C
Relative Humidity	ASHRAE Standard 62.1 - 2010	30 - 65%*
Particulate Matter (PM_{10})	Health Canada Indoor Air Quality in Office Buildings: A Technical Guide - 1995	< 10 $\mu g/m^3$

*ASHRAE 62.1-2010 only cites an upper limit for RH. Please see below for lower limit justification.

ASHRAE Standard 62.1-2010 recommends that carbon dioxide concentrations do not exceed 700 ppm above outdoor concentrations. As outdoor levels typically range from 350 to 400 ppm, that translates into an upper limit of about 1,050 to 1,100 ppm.

Health Canada states that carbon monoxide levels above 5 ppm indicate the undesirable presence of combustion pollutants. The reference was used as it more readily applies to the spot measurements taken within the schools. ASHRAE suggests that the 8-hour average exposure limit for carbon monoxide should not exceed 9 ppm. However, as locations were not tested for long term measurements the standard is not applicable for this study.

ASHRAE standard 55-2010 determines acceptable operating temperatures based on a combination of temperature, relative humidity, air movement, type of dress, and the level of occupant activity. Based on winter attire, 30% relative humidity, and primarily sedentary activity, ASHRAE recommends a temperature range of 20.5 to 25.5°C. The same assumptions (attire and activity) based on 60% relative humidity has a recommended temperature range of 20 to 24°C. A temperature range of 20 to 25.5°C was chosen for this study as relative humidity was not known prior to sampling, but type of dress and occupant activity could be assumed based on the season and setting.

ASHRAE 62.1-2010 recommends relative humidity remain below 65% to prevent microbial growth. ASHRAE does not set a lower limit for humidity levels, however they do acknowledge that levels below 30% may cause dry nasal passages, itchy eyes and coughing and exacerbation of cold and flu symptoms. A range of 30-65% relative humidity was chosen for comparison in this study, despite ASHRAE only citing an upper limit.

Unfortunately, very few guidelines for particulate matter are available. The EPA ambient air quality standard for particles less than 10 microns (PM_{10}) is 50 micrograms per cubic metre of air per building ($\mu g/m^3$) per hour, for an annual average of 150 $\mu g/m^3$

for 24 hours. Based on the short term testing conducted in the school division, this guideline was not used.

Health Canada's "Indoor Air Quality in Office Buildings: A Technical Guide" (1995) indicates that the average particulate concentration for (PM_{10}) in an office environment is about 10 $\mu g/m^3$. Health Canada does not reference if 10 $\mu g/m^3$ as an adequate amount for indoor air; it simply states that it is the average concentration in an office environment. This reference was chosen as it is more applicable than the EPA guideline; however, there is clearly a limited amount of references available for acceptable concentrations of particulate matter in a non-industrial setting.

3.4 Results

The IAQ assessment was conducted in a Winnipeg school division from January 10, 2012 to February 28, 2012. All measurements were taken in the afternoon from approximately 13:00-15:00. Summarized results are presented in the following tables; detailed information is presented in Appendix I.

Schools have been lettered for anonymity at the request of the school division. IAQ parameters that did not meet recommendations were grouped into the following categories:

- Widespread: Concern is measured over all or most of school (greater than 80%);
- Intermittent: Concern is measured in a multiple locations (31 – 79%);
- Isolated: Concern is only measured in a few locations (less than 30%).

3.4.1 Carbon Dioxide

A majority of schools, 67%, did not meet the chosen carbon dioxide standard (<1,100 ppm). Figure 1 shows the carbon dioxide concentrations measured in the schools. More detailed information about each location is tabulated in Appendix I.

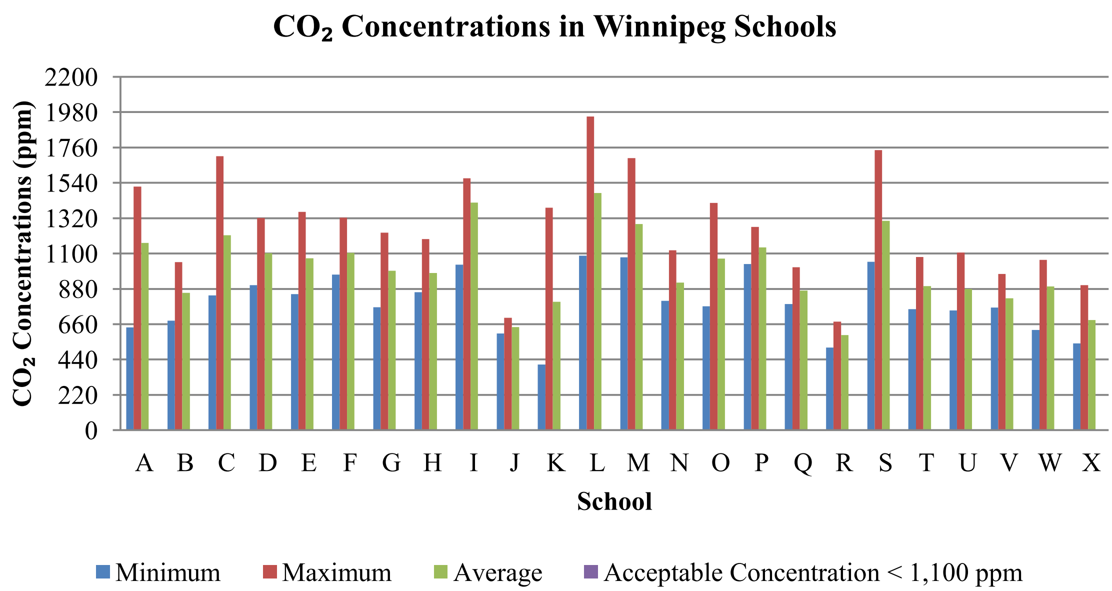

Figure 1: Carbon dioxide concentrations in Winnipeg schools.

Concentrations ranged from 409 to 1,952 ppm. Schools were affected by elevated carbon dioxide concentrations at varying degrees. Widespread issues (impacting 80% or more of the school) were observed in four schools; intermittent issues (impacting 31-79% of the school) were observed in six schools; and isolated issues (impacting less than 30% of the school) were observed in six schools.

Schools A, E, F, G, and K had isolated areas of the building that did not meet acceptable carbon dioxide concentrations. For example, School A is comprised of an original building and a newer addition. HVAC is operated differently in these spaces.

The original wing of the school supplies fresh air in the hallway, and the newer wing of the school has fresh air supplies in each classroom. All of the rooms with carbon dioxide concentrations above guidelines were located in the newer portion of the building. Schools E, F, and G also had elevated levels focused to a certain wing, floor, addition, etc. In these situations the ventilation serving these particular problems areas should be identified and adjusted for increased volumes of fresh air.

Occupant control also had an impact on carbon dioxide levels. For example, in School K only the portable classrooms failed to meet carbon dioxide recommendations. The portable classrooms have individual HVAC units, managed by teacher control (i.e. they can turn on and off at their will). Figure 2, shows the individual HVAC units. Many of the units were off at the time of assessment.

A similar problem arose in School M. It was reported by a staff member, and confirmed upon visual observation, that some teachers turn off their HVAC units. The conventional box units, as seen below in Figure 3, have controls for adjustment. Multiple teachers reported complaints about the noise levels generated from the units. The highest concentration, observed in Room 11, had their system turned off at the time of testing.

Figure 2: Individual HVAC units in the portable classrooms in School K.

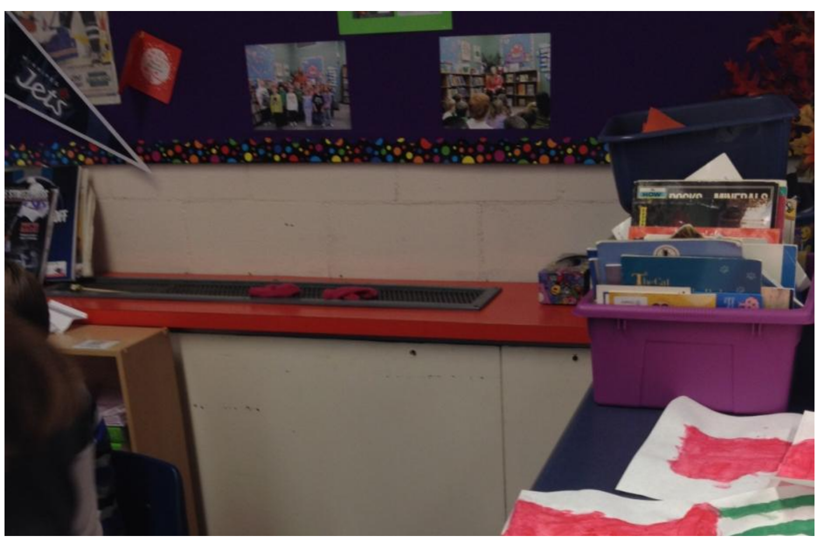

Figure 3: HVAC units in School M.

Locations were tested in the afternoon. Most rooms were fully occupied at the time of testing; however some classrooms were recently emptied (approximately five minutes prior to testing) due to gym class, music class, etc. The average classroom occupancy was approximately 20 people.

3.4.2 Carbon Monoxide

All schools met the recommendations (<5 ppm) for carbon monoxide concentrations. Carbon monoxide ranged from below detection limit to 1 ppm. Schools C, K, and L had locations with low levels of detectable limits. Sources that may have generated carbon monoxide were not negatively impacting the air quality at the time of testing.

3.4.3 Thermal Comfort

Temperature

About one third of schools, 29%, did not meet the acceptable temperature range (20 to 25.5°C). Figure 4 shows the temperature in schools. More detailed results are tabulated in Appendix I.

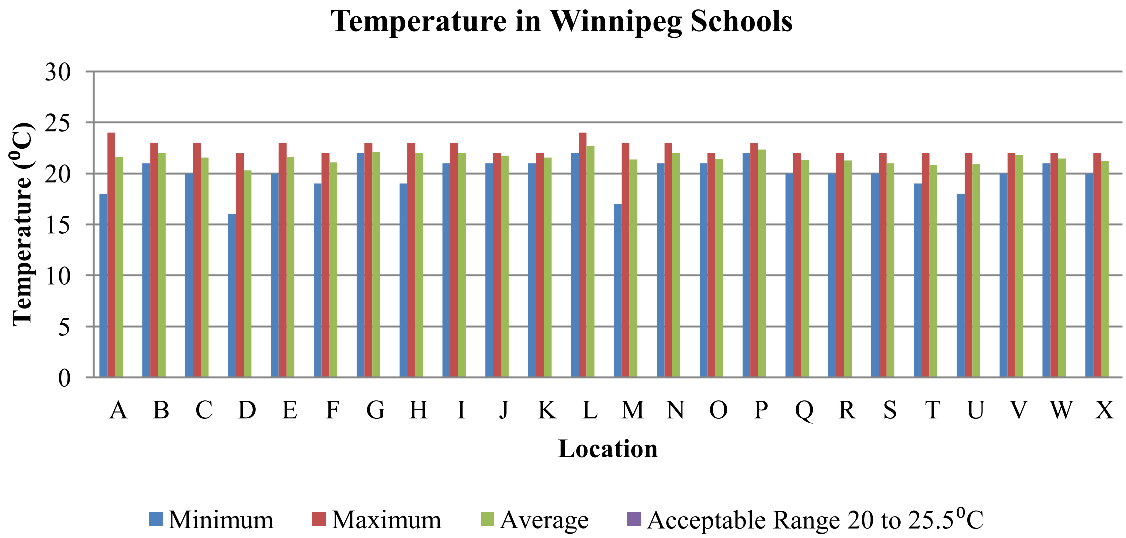

Figure 4: Temperature in Winnipeg schools.

None of the schools exceeded the temperature range, issues were isolated to cold temperatures. The coldest location was measured in School D at 16°C. Isolated issues (impacting less than 30% of the school) were observed in all seven schools.

A majority of the cold temperatures were observed in the Main Office's of schools (Schools A, D, H, M, T, and U). The Main Office was usually occupied by 1-3 staff members and is in close proximity to the front door. Cold temperatures were only observed in three classrooms (School F, Room 25; School D, Room 6S1; and School A, Room 4); all of the temperatures in these locations were 19°C.

Although cold temperatures were measured, temperatures preferences are very personal and these conditions may be acceptable to the occupants. However, some visual observations in School L indicate that occupants may be unsatisfied with their thermal conditions. Thermostats in the building were covered with plastic casings, making adjustments inaccessible. However, three classrooms were observed to have paperclips (and or other small objects) stuck in the holes of the plastic covers, possibly used in order to adjust the thermostat.

This adaptation is a sign that indoor conditions are not meeting occupant needs. The coverings were likely installed to keep occupants from causing higher energy use beyond standard set points. It is widely agreed that individual control of local environments is necessary for comfort and contentment (Fanger, 1970). The paperclips are likely a sign of occupant's frustration and attempts to adjust an uncomfortable environment.

Relative Humidity

A majority of schools, 67%, did not meet the recommended relative humidity range (30-65%). Figure 5 shows the relative humidity measured in schools. More detailed results are tabulated in Appendix I.

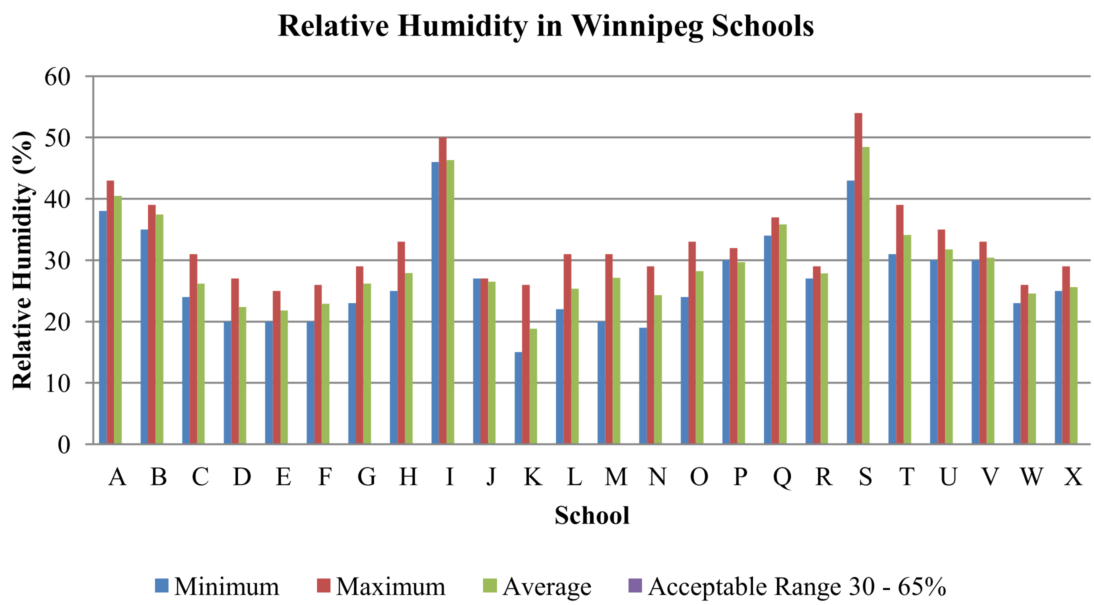

Figure 5: Relative humidity in Winnipeg schools.

None of the schools exceeded the relative humidity range, issues were isolated to low relative humidity. The lowest relative humidity was measured in School K at 15%. Eighty-eight percent had widespread issues of humidity (impacting 80% or more of the school). Maintaining relative humidity within the range is particularly difficult in Manitoba during winter months (Hutcheon, 1960). Dry air is a common conditions associated with indoor environments during this time of year (Hutcheon, 1960).

3.4.4 Particulate Matter

Half of the schools did not meet particulate matter guidelines (<10 μg/m^3). The guideline chosen is based on an office setting, and the elevated ranges in this study may be typical for a school environment. Figure 6 displays the levels of particulate matter measured in the schools. More detailed results are tabulated in Appendix I. Particulate matter was not measured in School B due to an equipment malfunction.

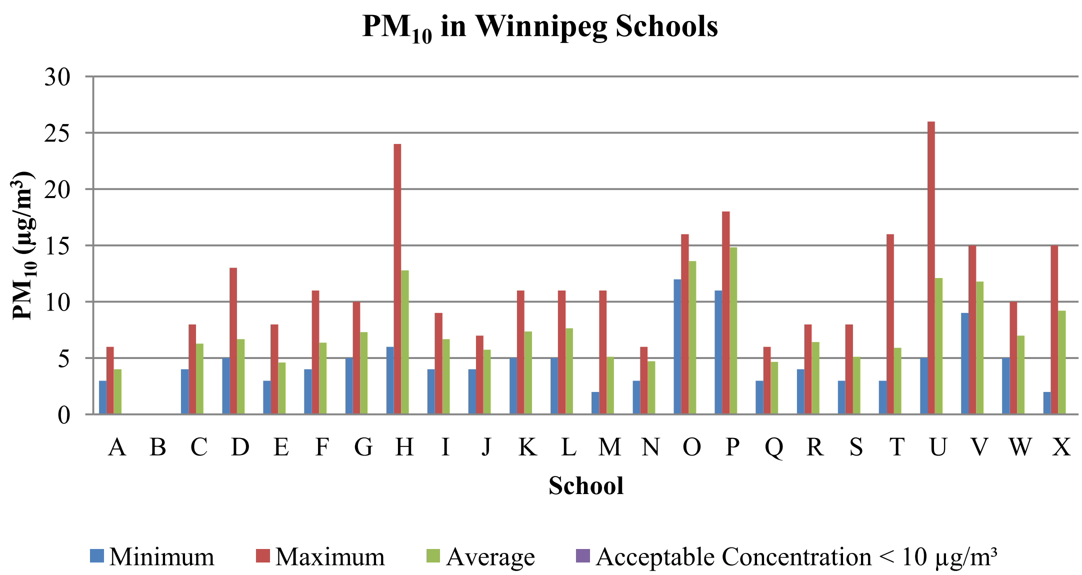

Figure 6: Particulate matter in Winnipeg schools.

The maximum concentration was 26 µg/m^3 and measured in School U. Schools were affected by particulate matter to varying degrees. Five of the schools had widespread issues; one school had an intermittent issue; and six schools had isolated issues. Almost all testing locations were carpeted and, as mentioned previously, were fully occupied at the time of testing. Visual observations noted that surfaces, diffusers, and vents in the immediate sampling areas appeared free of any dirt or debris.

3.4.5 Visual Observations

Blocked diffusers were observed in several schools (B, C, M, and Q). Figures 7 and 8 show some of the conditions observed. It was noted that many of the classrooms used their box units as shelving.

Figure 7: Blocked ventilation in School B (a).

Figure 8: Blocked ventilation in School B (b).

No foul odours were noted, and housekeeping appeared adequate throughout the schools.

3.5 Discussion

Most schools had a number of testing locations that did not meet the chosen recommendations. The most commonly measured IAQ problems in the division were low relative humidity and high carbon dioxide, each impacting 67% of the tested schools. Fifty percent of the schools were also impacted by high levels of particulate matter, and 29% of schools were affected by low temperatures. All schools met the guidelines for carbon monoxide.

The issues measured in the school division are reflective of conditions measured in similar environments, indicating that poor IAQ is common in schools. However, few studies have provided the IAQ conditions in schools. Further data is essential in order to prioritize corrective actions (Mendell & Heath, 2005). The only schools to meet all guidelines were schools B and Q. However, particulate matter was not tested at School B and may have had unidentified levels above the recommendation.

3.5.1 Carbon Dioxide

Elevated concentrations of carbon dioxide (greater than 1,100 ppm) impacted at least one area in 16 of the 24 schools assessed. Widespread issues (impacting 80% or more of the school) were observed in four schools; intermittent issues (impacting 31-79% of the school) were observed in six schools; and isolated issues (impacting less than 30% of the school) were observed in six schools. Several locations noted issues specifically in portable classrooms. Testing locations were observed under normal conditions, usually with full occupancy at the time of testing.

The elevated carbon dioxide concentrations found in this study are consistent with the results found in the literature. Chatzidiakou, Mumovic, and Summerfield (2012) reviewed the published literature of carbon dioxide concentrations in classrooms. They found approximately 30% of tested classrooms exceed 1,500 ppm. This agrees with Daisey et al.'s (2003) review of the literature which found elevated carbon dioxide concentrations in a majority of US and Canadian schools.

High carbon dioxide concentrations in portable classrooms have also been previously documented by other authors (Daisey, Angell, & Apte, 2003). Most portables rooms observed in the school division had one mechanical, wall-mounted HVAC system. These ventilation systems are known to have problems providing adequate levels of outside air and create poor acoustics (Environmental Protection Agency, 2012).

Carbon dioxide is used to indirectly indicate that amount of fresh air being provided to a space, relative to the number of occupants. This indicates that the supply of outdoor air was inadequate for the occupancy loading in most schools at the time of assessment. Schools have a specific challenge when meeting fresh air needs because although the amount of floor space is similar to an office environment, the occupancy level is four times as many (Environmental Protection Agency, 2012). The EPA (2012) states that high carbon dioxide concentrations in schools are commonly caused by room changes from their original design and inadequate amounts of outside air.

3.5.2 Carbon Monoxide

All schools met the recommendations for carbon monoxide concentrations. These results indicate that exhaust or combustion gases were not being generated within or drawn into the buildings at the time of assessment. Little research on carbon monoxide levels in schools has been conducted. One study by Chaloulakou et al. (2003) has consistent results with this assessment. Carbon monoxide concentrations met recommendations with an average indoor concentration of 1.17 ppm during the summer and 3.96 ppm in the winter (Chaloulakou et al., 2003). Some detectable levels of carbon monoxide were measured in this study; however, the average concentration for all locations was 0 ppm.

3.5.3 Thermal Comfort

Cold temperatures (below 20^0C) impacted seven of the 24 schools. Isolated issues (impacting less than 30% of the school) were observed in all seven schools. Although cold temperatures were measured, temperatures preferences are very personal and these conditions may be acceptable to some occupants. However, no thermal environment can satisfy all occupants, and it is widely agreed that individual control of local environments is necessary for comfort and contentment (Fanger, 1970).

There are very few studies to verify if this condition is common for schools in cold climates. Studies on thermal comfort in schools are limited overall, and most studies are conducted in tropical climates (Kwok and Chun, 2003; Wong and Khoo, 2003; Hwang et al., 2006; Liang et al., 2012). A few studies have been conducted in mild climates (Corgati et al. 2007; Mumovic et al., 2009), and only one found article has been conducted in a cold climate (Mors et al., 2011).

However, we can derive indoor classrooms temperatures from the figure in the study by Mors et. al. (2011). From the figure we can equate that the coldest outdoor temperatures yielded indoor temperatures of approximately 19 to 23°C.

Mors et al.'s study only measured outdoor temperatures of -5°C, whereas the outdoor temperatures recorded during this study had a mean average of approximately -20°C. The authors use this figure to describe how interior temperatures fluctuate with outdoor temperature (little variation in the winter seasons and high increased interior temperatures with increased outdoor temperatures). This may indicate that Winnipeg's colder climate would not greatly impact a larger change in interior temperatures than in Mors et al.'s study. The coldest interior temperature measured in the Winnipeg study was 16°C.

Although low temperatures were experienced in this division, a majority of the researched has noted high temperatures a common classroom condition (Wargocki & Wyon, 2007). A survey of temperatures in a Swedish school found that classroom temperatures were generally 23-25°C from April-September. Teachers and students preferred temperature 3-6°C below this (Eriksson et al., 1967). Although Sweden is also a cold country, these results may not be a strong comparison due to the difference in seasons. The school division in Winnipeg may experience similar conditions in a warmer season.

Low relative humidity (below 30%) impacted 16 of the 24 schools. Eighty-eight percent had widespread issues of humidity (impacting 80% or more of the school). There is evidence to suggest that humidification during the winter heating season reduces respiratory illness in occupants (Green, 1974; Sale 1972).

Like temperature, there were very few studies found that measured relative humidity in cold climates. In the study conducted by Mors et al. (2011) they found that classroom relative humidity levels ranged from 20 to 50% year round. The relative humidity measured in Winnipeg schools in the winter had a slightly larger range of 15 to 54%.

Low relative humidity is a common winter time condition in Canadian buildings as low outdoor temperatures tend to produce low indoor relative humidity (Hutcheon*, 1960)*. Outdoor temperatures below -10°C limit indoor relative humidity to about 30% (Manitoba Hydro, n.d.). Winnipeg's average outdoor temperature in winter is about -20°C (Environment Canada, 2013), making it very difficult for buildings to meet the chosen relative humidity guideline in winter. The school division may wish to re-asses the humidity in the spring/summer to confirm if low relative humidity is limited to winter time conditions. There is evidence to suggest that humidification during the winter heating season reduces respiratory illness in occupants (Green, 1974; Sale 1972).

3.5.4 Particulate Matter

Elevated levels of particulate matter (greater than 10 $\mu g/m^3$) were observed in 12 of the 24 schools. Five of the schools had widespread issues; one school had an intermittent issue; and six schools had isolated issues. Sources of particulate matter in schools are most commonly from human activities, plants, building materials, ventilation, and infiltration from outdoors (Chatzidiakou, Mumovic, & Summerfield, 2012).

High concentrations of particulate matter in schools has been documented in many previous studies (Branis et al., 2005; HESE, 2006; ODPM, 2006; Fromme et al., 2007; Heudorf et l., 2007). Chatzidiakou, Mumovic, and Summerfield (2012) reviewed the existing literature on particulate matter in European classrooms and found the daily mean concentrations of PM_{10} ranged from 43 to 169 μg/m^3. The maximum value measured in this study was 26 μg/m^3 in School U. None of the schools averages for particulate matter exceeded the EPA's ambient air quality standard of 50 μg/m^3.

This study's data, along with the others reviewed, suggests that school environments have much higher concentrations of particulate matter than in office environments. A review of Environmental Protection Agency data confirms that schools have a mean concentration of PM_{10} 73% higher than in offices (Ligman et al., n.d.).

The physical activity of occupants leads to the re-suspension of particles (Almedia et al, 2011) which is exaggerated in schools because of the high occupancy. Yip et al. (2004) demonstrated this in their study by finding that schools indoor levels of PM_{10} were always higher than outdoors, except on the weekends. The results of this study found similar results, as all locations with elevated particulate levels were fully occupied at the time of assessment.

3.6 Recommendations and Conclusion

Basic solutions for improved IAQ in the division are listed below. Many of the following recommendations are based on *Indoor Air Quality: Tools for Schools Action Kit* (Health Canada, 2003). It is recommended that schools adopt the action kit to help maintain and manage IAQ. The school division should consider the cost benefit of each scenario before employing any proposed solution.

3.6.1 Carbon Dioxide

Prior to alterations, it is recommended that a review of the original and current ventilation design is conducted (Health Canada, 2003). It is common for room layouts and class sizes to change over time without adjustment to the HVAC system. A lack of HVAC adjustments are likely the cause of some the under-ventilation issues in the school division.

Sufficient levels of outdoor air will control levels of carbon dioxide (CCOHS, 2008). Before outdoor air is increased, it is recommended that maintenance confirm that supply and return ventilation is open and unblocked (Health Canada, 2003). Airflow can be checked by holding lightweight paper (i.e. tissue paper) near the supply and return grilles. If air is flowing from the supply it will push the paper away from the vent. If air is flowing in the return it will suck the paper towards the vent.

If the ventilation system is in working order, increased fresh air in the area will dilute carbon dioxide. In the case of portable classrooms, the thermostat fan switch should be set to continuous in order to provide an outdoor air supply. While increased ventilation will decrease levels of carbon dioxide, more fresh air will need to be heated appropriately, potentially adding a significant cost to HVAC system operation.

Health Canada (2003) states that modification in the space occupancy or use may be other effective methods to dilute carbon dioxide. However, this may be a more challenging option if schools are at high occupancy.

3.6.2 Carbon Monoxide

No carbon monoxide issues were found in the school division. However, as a safety precaution carbon monoxide detectors should be installed (if not already done so). In addition, a regular inspection of combustion appliances is recommended (Health Canada, 2003). These inspections would include a visual examination to verify that flue components, ducting, etc. are in working order. The inspector should note any damp/musty smells or combustion gas odours. These scents may indicate a leak or back drafting problem (Health Canada, 2003).

3.6.3 Thermal Comfort

Some issues of relative humidity and temperature were identified. It is recommended that administrators note if these problems exist in their schools, but only consider alternations if concerns are expressed by the occupants. Health Canada (2003) recommends ensuring at least 80% of the occupants are comfortable.

Personal control is a large factor of thermal comfort. Installing programmable thermostats would provide occupants with personal control over their local environments and increase satisfaction. Although high temperatures were not measured in this assessment, altering occupancy by reducing class sizes would help to improve conditions in rooms that are considered warm. Temperature can be altered as needed by adjusting the thermostat; however the additional heating will increase the cost HVAC operation.

Relative humidity is a more complex alteration. Adding a humidifier (frequently through steam wand) into a forced air system can successfully increase relative humidity. However, altering the HVAC system will require professional consulting.

Building management systems (BMS) would help control both temperature and relative humidity. BMS are computer based control systems that can manage the mechanical and electrical services in a building. BMS can provide heating and cooling to ensure thermal comfort regardless of the number of occupants or individual preferences. Multiple comfort zones can be created to individualise comfort control, again providing occupants with management over their local environment. Prices to install these systems vary but are often expensive; however BMS are an efficient way to cut utility costs. In new buildings BMS can allow energy savings up to 40% (Borkowski et. al, 2011).

3.6.4 Particulate Matter

Floors should be vacuumed daily at minimum. A proper vacuum will include brushes, beater bars, strong suction, and a high efficiency filter bag (will filter particles at least 3 micron) (Health Canada, 2003). The Canadian Carpet Institute recommends periodic extraction cleaning, wet or dry, and complete removal of the moisture and cleaning agents in schools. Steam cleaning is recommended once every three months (Canadian Carpet, 2013).

Dust from heating, cooling, and ventilation air return grilles and air supply vents should be vacuumed periodically (Health Canada, 2003). Areas with concerns should also consider checking the filters in the ventilation systems. If filters are grossly overloaded it may be time for replacement. It is recommended to review the maintenance schedule to determine the last time the filters were changed and to contact the service provider to determine the recommended frequency of replacement.

Further housekeeping recommendations in order to improve particulate matter include (Health Canada, 2003):

- Purchase and maintain barrier floor mats for all school entrances. Barrier mats should be long enough to allow five full steps and should be vacuumed daily (or more if required).
- Use proper dust wiping techniques, using a wiping motion with a folded wipe rather than a flicking motion with a crumpled wipe.
- Clean chalkboards/whiteboards and ledges with a damp cloth (or other method) to collect dust and prevent its release.

3.6.5 Staff Information

Finally, staff should be informed of operations systems and how their activities directly affect ventilation pathways in their school. Changing thermostat settings or blocking ventilation can worsen comfort problems and may also have an adverse affect on others parts of the school (Health Canada, 2003). Educating occupants will inform staff of the guidelines to using HVAC equipment properly and may alleviate some IAQ issues.

4.0 CHAPTER 4: RADON IN WINNIPEG SCHOOLS

4.1 Introduction

Radon is a naturally occurring radioactive gas formed by the breakdown of uranium in soil, rock, and water. When radon escapes the ground to outdoor air it is diluted to levels below concern. Radon can be a concern when it accumulates in a building as it is a known health risk associated with an increased risk of developing lung cancer (Health Canada, 2012). Results from a two year cross Canada survey indicate that Manitoba has more prevalent levels of high indoor radon when compared to most other provinces. In the Winnipeg Health Region (where the assessed school division is located) 12.1% of participants exceeded Health Canada guideline (Health Canada, 2012). The purpose of radon testing in the school division is to evaluate radon concentrations in order to determine the need for remedial action to protect the building's occupants.

The following chapter provides the details of how this aspect of IAQ was studied in Winnipeg schools. Long-term electret ion chambers were deployed in all schools with below grade occupied rooms. The results found that none of the locations exceeded Health Canada's guideline of 200 Bq/m^3. Based on the results, no further measurements or remediation is necessary. However, schools are recommended to consider re-testing if major renovations are undertaken.

4.2 Study Area

Radon was measured in all schools with below grade occupied areas. This included ten schools in the school division. Health Canada (2008) recommends measuring radon "in the lowest-level occupied (occupied by an individual for more than 4 hours per day) classrooms or offices of the building". In some cases this would include the main floor for buildings without a basement. However, based on budgetary constraints only ten schools could be tested.

Electret ion chambers were deployed in schools F, P, V, and X from the previous chapter. Six additional schools were also tested (schools Y, Z, AA, BA, CA, DA). The measurements were made in the lowest occupied level of the schools. Radon tends to be heavier than air, meaning the highest concentrations are likely to be measured in the lowest level of a building. Each below grade classroom was tested for radon.

4.3 Methodology

4.3.1 Field Procedures

Radon testing was done in accordance to Health Canada's (2008) *Guide for Radon Measurements in Public Buildings (Schools, Hospitals, Care Facilities, Detention Centres).* Long term E-Perm electret ion chambers were deployed to collect radon measurements. Radon devices were deployed on February 2, 2012 at Schools E, V, X, Y, Z, AA, BA, CA, and DA. Devices were deployed on February 10, 2012 at School P. All devices were collected on May 4, 2012.

In order to ensure that the electrets ion chambers were not disturbed during the measurement period, the devices were hung from the ceiling. The devices hung at approximately 2.5 to 3 meters from the floor, at least 50 centimeters from the ceiling, and 20 centimeters from other objects. The detectors were placed approximately 40 centimeters from an interior wall or approximately 50 centimeters from an exterior wall. Serial number, location, and time were recorded upon deployment.

4.3.2 Data Analysis

The electrets drop in voltage is associated to the radon concentration. Therefore, pre and post voltage was measured using a Rad Elec Inc. Voltage Reader. Radon concentration was calculated using Winsper V22 software. Equipment was calibrated to manufacture specifications prior to use.

The Government of Canada Radon Guideline (Health Canada, 2009) was used to compare results. Concentrations below 200 Bq/m^3 were considered acceptable. Health Canada's recommendations are provided in Table 2 below.

Table 2: Radon guidelines.

<table>
<tr><th>Reference</th><th>Concentration</th><th>Recommended Action</th></tr>
<tr><td rowspan="3">Health Canada
Government of Canada Radon Guideline - 2009</td><td>< 200 Bq/m^3</td><td>No Action Required</td></tr>
<tr><td>200 – 600 Bq/m^3</td><td>Mitigation within two years</td></tr>
<tr><td>> 600 Bq/m^3</td><td>Mitigation within one year</td></tr>
</table>

4.4 Results

All schools tested for radon were below Health Canada's guideline of 200 Bq/m^3. Radon ranged from 10.4 to 181.6 Bq/m^3 in the tested locations. A summary of results is presented in Table 3. Appendix II presents the full results of long term radon testing.

Table 3: Radon results.

School	Results (Bq/m^3)
School E	29.2 - 29.8
School P	27.7 – 69.0
School V	67.8
School X	10.4 – 67.6
School Y	19.7 – 31.0
School Z	24.3 – 70.1
School AA	21.9 – 31.2
School BA	76.5 – 181.6
School CA	44.4 – 129.8
School DA	15.2 - 28.6

4.5 Discussion and Recommendations

Radon in buildings is a factor for an increased risk of developing lung cancer and should be remediated if test results exceed Health Canada's guidelines. If long-term measurement results are below 200 Bq/m^3, the average annual concentration in the building is also likely below 200 Bq/m^3 (Health Canada, 2008). Further measurements are not necessary and remedial action is not recommended.

It is recommended that schools consider re-testing if major renovations take place. Specifically, renovations that might change the ventilation or airflow in the building or the use of rooms in the lowest occupied level.

5.0 CHAPTER 5: LOST WORK TIME AND IAQ IN A WINNIPEG SCHOOL DIVISION

5.1 Introduction

The literature on indoor air quality and absenteeism in schools was reviewed in Chapter 2. Although the body of research is growing, there little direct scientific research in the area. Some of the review had inconsistent results and was missing statistical data. Nevertheless, a majority of the reviewed studies has found suggestive evidence that poor IAQ is related to lost work time. The following study evaluates if a relationship exists between staff absenteeism and carbon dioxide, temperature, relative humidity, and/or particulate matter.

This chapter describes the correlational research design employed in this thesis study to measure the association of IAQ and lost work time in a Winnipeg school division. The study includes the same schools who participated in the previous chapter. Pearson Product-Moment Correlations were completed to compare the number of staff sick days with the associated levels of carbon dioxide, temperature, relative humidity, and particulate matter. The results concluded that there is no association between absenteeism and the variables. However, there is a non-significant trend for absenteeism to be positively associated with relative humidity. Multiple Regression Analysis was also run for all combinations of the variables. None of the results were of statistical significance. Limitations to the project, especially the small sample size, may have contributed to these results.

5.2 Methodology

5.2.1 Absentee Data

The total number of staff sick days for the 2010-2011 school year was provided by the school division. The only information reported was the total number of staff sick days in each school. This was done in order to meet confidentiality requirements approved by the school division and the University of Manitoba Human Ethics Office.

The total number of staff sick days (per school) was divided by the total number of possible sick days and multiplied by 100. The total number of possible sick days was calculated as the number of staff per school multiplied by total working days per school year (196). Absentee percentage was calculated for each school. In order to account for a variety of staff sizes in each building, absentee percentage was calculated as follows:

IAQ Parameters

The IAQ results were collected by the methods outlined in Chapter 3. Because the only identifier of absentee data was school, the data could not be associated to specific work location (i.e. room number). Therefore, the data was compared to the school averages for each parameter.

5.2.2 Statistical Analysis

All statistical tests were conducted in IBM SPSS Statistics 20 Software. The Pearson Product-Moment Correlation was used to measure the strength of the association between two ranked variables (staff absenteeism and carbon dioxide/temperature/relative humidity/particulate matter). Carbon monoxide was not evaluated as it was not detected in a majority of locations.

A Multiple Regression Analysis is the expansion of a simple linear regression, and used when the dependent variable is based on the value of two or more other variables. Staff absenteeism was measured with all possible combinations of carbon dioxide, temperature, relative humidity, and particulate matter. Carbon monoxide was again excluded.

5.3 Results

5.3.1 Pearson – Test Determination

Prior to measuring correlation, a series of statistical tests were conducted in order to determine which correlation test could be used. The requirements necessary for a Pearson Correlation include:

1. Random sample of paired variables
2. Variables have a linear association
3. Variables are measured at interval or ratio scale
4. Variables are bivariate normally distributed (Lund Research Ltd., 2013a).

The data collected satisfied conditions 1-3. Condition four did not meet requirements as determined by a KS test. Therefore, data was transformed to meet the assumption.

The results of the KS test proved that relative humidity did not meet the limits for normality. All other parameters were determined normal. In a normal distribution, the values of skewness and kurtosis are equal or approximate to zero. Skewness and kurtosis for relative humidity were 1.25 and 1.039 respectively, indicating a non-normal distribution. Additionally, the significance value was less than 0.05, in a normal distribution a significance value must be greater than 0.05. Therefore, an inverse transformation was applied to relative humidity in order to achieve normal data. The results of the KS including the transformed relative humidity data are shown in Table 4. The data met all requirements to perform the KS test: Single random sample, population continuously distributed, and variable measured at the ordinal scale.

Table 4: KS results.

Parameter	Skewness	Kurtosis	Kolmogorov-Smirnov Sig.
Absenteeism	.738	-.101	.200
Carbon Dioxide	.234	-.303	.200
Relative Humidity	-.140	-.003	0.200
Temperature	-.016	.261	.200
Particulate Matter	.843	.200	.053

5.3.2 Pearson - Measuring Correlation

A Pearson correlation was carried out on absenteeism and carbon dioxide, relative humidity, temperature, and particulate matter. The results are presented in Table 5. The tests revealed the following:

- There was no statistically significant correlation between absenteeism and carbon dioxide $r(24) = .161$, $p > .05$.
- There was no statistically significant correlation between absenteeism and relative humidity $r(24) = .38$, $p > .05$ (computed $p = 0.067$, which is a trend towards significance) .

- There was no statistically significant correlation between absenteeism and temperature $r(24) = .161$, $p > .05$.
- There was no statistically significant correlation between absenteeism and particulate matter $r(23) = -.025$, $p > .05$.

Therefore, there is no association between absenteeism and carbon dioxide, temperature, and particulate matter. However, there is a non-significant trend for absenteeism to be positively associated with relative humidity.

Table 5: Pearson results.

Parameter	Correlation Coefficient	Sig. (2-tailed)
Carbon Dioxide	.140	.514
Relative Humidity	.380	.067
Temperature	.161	.453
Particulate Matter	-.025	.910

5.3.3 Multiple Regression Analysis - Test Determination

Prior to conducting a multiple regression analysis, a series of statistical tests were conducted in order to meet the assumptions of the test. The requirements necessary for a multiple regression include:

1. Independence of errors
2. A linear relationship between the independent variables and dependent variable
3. Homoscedasticity of residuals
4. No multicollinearity
5. No significant outliers (Lund Research Ltd., 2013b).

6. Errors are normally distributed

The data collected satisfied all assumptions. An independence of errors was assessed by the Pearson correlation above and with the use of Durbin-Watson statistics. The linear relationship was also determined for the Pearson test. Homoscedasticity of residuals was verified by plotting the studentized residuals against the predicted values. All data showed the residuals did not increase or decrease with the predicted values. No multicollinearity problems were detected as correlations were not larger than 0.7, and all tolerance values are greater than 0.1.

No significant outliers were determined as in all cases leverage values were mostly safe (less than 0.2) with some risk (between 0.2 and 0.5), and no influential values were detected in any data determined by Cook's Distance (all values below 1). However, the following combinations did detect one residual greater than three standard deviations:

- Carbon dioxide, temperature, relative humidity, particulate matter
- Carbon dioxide, relative humidity, particulate matter
- Temperature, relative humidity, particulate matter
- Relative humidity, particulate matter

The data was determined normal in section 5.4.1. Like the Pearson test, an inverse transformation was applied to relative humidity in order to achieve normal data.

5.3.4 Multiple Regression Analysis – Measuring Outcome

A multiple regression was run for all combinations of the variables. None of the regressions were of statistical significance. The following section outlines the results of each combination:

A multiple regression was conducted with the following predictor variables: Carbon Dioxide, temperature, relative humidity, and particulate matter, with absenteeism as the outcome variable. The model produced an R square of .546, which was not statistically significant, [$F(4,18) = 1.916$, $p > .05$. The results of the regression analysis are shown in Table 6.

Table 6: Multiple regression analysis of absenteeism with carbon dioxide, temperature, relative humidity, and particulate matter as predictor variables.

Predictor	**R^2**	***t***	***p***
Constant	-1.489	-.116	.909
Carbon Dioxide	.002	1.479	.157
Temperature	.011	.018	.986
Relative Humidity	103.243	2.608	.018
Particulate Matter	.028	.391	.701

A multiple regression was conducted with the following predictor variables: Carbon dioxide, temperature, and relative humidity, with absenteeism as the outcome variable. The model produced an R square of .214, which was not statistically significant, [$F(3,20) = 1.811$, $p > .05$. The results of the regression analysis are shown in Table 7.

Table 7: Multiple regression analysis of absenteeism with carbon dioxide, temperature, and relative humidity as predictor variables.

Predictor	R^2	*t*	*p*
Constant	-7.559	-.600	.556
Carbon Dioxide	.001	1.015	.322
Temperature	.380	.645	.526
Relative Humidity	80.379	2.113	.047

A multiple regression was conducted with the following predictor variables: Carbon dioxide, temperature, and particulate matter, with absenteeism as the outcome variable. The model produced an R square of .034, which was not statistically significant, [$F(3,19) = .220$, $p > .05$. The results of the regression analysis are shown in Table 8.

Table 8: Multiple regression analysis of absenteeism with carbon dioxide, temperature, and particulate matter as predictor variables.

Predictor	R^2	*t*	*p*
Constant	-1.094	-.075	.941
Carbon Dioxide	.001	.624	.540
Temperature	.233	.335	.741
Particulate Matter	-.004	-.054	.958

A multiple regression was conducted with the following predictor variables: Carbon dioxide, relative humidity, and particulate matter, with absenteeism as the outcome variable. The model produced an R square of .299, which was not statistically significant, [$F(3,19) = 2.697$, $p > .05$. The results of the regression analysis are shown in Table 9.

Table 9: Multiple regression analysis of absenteeism with carbon dioxide, relative humidity, and particulate matter as predictor variables.

Predictor	R^2	*t*	*p*
Constant	-1.263	-.524	.606
Carbon Dioxide	.002	1.588	.129
Relative Humidity	.028	.408	.688
Particulate Matter	103.342	2.708	.014

A multiple regression was conducted with the following predictor variables: Temperature, relative humidity, and particulate matter, with absenteeism as the outcome variable. The model produced an R square of .213, which was not statistically significant, $[F(3,19) = 1.719, p > .05$. The results of the regression analysis are shown in Table 10.

Table 10: Multiple regression analysis of absenteeism with temperature, relative humidity, and particulate matter as predictor variables.

Predictor	R^2	*t*	*p*
Constant	-4.013	-.307	.762
Temperature	.007	.095	.925
Relative Humidity	85.299	2.196	.041
Particulate Matter	.266	.437	.667

A multiple regression was conducted with the following predictor variables: Carbon dioxide and temperature, with absenteeism as the outcome variable. The model produced an R square of .038, which was not statistically significant, $[F(2,21) = .416, p > .05$. The results of the regression analysis are shown in Table 11.

Table 11: Multiple regression analysis of absenteeism with carbon dioxide and temperature as predictor variables.

Predictor	R^2	*t*	*p*
Constant	-4.560	-.337	.739
Carbon Dioxide	.404	.635	.532
Temperature	.001	.517	.610

A multiple regression was conducted with the following predictor variables: Carbon dioxide and relative humidity, with Absenteeism as the outcome variable. The model produced an R square of .197, which was not statistically significant, [$F(2,21) = 2.580$, $p > .05$. The results of the regression analysis are shown in Table 12.

Table 12: Multiple regression analysis of absenteeism with carbon dioxide and relative humidity as predictor variables.

Predictor	R^2	*t*	*p*
Constant	.454	.215	.832
Carbon Dioxide	.002	1.180	.251
Relative Humidity	80.851	2.156	.043

A multiple regression was conducted with the following predictor variables: Carbon dioxide and particulate matter, with Absenteeism as the outcome variable. The model produced an R square of .028, which was not statistically significant, [$F(2,20) = .287$, $p > .05$. The results of the regression analysis are shown in Table 13.

Table 13: Multiple regression analysis of absenteeism with carbon dioxide and particulate matter as predictor variables.

Predictor	**R^2**	***t***	***p***
Constant	3.765	2.133	.045
Carbon Dioxide	.001	.748	.462
Particulate Matter	-.001	-.014	.989

A multiple regression was conducted with the following predictor variables: Temperature and relative humidity, with Absenteeism as the outcome variable. The model produced an R square of .173, which was not statistically significant, [$F(2,21) = 2.198$, $p > .05$. The results of the regression analysis are shown in Table 14.

Table 14: Multiple regression analysis of absenteeism with temperature and relative humidity as predictor variables.

Predictor	**R^2**	***t***	***p***
Constant	-8.371	-.665	.513
Temperature	.497	.859	.400
Relative Humididty	71.772	1.934	.067

A multiple regression was conducted with the following predictor variables: Temperature and particulate matter, with Absenteeism as the outcome variable. The model produced an R square of .014, which was not statistically significant, [$F(2,20) = .140$, $p > .05$. The results of the regression analysis are shown in Table 15.

Table 15: Multiple regression analysis of absenteeism with temperature and particulate matter as predictor variables.

Predictor	**R^2**	***t***	***p***
Constant	-2.408	-.169	.867
Temperature	.342	.517	.611
Particulate Matter	-.012	-.155	.878

A multiple regression was conducted with the following predictor variables: Relative humidity and particulate matter, with absenteeism as the outcome variable. The model produced an R square of .206, which was not statistically significant, [$F(2,20) = 2.588$, $p > .05$. The results of the regression analysis are shown in Table 16.

Table 16: Multiple regression analysis of absenteeism with relative humidity and particulate matter as predictor variables.

Predictor	**R^2**	***t***	***p***
Constant	1.645	1.012	.324
Relative Humidity	.010	.137	.892
Particulate Matter	86.275	2.272	.034

5.4 Discussion

It was not possible to show any significant effect of carbon dioxide, relative humidity, temperature, or particulate matter on absenteeism in this study. It would be a mistake to conclude that these IAQ parameters have no influence on absenteeism or productivity in schools, particularly as a large percentage of rooms exceeded one or more of the recommended measures outlined in Chapter 3 and as a high number of survey respondents reported problems a detailed in the next chapter. Many limitations, discussed below, may have contributed to the results.

5.4.1 Limitations

One of the greatest limitations includes the small sample size used in this study. A larger sample may have increased precision and accuracy.

Absentee and IAQ data was generalized by school and not related to a particular location. As seen from the results in Chapter 3, IAQ varied between rooms in each school. Using an average may have been a false representation of each location's IAQ. However, an alternative method (correlating each room's IAQ and absenteeism) could not be conducted based on the ethical restraints placed on the amount of detail given for the absenteeism results.

Furthermore, the collection of spot measurements applies only to the time and conditions of testing. The measurements may not have been a reliable predictor to generally apply as conditions for all working days. Continuous long-term measurements would have provided more data as to the changes in IAQ throughout the day and through the year.

5.5 Conclusion and Recommendations

There have been mixed results on the studies measuring the association of IAQ and lost work time. Further strongly designed research is needed in order to draw conclusions. When developing future studies, researchers should consider an interdisciplinary approach involving engineers, statisticians, IAQ professionals, health care workers, and any others with knowledge in the area. Studies should also include a larger sample size. This could possibly be done by including more schools and/or including students in the study. Studies will have to find a way to balance the demands of ethical needs, specifically anonymity, and research requirements in order to draw accurate conclusions. Specifically, it will be important to interpret absentee data with the rooms staff occupy (and not generalized school data as used in this study). Coding staff names and room numbers may be an option to gain data and provide anonymity.

6.0 CHAPTER 6: PERCEIVED IAQ IN A WINNIPEG SCHOOL DIVISION

6.1 Introduction

Good indoor air quality (IAQ) contributes to comfort, health, and well being (Environmental Protection Agency, 2012). However, a number of environmental, physiological, and psychological factors contribute to the perceived air quality (PAQ) of an environment. The total indoor environment and workstation design should also be considered when assessing PAQ. Previous reviews of the literature have found that a linkage exists between building related symptoms and productivity, and furthermore the prevalence of symptom can be reduced if the quality of the indoor environment is improved (Niemela et al., 2006).

Surveys were distributed to staff (teachers and office administrators) in a Winnipeg school division in order to determine perceived air quality. Surveys were distributed during an indoor air quality assessment of the division. The results found that about 96% of respondents found IAQ problems in their workplace, 79% of staff show signs of SBS like symptoms, and 51% consider their school to have bad indoor air quality. Some specific recommendations were made based on the results of the survey. Overall recommendations provided in Chapter 3 are offered to improve indoor air quality operations. Staff members with complaints, especially those experiencing health symptoms, are encouraged to address their issues with a supervisor.

6.2 Study Area

Surveys were distributed to teachers and office staff present at each testing location during IAQ sampling (see Chapter 3). Distribution was limited to school division employees and did not include substitutes or part time workers. At the request of the school division, the identity of participant are anonymous. Staff members were not identified by sex, age, room number, etc.

6.3 Methodology

The survey was adapted from the *Indoor Air Quality Health and Safety Guide* prepared by the Canadian Centre for Occupation Health and Safety (CCOHS, 2008). The survey and terms of administration were approved by the University of Manitoba Human Ethics Office and the school division prior to distribution. The survey included ten multiple choice questions in relation to PAQ and possible symptoms related to poor IAQ. The survey had an estimated completion time of < 5 minutes and was voluntary and anonymous.

Surveys were distributed to teachers and office staff present at each testing location during IAQ sampling (see Chapter 3). Staff members were given paper versions of the survey and consent form to complete, a copy of each are provided in Appendix III. In most cases the survey was completed upon delivery. However, as timing was inappropriate in some circumstances (i.e. class was in session) staff could anonymously submit their surveys through inter-office mail.

6.4 Results

The results of the returned surveys are summarized in the following charts. Two hundred and thirteen surveys were distributed during the IAQ assessment. Of those, 67 surveys were returned, yielding a response rate of approximately 31%. Table 17 displays the number of responses at each school:

Table 17: Survey response.

School	Total Responses	Total Distributed	Response Rate (%)
School A	9	11	82
School B	6	11	55
School C	8	11	73
School D	6	13	46
School E	5	11	45
School F	6	11	55
School G	1	10	10
School H	3	11	27
School I	1	7	14
School J	0	4	0
School K	3	11	36
School L	3	11	27
School M	0	8	0
School N	0	0	0
School O	2	10	20
School P	1	6	17
School Q	2	6	33
School R	4	7	57
School S	2	9	22
School T	1	10	10
School U	3	9	33
School V	1	10	10
School W	0	11	0
School X	0	5	0
Total	**67**	**213**	**31**

School A had the highest return rate (82%) of surveys. Three schools, School J, School W, and School X, did not return surveys. Surveys could not be distributed at School N due to a shortage of material.

In the survey participants were asked if they thought their school had adequate IAQ. Fifty-one percent of respondents (n=34) did not think their school had adequate IAQ. Forty percent (n=27) did think their school had adequate IAQ. Nine percent (n=6) did not respond.

Participants were asked which common IAQ conditions were true of their workplace. The results are detailed in Figure 9. Eighty-eight percent of staff found that temperature varies from room to room. Dust and dry air also had high response rates of 46% and 45%, respectively. Participants were instructed to choose all applicable answers. Sixty four participants responded to the question (96%), indicating that 4% of staff do not find any of the adverse IAQ issue true of their school.

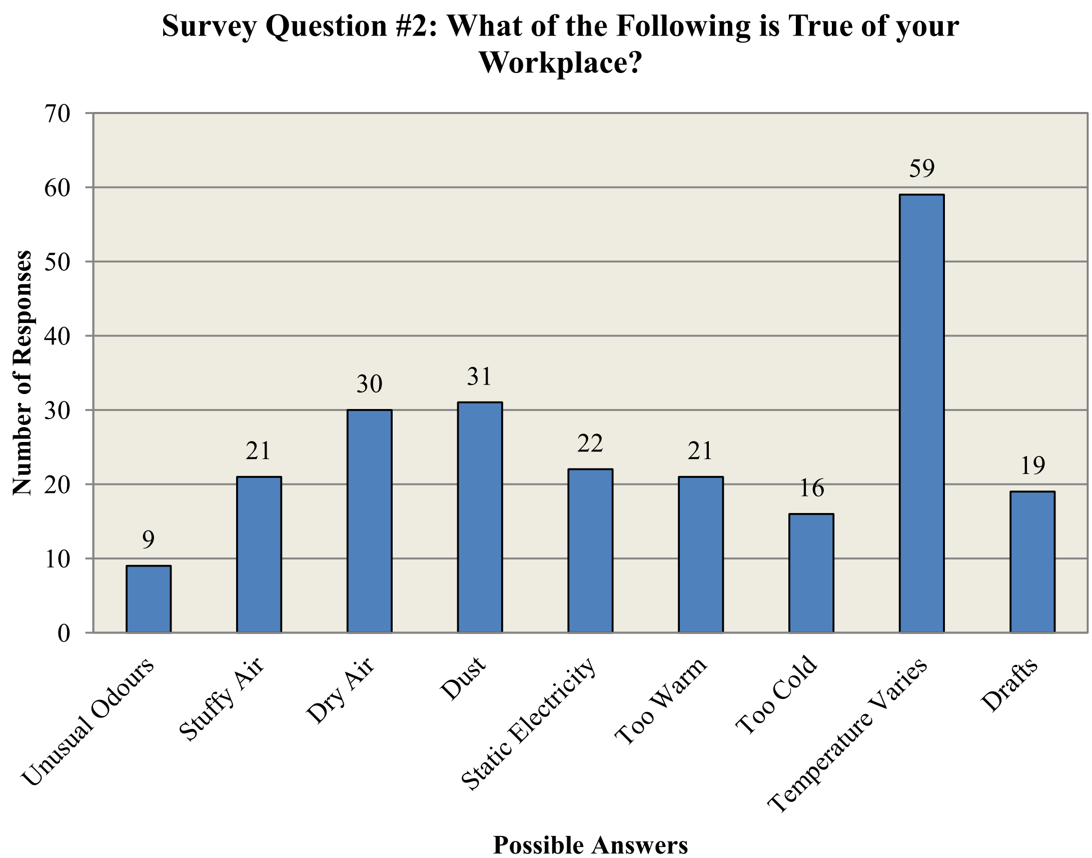

Figure 9: IAQ factors in Winnipeg schools.

The survey also questioned participants of any experienced SBS symptoms. The results are detailed in Figure 10. The highest response rates were for headache (52%), tiredness/fatigue (43%), and irritation of eyes, nose, and throat (34%). Participants were instructed to choose all applicable symptoms. Seventy-nine percent of participants (n=53) responded to the question so it is assumed that 21% of participants do not experience any of the listed symptoms.

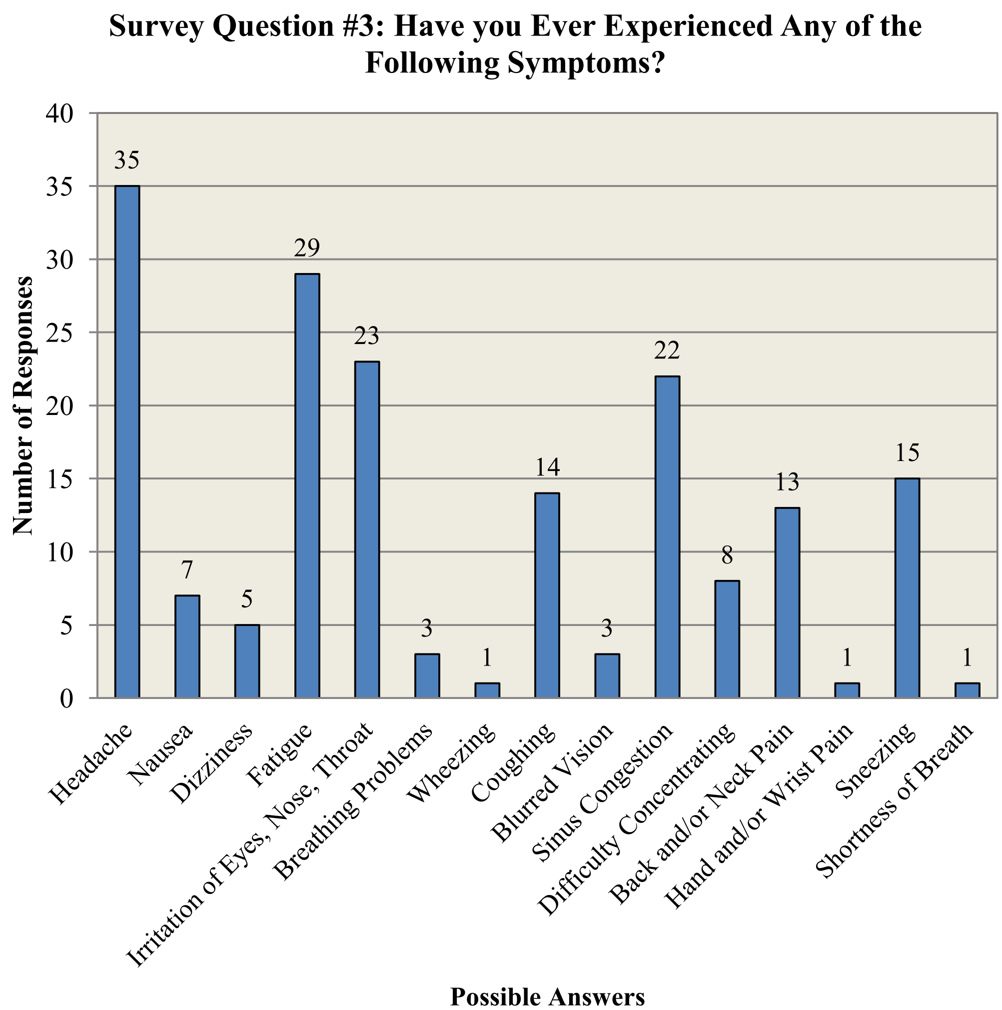

Figure 10: SBS symptoms in Winnipeg schools.

Twenty-five percent (n=17) stated that they had health conditions that may make symptoms worse (i.e. allergies, respiratory disease, etc.). Thirty percent (n=20) said they had seen a doctor for any of the previously mentioned symptoms. Eighteen percent (n=12) reported that the pain has caused them to take time off of work. Forty-two percent (n=28) said that they were aware of coworkers with similar concerns.

Only participants who reportedly experienced symptoms were asked the remaining questions. Staff members without symptoms were asked to disregard. This would apply to 53 (79%) of those surveyed.

Thirty-one percent of those with symptoms (n=21) noticed onset between two to four hours into the work day, 21% (n=14) said multiple days, 10% (n=7) said less than one hour, 4% (n=3) said one day. Twelve percent (n=8) of those with symptoms did not respond.

Fifty-one percent of participants (n=34) reported that symptoms went away overnight. Nine percent (n=6) said that symptoms rarely/never went away, and 6% (n=4) said after a week. Thirteen percent (n=9) of those with symptoms did not respond.

6.5 Discussion

Most of the studies that have explored PAQ are designed as IAQ experiments and interventions and only measure PAQ and one IAQ parameter (Smedje et al., 1997). Much less data has been collected on subjects' baseline PAQ in their work environment. Studies by Smedje, Norback, and Edling (1997) and Andersson, Fagerlund, and Aslaksen (2008) have measured the PAQ in schools. Given the similarities in setting and design their results will be the primary comparison for the results measured in the study of a Winnipeg school division.

A comparison of staff members PAQ and their schools air quality was completed. Due to the high anonymity of the survey the survey results could not be compared to specific classrooms and offices. This is also true of staff members PAQ and personal factors (i.e. gender, age, etc.).

There are a number of factors such as age, sex, and stress level that influence the perception of the indoor environment. A previous study by Andersson et. al (2008) found that teachers had the most negative reaction of IAQ compared to other school staff. Furthermore, it was found that female teachers complain more about the indoor environment and report more symptoms in general. Future surveys should consider social factors as they have a known influence on results.

Most staff reported IAQ problems in the workplace. The results of this study are very similar to the results of the study of Swedish schools by Andersson, Fagerlund, and Aslaksen (2008). Issues of temperature, relative humidity, and dust all had a similar percentage of perception. In my thesis study staff identified many of the IAQ problems found in their schools. A majority of staff identified temperature variation, low relative humidity, and dust. Less staff was able to identify the problems of cold air and stuffy air.

6.5.1 IAQ Parameters

Elevated levels of carbon dioxide were found in 67% of schools. Of those surveyed in schools with elevated carbon dioxide, 32% found the air as stuffy. The perception of warm and stuffy classrooms is likely due to overcrowding in schools. Smedje et al. (1997) previously found that complaints about air quality are not related to the concentration of carbon dioxide. Although elevated levels of carbon dioxide were found in a majority of schools, in this study it was also not a major complaint among IAQ.

Cold temperatures were noted as a common problem in the IAQ assessment in Chapter 3. Forty-eight percent of schools had locations with temperatures considered cold by ASHRAE standards. Of those surveyed in cold schools, only 21% noted cold temperatures as a common condition in their workplace. This could be due to the varying temperatures within the workplace. Overall, 24% of staff members in Winnipeg found their workplace too cold, which is similar to the findings of Andersson et al. (20%).

Temperature variation was reported as the most common condition in Winnipeg schools. Eighty-eight percent of staff identified this issue in their workplace. The average temperature variation in schools was approximately 2.5^{o}C. However some schools had a much larger range. For instance, Schools A, D, and M had the maximum variation of 6^{o}C. This indicates that staff members are aware of the temperature variation between classrooms. This may also serve as an explanation why more surveyors did not identify cold classrooms in the workplace. Dust and dry air were the next most commonly identified workplace conditions, at 46% and 45% respectively.

Thermal discomfort in School L was confirmed in the survey. During the IAQ assessment signs of possible thermal discomfort were noted (paperclips in the thermostat covers). Although only three staff members in this school responded to the survey, there were noted complaints in regards to temperature. One staff member found the school too cold, another too warm, and two people found that temperatures varied from room to room.

Low relative humidity was the most common problem measured in the Winnipeg schools, as 66% of schools had levels below the recommended minimum level. Of those surveyed in the schools with low relative humidity 54% noted dry air and 27% noted shocks from static electricity. A majority of staff identified dry air in schools with low relative humidity. Relative humidity was not measured in Swedish schools; however dry air was noted by 30% of Swedish staff (Andersson et al., 2008).

Forty-six percent of survey respondents reported that dust was a common condition in their schools. Forty-five percent also reported this in the study of Andersson et. al (2008). High concentrations of particulate matter in schools has been documented in many previous studies (Branis et al., 2005; HESE, 2006; ODPM, 2006; Fromme et al., 2007; Heudorf et l., 2007), and impacted 50% of the schools in my thesis study. Based on the Health Canada reference, twelve schools had elevated particulate matter. Of those surveyed in dusty schools, 59% noted dust as a problem.

In the study by Andersson et al. (2008) elevated dust was attributed to insufficient cleaning. Smedje et al. (1997) noted that cleaning in schools is much less comprehensive than in offices, and cleaning routines are frequently limited to the floor. Desks, chairs, and fabrics should also be cleaned. A previous study by Raw et. al (1993) found that cleaning furniture and fabrics significantly reduced SBS symptoms in an office building. The cleaning routine in Winnipeg schools was not identified, but could be limited to the floor only, as Smedje identifies as a common practice in schools.

Schools B and Q were the only schools to meet all recommended guidelines in the IAQ assessment. Most staff in these schools (63%) did agree that their school had good IAQ. However, 88% of staff did note that temperature varies from room to room. In this thesis study temperature was only deemed acceptable if it was within 20 to 25.5^{o}C. Future studies should also consider an acceptable range of variation, as a large majority of staff had complaints in this area.

6.5.2 SBS Symptoms

Previous surveys have shown a positive relationship in the number of reported problems and symptoms (Andersson et al., 2008). About 79% of staff in Winnipeg reported symptoms that could be associated with poor IAQ. The reported symptoms in Winnipeg are very similar to those reported in Finnish office workers (Ervasti et al., 2012) and staff members in Swedish schools (Andersson et al., 2008). As symptoms are similar to that of the common cold or flu, it is difficult to diagnose if IAQ is the casual agent. Experts will generally ask a series of questions in relation to onset and duration of symptoms to help identify if IAQ is a suspect cause. Some staff members are experiencing symptoms that are reflective of an IAQ problem.

If symptoms are related to IAQ onset will usually occur within two to four hours of the workday (CCOHS, 2008), which 39% of those with symptoms reported. Symptoms should also go away after leaving the building (CCOHS, 2008) which 64% of those with symptoms reported. Further diagnosis would consider if several staff members in the same area are experiencing similar symptoms.

Twenty-nine percent of those that responded (n=58) stated that they had health conditions that may make symptoms worse (i.e. allergies, respiratory disease, etc.). Those with allergies are usually more impacted by poor IAQ and report more symptoms and perceive the air quality as worse (Smedje et al., 1997; Andersson et al., 2008).

The high response of people stating they knew others with similar symptoms suggests that a wider sample size may have yielded more responses in relation SBS symptoms. Fifty-three percent of respondents were aware of coworkers with similar symptoms.

When schools are identifying IAQ problems the location of those suffering should be considered. Coworkers sharing similar symptoms may be isolated to a particular room or wing of the building. Determining the locations extent will help to diagnose and remediate the problem.

6.6 Conclusion and Recommendations

The results of this survey are further motivation for the school division to make the recommendations provided in Chapter 3. Staff members are noting IAQ problems in the workplace and are experiencing SBS symptoms. The assessment in this study was only preliminary, and if SBS symptoms do not improve following adjustments further assessments of other IAQ parameters (i.e. TVOCs, mould, etc.) may be necessary.

In addition to the recommendations made in Chapter 3, housekeeping procedures should be reviewed in the schools and include cleaning of desks, chairs, and fabrics. It is also recommended that future studies include social factors in their surveys, and consider including an acceptable range of temperature variation as part of the recommendations for good thermal comfort.

Staff members with IAQ complaints, especially those experiencing any health symptoms, are encouraged to address their issues with the proper supervisor. It is recommended that schools establish procedures for reporting IAQ problems. A possible framework is detailed below:

Written reports are preferred when gathering data about IAQ problems. A report should include the date, the work area (floor, room number), and symptoms experienced.

It is also important to gather a history of the symptoms such as when the employee first noticed the problem and the frequency, onset, and duration of symptoms.

A survey like the one used in this study may be a useful questionnaire for the Health and Safety Committee to use when gathering information. A review should look for patterns in the type of symptoms reported, duration and frequency, and the area and number of people impacted (CCOHS, 2008). It can be useful to map out complaint areas on a floor plan shown.

The Canadian Centre for Occupational Health and Safety (2008) recommends keeping in mind the following considerations while reviewing IAQ data:

- Do not ignore a problem if only a few people are affected. Sensitivity varies. IAQ may continue to degrade and more people may become affected.
- Health problems may still occur even if exposures are below an acceptable limit due to combined exposures of several agents.

Multiple IAQ assessments may be needed. Preliminary assessments usually measure temperature, relative humidity, and carbon dioxide to ensure the HVAC systems are in working order. Further assessments may include an assessment of contaminants originating inside the building or entering with outside air intake.

7.0 CONCLUSION

It is the responsibility of schools to provide an optimal indoor environment for work and learning. Although this study did not find any statistically significant associations between IAQ and absenteeism, the results of the survey and IAQ assessment have shown that a majority of staff have experienced poor IAQ in the workplace and are experiencing SBS symptoms. Eighteen percent of survey respondents reported that they have missed worked due to SBS-like symptoms. These results may also indicate that staff members are losing work time through other measures (i.e. reduced productivity or performance).

Based on the results of the IAQ assessment, it is recommended that schools make the corrective actions suggested in Chapter 3. The recommendations include: increasing the amount of fresh air, installing programmable thermostats or building management systems, additional housekeeping practices for particulate management, and staff education on the operation of systems.

Low relative humidity and high carbon dioxide were the most common problems in the school division and should be prioritized for mitigation. Although low relative humidity may not disturb occupants during more humid seasons (i.e. spring), corrective actions should still be considered as the occupied season of Winnipeg schools is mainly winter. The results of this IAQ assessment showed similar findings to other school assessments, adding to the body of research of poor IAQ in schools.

Future studies in this area should strive for a larger sample size. This would have increased precision and accuracy, possibly showing a statistically significant association between IAQ and absenteeism and providing more survey results. Research should also be able to associate classroom IAQ and absenteeism, in this study the IAQ data was generalized by schools and not related to a particular location. Other factors of lost work (i.e. reduced productivity) should also be considered in future studies as they may play a larger role in lost work time than absenteeism. This may be of particular interest to school administration as students' learning abilities may be affected by deteriorated indoor air.

The IAQ assessment in this study was very basic and more knowledge on building history, such as age of the school, would have been useful data. More information on the HVAC system in each building, and a possible HVAC inspection of the school, would have also served as an interesting component to the study. Although this assessment included the IAQ parameters in a preliminary assessment, other assessments may wish to explore the affects of additional parameters, such as TVOCs, mould, etc.

It is recommended that the division adopt an IAQ management program to direct their schools for good air quality. This framework will improve IAQ, help manage complaints and health concerns (Chapter 6), and provide tools for cost savings. Although many IAQ management programs are available it is recommended that the division looks to a well established program specifically for the school environment, such as *Indoor Air Quality Tools for Schools Action Kit for Canadian Schools* (Health Canada, 2003) adapted from *IAQ Tools for Schools* (Environmental Protection Agency, 2012). If a program is already in place, the division should consider reviewing and revising their practices as many schools did not meet IAQ recommendations.

School divisions who have not yet started assessing IAQ can follow the *Tools for Schools Action Kit* recommendations to get started. These tasks include: choosing an IAQ Coordinator, gaining administrative support, and creating the IAQ team. Although measuring IAQ is important, the start up recommendations is an important first step to creating an IAQ management system.

"Good IAQ contributes to a favorable learning environment for students, productivity for teachers and staff, and a sense of comfort, health, and well-being for all school occupants. These combine to assist a school in its core mission – educating children" (Health Canada, 2003). Once good IAQ is established a healthy indoor environment can be more easily maintained. All schools should strive to improve IAQ in order to provide a more favorable indoor environment for students and staff.

8.0 REFERENCES

1. Almedida, S.M, Canha, M., Silva, A., Freitas, M.C., Pega, P., Alves, C., Evtyugina, M., et al. (2011). Children exposure to atmospheric particles in indoor of Lisbon primary schools. *Atmospheric Environment, 45*, 7594-7599.

2. Apte, M.G., Fisk, W.J., & Daisey, J.M. (2000). Associations between indoor CO_2 concentrations and sick building syndrome symptoms in US office buildings: An analysis of the 1994-1996 BASE study data. *Indoor Air, 10,* 246-257.

3. American Lung Association. (2000). Indoor air quality and its effect on health. *Asthma Magazine, 5*(5), 22-23.

4. Andersson, K., Fangerlund, I., Aslaksen, W. (2008). The perceived indoor climate of Swedish schools. *Indoor Air,* 17-22.

5. ASHRAE. (2010). ANSI/ASHRAE standard 62.1-2010: Ventilation for acceptable indoor air quality. Atlanta, GA: ASHRAE.

6. ASHRAE. (2010). ANSI/ASHRAE standard 55-2010: Thermal environmental conditions for human occupancy. Atlanta, GA: ASHRAE.

7. Bako-Biro, Z., Wargocki, P., Weschler, C.J., & Fanger, P.O. (2004). Effects of pollution from personal computers on perceived air quality, SBS symptoms and productivity in offices. *Indoor Air,14,* 178-187.

8. Borkowski, M., Pawlowski, M., & Makowiecki, T. (2011). Economical aspects of building management systems implementation. *PowerTech, 2011 IEEE Trondheim*, 1-6.

9. Brundage, J., Scott, R., Lednar, W., Smith, D., & Miller, R. (1988). Building associated risk of febrile acute respiratory diseases in army trainees. *Journal of the American Medical Association,259,* 2108-2112.

10. Burroughs, H.E. & Hansen, S.J. (2008). *Managing IAQ* (4^{th} ed.). Lilburn, GA: Fairmont Press.

11. CCOHS. (2008). *Indoor air quality and health and safety guide* (3^{rd} ed.). Hamilton, ON: Canadian Centre for Occupational Health and Safety.

12. Chaloulakou, A. & Mavroidis, I. (2002). Comparison of indoor and outdoor concentrations of CO at a public school. Evaluation of an indoor air quality model. *Atmospheric Environment,36,*1769-1781.

13. Chaloulakou, A. & Mavroidis, I. (2003) Indoor and outdoor carbon monoxide concentration relationship at different microenvironments in the Athens area. *Chemosphere, 52*(6), 1007-1019.

14. Chatzidiaku, L., Mumovick, D., & James, A. (2012). What do we know about indoor air quality in classrooms? A critical review of the literature. *Intelligent Buildings International,4*(4), 228-259.

15. Chen, L., Jennison, B.L., Yang, W., & Omaye, S.T. (2000). Elementary school absenteeism and air pollution. *Inhalation Toxicology Journal,12,*997-1016.

16. Corgnati, S.P., Filippi, M. & Viazzo, S. (2007) Perception of the thermal environment in high school and university classrooms: subjective preferences and thermal comfort. *Building Environment,42*(2), 951-959.

17. Currie, J., Hanushek, E., Kahn, M., Neidell, M., & Rivkin, S. (2009) Does pollution increase school absences? *Review of Economics and Statistics, 91*(4), 682-694.

18. Daisey, J.M., Angell, W.J., & Apte, M.G. (2003). Indoor air quality, ventilation and health symptoms in schools: an analysis of existing information. *Indoor Air, 13*, 53-64.

19. Dybendal, T. & Elsayed, S. (1992). Dust from carpeted and smooth floors. V. Cat (Fel d I) and mite (Der p I and Der f I) allergen levels in school dust. Demonstration of the basophil histamine release induced by dust from classrooms. *Clinical and Experimental Allergy, 22,* 1100-1106.

20. Environment Canada. (2013). 1981 to 2010 Canadian climate normals. Retrieved July 20, 2013, from http://www.climate.weatheroffice.gc.ca/winners/categorydata_e.html?SelectedCategory=2&submit=Submit

21. Environmental Protection Agency. (2012). IAQ tools for schools. Retrieved November 14, 2012, from http://www.epa.gov/iaq/schools/index.html

22. Environmental Protection Agency & National Institute of Occupational Safety and Health. (1998). Common IAQ measurements - a general guide. In *Building air quality action plan* (pp. 109-119). Retrieved November 12, 2012, from http://www.epa.gov/iaq/largebldgs/pdf_files/baqactionplan.pdf

23. Erdmann, C.A., Steiner, K.C., & Apte, M.G. (2002) Indoor carbon dioxide concentrations and sick building syndrome symptoms in the BASE study

revisited: analysis of the 100 building dataset. *Proceedings of Indoor Air 2002,2,* 443-448.

24. Eriksson, B.E., Mandorff, S., & Boysen, A. (1967) Teachers' opinions of classroom climate – A questionnaire survey. BFR Report 31: 1967. Stockholm: Building Research Council.
25. Ervasti, J., Kivimaki, M., Kawachi, I., Subramanian, S., Pentti, J., Oksanen, T., Puusniekka, R., et al. (2012). School environment as predictor of teacher sick leave: data-linked prospective cohort study. BMC Public Health, 12(770). Retrieved August 18, 2013 from, http://www.biomedcentral.com/1471-2458/12/770
26. Fang, L., Wyon, D.P., Clausen, G., & Fanger, P.O. (2002). Sick building syndrome symptoms and performance in a field laboratory study at different levels of temperature and humidity. *Proceedings of Indoor Air 2002,3,* 466-471.
27. Fanger, O. (1970). *Thermal comfort: analysis and applications in environmental engineering.* Copenhagen: Danish Technical Press.
28. Fisk, W.J., Price, P.N., Faulkner, D., Sullivan, D.P., Dibartolomeo, D.L., Federspiel, C.C., Liu, G., et al. (2002). Worker performance and ventilation: analyses of time series data for a group of call center workers. *Proceedings of the 9th International Conference on Indoor Air Quality and Climate,1,* 790-795.
29. Fisk, W.J., Seppanen, O., Faulkner, D., & Huang, J. (2003). Economizer system cost effectiveness, accounting for the influence of ventilation rate on sick leave. *Proceeding of Healthy Buildings 2003, at the National University of Singapore,* 361-367.
30. Godwin, C. & Batterman, S. (2007). Indoor air quality in Michigan schools. *Indoor Air, 17*, 109-121.
31. Green, G.H. (1974). The effect of indoor relative humidity on absenteeism and colds in schools. *ASHRAE Transactions,80,* 131-141.
32. Health Canada. (1995). Indoor air quality in office buildings: A technical guide. Retrieved November 12, 2012, from http://www.hc-sc.gc.ca/ewh-semt/pubs/air/office_building-immeubles_bureaux/index-eng.php
33. Health Canada. (2003). Indoor air quality: Tools for schools action kit for Canadian schools. Retrieved November 11, 2012, from http://www.hc-sc.gc.ca/ewh-semt/pubs/air/tools_school-outils_ecoles/index-eng.php

34. Health Canada. (2008). *Guide for radon measurements in public buildings.* Ottawa: Minister of Health.

35. Health Canada. (2009). Government of Canada radon guideline. Retrieved November 11, 2012, from http://www.hc-sc.gc.ca/ewh-semt/radiation/radon/guidelines_lignes_directrice-eng.php

36. Health Canada. (2012). Cross-Canada survey of radon concentrations in homes, final report. Ottawa: Minister of Health.

37. Hoge, C.W., Reichler, M.R., Dominguez, E.A., Bremer, J.C., Mastro, T.D., Hendricks, K.A. Musher, D.M., et al. (1994). An epidemic of pneumococcal disease in an overcrowded, inadequately ventilated jail. *New England Journal of Medicine,331,* 643-648.

38. Hutcheon, N.B. (1960). Humidity in Canadian buildings. *Canadian Building Digests, 1*. Retrieved July 20, 2013, from http://archive.nrc-cnrc.gc.ca/eng/ibp/irc/cbd/digest-index.html

39. Hwang, R.L., Lin, T.P., & Kuo, N.J. (2006). Field experiments on thermal comfort in campus classrooms in Taiwan. *Energy and Buildings, 38*(1), 53-62

40. Jones, S., Smith, A., Wheeler, L., & McManus, T. (2010). School policies and practices that improve indoor air quality. *Journal of School Health, 80*(6), 280-286.

41. Kacamarczyk, J., Melikov, A., & Fanger, P.O. (2004). Human response to personalized ventilation and mixing ventilation. *Indoor Air, 14,* 17-29.

42. Kajtar, L., Herczeg, L., & Lang, E. (2003). Examination of influence of CO_2 concentration by scientific methods in the laboratory. *Proceedings of Healthy Buildings Conference, Singapore 2003,* 3, 176-181.

43. Kwok, A.G. & Chung, C. (2003). Thermal comfort in Japanese schools. *Solar Energy, 74*(3), 245-252.

44. Largercrantz, L., Wistrand, M., Willen, U., Wargocki, P., Witterseh, T., & Sundell, J. (2000). Negative impact of air pollution on productivity: Previous Danish findings repeated in new Swedish test room. *Proceedings of the Healthy Buildings 2000 Conference, Helsinki, Finland, 1*, 653-658, Helsinki: SIY Indoor Air.

45. Lee, S.C., & Chang, M. (2000). Indoor and outdoor air quality investigation at schools in Hong Kong. *Chemosphere, 41,* 109-113.

46. Liang, H.H., Lin, T.P., & Hwang, R.L. (2012). Linking occupants' thermal perception and building thermal performance in naturally ventilated school buildings. *Applied Energy, 94*, 355-363.

47. Ligman, B., Casey, M., Braganza, E., Coy, A., Redding, Y. & Womble, S. (n.d.). Airborne particulate matter within school environments in the United States. Retrieved July 20, 2013, from http://www.epa.gov/iaq/base/pdfs/base_4_0255.pdf

48. Lund Research Ltd. (2013a). Pearson product-moment correlation. Retrieved August 18, 2013, from https://statistics.laerd.com/statistical-guides/pearson-correlation-coefficient-statistical-guide.php

49. Lund Research Ltd. (2013b). Multiple regression analysis. Retrieved August 18, 2013, from https://statistics.laerd.com/spss-tutorials/multiple-regression-using-spss-statistics.php

50. Macferran, E. (2010). Making a case for reduced classroom ventilation. *Heating Piping Air Conditioning Engineering*, *82,* 12.

51. Manitoba Hydro. (n.d.). Indoor air quality and ventilation. Retrieved July 20, 2013, from http://www.hydro.mb.ca/your_home/resources/8_indoor_air_quality_ventilation.pdf

52. Matela, D. (2006). Air filtration: green and clean - how to improve indoor air quality. *Filtration and Separation,43*(9), 24-27.

53. Mendell, M.J. & Heath, G.A. (2005). Do indoor pollutants and thermal conditions in schools influence student performance? A critical review of the literature. *Indoor Air, 15,* 27-52.

54. Mendell, M.J., Fisk, W.J., Petersen, M.R., Hines, C.J., Dong, M., Faulkner, D., Deddens, J.A., et al. (2002). Indoor particles and symptoms among office workers: results from a double-blind cross over study. *Epidemiology, 13,* 296-304.

55. Milton, D.K., Glencross, P.M., & Walters, M.D. (2000). Risk of sick leave associated with outdoor air supply rate, humidification, and occupant complaints. *Indoor Air, 10,* 212-221.

56. Mors, S., Hensen, J., Loomans, M., & Boerstra, A. (2011) Adaptive thermal comfort in primary school classrooms: creating and validating PMV-based comfort charts. *Building and Environment, 46*(12), 2454-2461.

57. Mumovic, D., Palmer, J., Davies, M., Orme, M., Ridley, I., Oreszczyn, T., Judd, C., et al. (2009). Winter indoor air quality, thermal comfort and acoustic performance of newly built secondary schools in England. *Building and Environment, 44*(7), 1466-1477.

58. Myatt, T., Staudenmayer, J., Adams, K., Walters, M., Rudnick, S., & Milton, D.K. (2002). A study of indoor carbon dioxide levels and sick leave among office workers. *Environmental Health, 1*(3). Retrieved July 20, 2013, from http://www.ehjournal.net/content/pdf/1476-069X-1-3.pdf

59. Myhrvold, A.N., Olsen, E., & Lauridsen, O. (1996). Indoor environment in schools – pupils health and performance in regard to CO_2 concentrations. *Proceedings of Indoor Air '96: The 7th International Conference on Indoor Air Quality and Climate, 4,* 369-374.

60. Nilsen, S.K., Blom, P., Rydock, J., Nersveen, J., & Fostervold, K. (2002). An intervention study of the relationship between indoor air related health problems, productivity and cleanliness in an office setting. *Proceedings of the 9th International Conference on Indoor Air Quality and Climate, 3,* 474-477.

61. Omaye, S. (2002). Metabolic modulation of carbon monoxide toxicity. *Toxicology, 180,* 139-150.

62. Park, H., Lee, B., Ha, E.H., Lee, J.T., Kim, H., & Hong, Y.C. (2002) Association of air pollution with school absenteeism due to illness. *Archives of Pediatrics and Adolescent Medicine, 156,* 1235-1239.

63. Pilotto, L.S., Douglas, R.M., Attewell, R.G., & Wilson, S.R. (1997). Respiratory effects associated with indoor nitrogen dioxide exposure in children. *International Journal of Epidemiology, 26*(4), 788-796.

64. Ransom, M. & Pope, A. (1992). Elementary school absences and PM10 pollution in Utah Valley. *Environmental Research, 58*(1), 204-219.

65. Raw, G., Roys, M., & Whitehead, C. (1993). Sick building syndrome: Cleanliness is next to healthiness. *Indoor Air, 3,* 237-245.

66. Niemela, R., Seppanen, O., Korhonen, P., & Reijula, K. (2006). Prevalence of building related symptoms as an indicator of health and productivity. *American Journal of Industrial Medicine, 49,* 819-825.

67. Rosen, K., & Richardson, G. (1999). Would removing indoor air particulates in children's environments reduce absenteeism- a hypothesis. *The Science of the Total Environment, 234,* 87-93.

68. Sale, C.S. (1972). Humidification to reduce respiratory illnesses in nursery school children. *Southern Medical Journal, 65,* 882-885.

69. Santamouris, M, Synnefa, A., Asssimakopoulos, M., Livada, I., Pavlou, K., Papaglastra, M., Gaitani, D., et al. (2008) Experimental investigation of the air flow and indoor carbon dioxide concentration in classrooms with intermittent natural ventilation. *Energy and Buildings, 40*, 1833-1843.

70. Seppanen, O., Fisk, W., & Faulkner, D. (2004a). Control of temperature for health and productivity in offices. Lawrence Berkeley National Laboratory: Lawrence Berkeley National Laboratory. LBNL Paper LBNL-55448. Retrieved from: http://escholarship.org/uc/item/39s1m92c

71. Seppanen, O.A. & Fisk, W.J. (2004b). Summary of human responses to ventilation. *Indoor Air, 14,* 102-118.

72. Sepannen, O., Fisk, W.J., & Lei, Q.H. (2006). Ventilation and performance in office work. *Indoor Air, 16*(1), 28-36.

73. Shaughnessey, R.J., Haverinen-Shaughnessy, U., Nevalainen, A., & Moschandreas, D. (2006). A preliminary study on the association between ventilation rates in classrooms and student performance. *Indoor Air, 16,* 465-468.

74. Shendell, D.G., Prill, R., Fisk, W.J., Apte, M.G., Blake, D., & Faulkner, D. (2004). Associations between classroom CO_2 concentrations and student attendance in Washington and Idaho. *Indoor Air, 14*, 333-341.

75. Smedje, G., Norback, D., & Edling, C. (1997). Subjective indoor air quality in schools in relation to exposure. *Indoor Air, 7*, 143-150.

76. Tham, K.W., Willem, H.C., Sekhar, S.C., Wyon, D.P, & Wargocki, P. (2003). Temperature and ventilation effects on the work performance of office workers: a study of a call-centre in the tropics. *Proceedings of the Healthy Buildings 2003 Conference, Singapore, 3,* 280-286. Singapore, NUS.

77. Wargocki, P., Lagercrantz, L., Witterseh, T., Sundell, J., Wyon, .P, & Fanger, P. (2002). Subjective perceptions, symptom intensity and performance: a comparison of two independent studies, both changing similarly the pollution load in an office. *Indoor Air, 12,* 74-80.

78. Wargocki, P. & Wyon, D.P. (2007). The effect of moderately raised classroom temperatures and classroom ventilation rate on the performance of schoolwork by children. *HVAC&R Research, 13*(2), 193-220.Wargocki, P., Wyon, D.P, Baik, Y.K., Clausen, G., & Fanger, P.O. (1999a). Perceived air quality, SBS-symptoms

and productivity in an office at two pollution loads. *Proceedings of Indoor Air 1999, Edinburgh, UK, the 8th International Conference on Indoor Air Quality and Climate*, *2,* 131-136. Garston, UK: BRE.

79. Wargocki, P., Wyon, D.P., Baik, Y.K., Clausen, G., & Fanger, P.O. (1999b). Perceived air quality, sick building syndrome 'symptoms and productivity in an office with two difference pollution loads. *Indoor Air, 9,* 165-179.

80. Wargocki, P., Wyon, D., Sundell, J., Clausen, G., & Fanger, 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,* 222-236.

81. Witterseh, T., Wyon, D.P., & Clausen, G. (2002). The effects of moderate heat stress and open plan office noise distraction on office work. *Proceedings of the 9th International Conference on Indoor Air Quality and Climate, 4,* 1084-1089.

82. Wong, N.H. & Khoo, S. (2003). Thermal comfort in classrooms in the tropics. *Energy and Building, 35(4)* 337-351.

83. Wyon, D.P. (2004). The effects of indoor air quality on performance and productivity. *Indoor Air, 14*, 92-101.

84. Wyon, D.P., Anderson, I., & Lundqvist, G.R. (1979). The effects of moderate heat stress on mental performance. *Scandinavian Journal of Work, Environment and Health, 5*(4), 352-361.

85. Wyon, D.P., Fang, L., & Fanger, P.O. (2003). Low winter humidity indoors has a negative effect on the performance of office work. *Proceedings of the 4th International Conference on Cold Climate HVAC, Trondeheim, Norway:* NTU CD-ROM\

86. Wyon, D. & Wargocki, P. (2013). Effects of indoor environment on performance. *ASHRAE Journal, March 2013*, 46-50.

87. Yip, F.Y., Keller, GJ., Dvonch, J.T., Robins, T.G., Parker, E.A., Israel, B.A., Brakefield-Caldwell, W. (2004). Personal exposure to particulate matter among children with asthma in Detroit, Michigan. *Atmospheric Environment, 38,* 5227-5236.

APPENDIX I

DETAILED IAQ RESULTS

School A

		CO_2 (ppm)	CO (ppm)	TEMPERATURE (°C)	RH (%)	PM_{10} ($\mu g/m^3$)
Main Office	Mean	639.52	0.00	18.07	40.17	2.88
	Min	482.00	0.00	15.10	37.00	1.00
	Max	686.00	0.00	19.60	48.00	6.00
Room 4	Mean	778.27	0.00	19.26	40.00	2.59
	Min	698.00	0.00	19.10	40.00	1.00
	Max	834.00	0.00	19.50	40.00	5.00
Room 5	Mean	1018.24	0.00	20.64	39.07	4.96
	Min	816.00	0.00	19.39	38.00	2.00
	Max	1138.00	0.00	21.30	40.00	18.00
Room 10	Mean	854.67	0.00	19.91	40.28	3.50
	Min	804.00	0.00	19.50	38.00	2.00
	Max	976.00	0.00	20.90	45.00	7.00
Room 15	Mean	1264.00	0.00	21.94	42.17	8.93
	Min	1008.00	0.00	21.10	42.00	2.00
	Max	1412.00	0.00	22.80	43.00	169.00
Room 17	Mean	1440.67	0.00	22.70	42.50	3.52
	Min	1416.00	0.00	22.00	42.00	2.00
	Max	1462.00	0.00	23.00	44.00	7.00
Room 19	Mean	1498.00	0.00	22.97	42.39	5.86
	Min	1470.00	0.00	22.70	42.00	3.00
	Max	1526.00	0.00	23.20	43.00	16.00
Room 20	Mean	1517.27	0.00	23.08	41.43	3.10
	Min	1436.00	0.00	22.70	41.00	2.00
	Max	1600.00	0.00	23.30	43.00	6.00
Room 18	Mean	1413.96	0.00	23.64	39.69	6.63
	Min	1312.00	0.00	22.90	38.00	2.00
	Max	1454.00	0.00	24.30	45.00	97.00
Room 16	Mean	1195.46	0.00	23.32	38.32	5.42
	Min	1140.00	0.00	23.20	38.00	3.00
	Max	1294.00	0.00	23.40	39.00	28.00

School B

		CO_2 (ppm)	CO (ppm)	TEMPERATURE (ºC)	RH (%)	PM_{10} (µg/m^3)
Main Office	Mean	724.06	0.00	21.59	36.56	N/A
	Min	666.00	0.00	20.80	34.00	N/A
	Max	808.00	0.00	22.30	47.00	N/A
Room 1	Mean	853.67	0.00	21.80	38.00	N/A
	Min	824.00	0.00	21.80	38.00	N/A
	Max	880.00	0.00	21.80	38.00	N/A
Room 2	Mean	898.29	0.00	21.43	38.17	N/A
	Min	752.00	0.00	20.50	37.00	N/A
	Max	1324.00	0.00	21.80	40.00	N/A
Room 3	Mean	681.92	0.00	21.44	37.79	N/A
	Min	634.00	0.00	20.90	36.00	N/A
	Max	800.00	0.00	22.30	40.00	N/A
Room 4	Mean	864.00	0.00	21.98	37.92	N/A
	Min	818.00	0.00	21.90	37.00	N/A
	Max	886.00	0.00	22.10	38.00	N/A
Room 5	Mean	887.78	0.00	22.14	38.06	N/A
	Min	854.00	0.00	21.80	37.00	N/A
	Max	1006.00	0.00	22.60	39.00	N/A
Room 6	Mean	1047.00	0.00	22.62	38.56	N/A
	Min	994.00	0.00	22.40	37.00	N/A
	Max	1080.00	0.00	22.80	40.00	N/A
Room 9	Mean	893.25	0.00	22.39	36.71	N/A
	Min	856.00	0.00	21.90	36.00	N/A
	Max	974.00	0.00	22.70	38.00	N/A
Room 10	Mean	860.33	0.00	22.41	37.17	N/A
	Min	850.00	0.00	22.00	36.00	N/A
	Max	872.00	0.00	22.80	39.00	N/A
Room 11	Mean	838.08	0.00	22.22	37.04	N/A
	Min	814.00	0.00	22.00	36.00	N/A
	Max	870.00	0.00	22.50	38.00	N/A
Room 12	Mean	867.20	0.00	23.31	35.00	N/A
	Min	864.00	0.00	22.90	34.00	N/A
	Max	872.00	0.00	23.50	37.00	N/A

School C

		CO_2 (ppm)	CO (ppm)	TEMPERATURE (ºC)	RH (%)	PM_{10} ($\mu g/m^3$)
Main Office	Mean	920.77	0.00	20.09	26.67	6.88
	Min	868.00	0.00	16.80	25.00	2.00
	Max	1004.00	0.00	21.90	31.00	26.00
Room 8	Mean	1015.67	0.00	21.52	23.36	9.52
	Min	848.00	0.00	21.10	22.00	3.00
	Max	1536.00	0.00	21.90	25.00	86.00
Room 9	Mean	1110.22	0.00	22.11	24.08	4.67
	Min	942.00	0.00	21.10	23.00	4.00
	Max	1590.00	0.00	22.60	27.00	5.00
Room 7	Mean	1083.33	0.00	22.32	27.28	4.33
	Min	952.00	0.00	21.90	26.00	3.00
	Max	1180.00	0.00	22.60	35.00	6.00
Room 6	Mean	1517.83	0.00	19.89	31.00	5.08
	Min	1190.00	0.00	15.60	27.00	3.00
	Max	1626.00	0.00	22.00	37.00	11.00
Room 5/4	Mean	956.62	0.00	21.28	25.74	6.89
	Min	868.00	0.00	20.50	23.00	4.00
	Max	1304.00	0.00	22.40	30.00	14.00
Room 2	Mean	839.67	0.00	20.99	26.83	8.36
	Min	800.00	0.00	20.70	26.00	5.00
	Max	916.00	0.00	21.30	28.00	19.00
Room 3	Mean	944.24	0.00	22.12	23.88	7.07
	Min	804.00	0.00	21.30	18.00	4.00
	Max	1388.00	0.00	23.00	27.00	11.00
Room 17	Mean	1575.17	0.00	23.23	26.29	11.80
	Min	1412.00	0.00	21.70	26.00	4.00
	Max	1678.00	0.00	24.00	27.00	66.00
Room 15	Mean	1705.86	0.05	22.10	27.10	9.60
	Min	1658.00	0.00	12.90	26.00	4.00
	Max	1734.00	1.00	22.90	34.00	53.00
Room 18	Mean	1688.63	0.02	22.25	25.91	6.55
	Min	1304.00	0.00	21.30	23.00	4.00
	Max	2132.00	1.00	23.30	29.00	16.00

School D

		CO_2 (ppm)	CO (ppm)	TEMPERATURE (ºC)	RH (%)	PM_{10} (µg/m^3)
Main Office	Mean	903.33	0.00	16.31	26.64	5.14
	Min	778.00	0.00	11.30	22.00	3.00
	Max	1048.00	0.00	20.60	57.00	12.00
Room 6S1	Mean	1010.25	0.00	19.32	22.92	6.00
	Min	992.00	0.00	19.00	22.00	3.00
	Max	1040.00	0.00	20.20	24.00	22.00
Room 4V2	Mean	1179.40	0.00	20.21	22.30	5.60
	Min	1048.00	0.00	20.10	22.00	3.00
	Max	1240.00	0.00	20.39	24.00	13.00
Room 5T4	Mean	1137.63	0.00	20.74	21.31	6.73
	Min	1074.00	0.00	20.39	21.00	3.00
	Max	1216.00	0.00	21.00	23.00	65.00
Room 4/5 D6	Mean	1002.33	0.00	21.31	20.72	6.08
	Min	974.00	0.00	20.20	20.00	4.00
	Max	1064.00	0.00	21.70	22.00	8.00
Room 4W7	Mean	1083.17	0.00	21.09	21.96	7.94
	Min	970.00	0.00	20.70	21.00	5.00
	Max	1152.00	0.00	21.50	23.00	14.00
Room 3J12	Mean	1094.17	0.00	22.14	20.83	6.78
	Min	1080.00	0.00	21.40	20.00	5.00
	Max	1134.00	0.00	22.70	23.00	15.00
Room 3R13	Mean	1322.00	0.00	22.28	22.80	12.81
	Min	1216.00	0.00	20.90	22.00	4.00
	Max	1580.00	0.00	22.50	24.00	175.00
Room 2P10	Mean	1038.89	0.00	21.27	19.78	6.58
	Min	984.00	0.00	20.30	18.00	4.00
	Max	1208.00	0.00	22.00	24.00	25.00
Room 2W18	Mean	1090.17	0.00	20.38	22.78	5.39
	Min	1048.00	0.00	19.80	22.00	4.00
	Max	1110.00	0.00	21.00	24.00	11.00

School D Cont.						
Room1P17	Mean	1095.00	0.00	20.28	22.21	5.68
	Min	1090.00	0.00	19.89	22.00	4.00
	Max	1102.00	0.00	20.39	23.00	10.00
Room 1/2 16	Mean	1185.67	0.00	20.53	24.00	9.21
	Min	1110.00	0.00	20.30	24.00	4.00
	Max	1248.00	0.00	20.60	24.00	35.00
Room 1H15	Mean	1190.52	0.00	20.44	22.44	5.77
	Min	1118.00	0.00	20.00	22.00	4.00
	Max	903.33	0.00	16.31	26.64	5.14

School E

		CO_2 (ppm)	CO (ppm)	TEMPERATURE (ºC)	RH (%)	PM_{10} ($\mu g/m^3$)
Main Office	Mean	848.48	0.00	20.46	22.90	3.90
	Min	812.00	0.00	19.70	20.00	1.00
	Max	936.00	0.00	21.00	24.00	22.00
Room 5	Mean	1168.17	0.00	20.75	19.69	3.46
	Min	946.00	0.00	20.50	19.00	2.00
	Max	1740.00	0.00	21.70	21.00	6.00
Room 6	Mean	961.67	0.00	21.98	19.61	4.73
	Min	948.00	0.00	21.60	19.00	3.00
	Max	1008.00	0.00	22.60	20.00	11.00
Room 7	Mean	1317.33	0.00	22.82	20.47	4.11
	Min	994.00	0.00	22.20	19.00	3.00
	Max	1800.00	0.00	23.20	22.00	10.00
Room 32	Mean	1359.20	0.00	22.30	21.00	4.47
	Min	1070.00	0.00	21.60	21.00	2.00
	Max	1766.00	0.00	22.50	21.00	20.00
Room 29	Mean	985.93	0.00	21.71	21.27	8.42
	Min	952.00	0.00	20.90	21.00	3.00
	Max	1052.00	0.00	22.00	22.00	9.00
Room 30	Mean	1062.83	0.00	22.05	21.79	4.73
	Min	1012.00	0.00	21.60	21.00	3.00
	Max	1106.00	0.00	22.40	23.00	10.00
Room 27	Mean	991.93	0.00	22.20	21.53	4.43
	Min	970.00	0.00	20.80	20.00	3.00
	Max	1044.00	0.00	22.70	25.00	12.00
Room 18	Mean	1013.83	0.00	21.29	24.92	4.75
	Min	996.00	0.00	20.80	24.00	3.00
	Max	1034.00	0.00	21.50	26.00	21.00
Room 15	Mean	986.17	0.00	21.34	24.13	13.48
	Min	974.00	0.00	20.80	24.00	3.00
	Max	1002.00	0.00	21.50	25.00	222.00

School F

		CO_2 (ppm)	CO (ppm)	TEMPERATURE (°C)	RH (%)	PM_{10} (µg/m^3)
Main Office	Mean	1218.56	0.00	20.02	25.59	6.18
	Min	844.00	0.00	17.30	22.00	1.00
	Max	1638.00	0.00	21.20	32.00	23.00
Room 2	Mean	968.75	0.00	21.27	23.21	3.59
	Min	930.00	0.00	20.90	22.00	2.00
	Max	1080.00	0.00	21.60	25.00	5.00
Room 3	Mean	1122.33	0.00	21.48	24.38	4.38
	Min	1096.00	0.00	21.30	24.00	2.00
	Max	1142.00	0.00	21.60	25.00	12.00
Room 5	Mean	1119.05	0.00	22.35	23.81	6.35
	Min	984.00	0.00	21.30	18.00	3.00
	Max	1210.00	0.00	24.70	25.00	44.00
Room 6	Mean	1324.13	0.00	21.76	24.40	7.58
	Min	1106.00	0.00	20.30	22.00	3.00
	Max	1880.00	0.00	22.90	26.00	43.00
Room 25	Mean	1069.92	0.00	19.17	26.29	4.21
	Min	936.00	0.00	14.00	24.00	4.00
	Max	1336.00	0.00	21.50	31.00	31.00
Room 21	Mean	1171.08	0.00	21.67	22.67	18.00
	Min	1062.00	0.00	21.20	18.00	3.00
	Max	1398.00	0.00	22.40	27.00	160.00
Room 27	Mean	1060.67	0.00	21.58	20.80	10.58
	Min	1014.00	0.00	20.90	19.00	4.00
	Max	1078.00	0.00	21.90	22.00	22.00
Room 26	Mean	1008.50	0.00	21.12	20.42	8.31
	Min	1000.00	0.00	20.50	20.00	5.00
	Max	1024.00	0.00	21.50	21.00	26.00
Room 22	Mean	1038.33	0.00	20.88	21.25	7.36
	Min	1028.00	0.00	20.60	21.00	4.00
	Max	1046.00	0.00	21.20	22.00	13.00

School F Cont.						
Room 23	Mean	1038.44	0.00	20.63	20.33	6.20
	Min	1030.00	0.00	20.50	20.00	5.00
	Max	1044.00	0.00	20.70	21.00	9.00

School G

		CO_2 (ppm)	CO (ppm)	TEMPERATURE (°C)	RH (%)	PM_{10} (μg/m^3)
Main Office	Mean	1007.70	0.00	21.68	26.11	8.27
	Min	908.00	0.00	21.00	24.00	4.00
	Max	1490.00	0.00	22.00	29.00	25.00
Room 15	Mean	1229.43	0.00	22.07	29.21	5.88
	Min	1204.00	0.00	21.80	28.00	4.00
	Max	1288.00	0.00	22.20	30.00	12.00
Room 14	Mean	1218.58	0.00	21.58	28.79	6.83
	Min	1098.00	0.00	21.10	27.00	3.00
	Max	1278.00	0.00	21.90	30.00	28.00
Room 16	Mean	1016.42	0.00	21.60	27.00	5.20
	Min	986.00	0.00	21.20	27.00	3.00
	Max	1082.00	0.00	22.20	27.00	10.00
Room 17	Mean	992.89	0.00	22.16	27.44	6.79
	Min	966.00	0.00	21.10	26.00	4.00
	Max	1070.00	0.00	22.70	29.00	19.00
Room 18	Mean	1072.83	0.00	21.77	26.58	6.08
	Min	890.00	0.00	20.90	23.00	4.00
	Max	1216.00	0.00	22.60	29.00	10.00
Room 8	Mean	878.00	0.00	22.50	23.75	5.09
	Min	866.00	0.00	22.10	23.00	3.00
	Max	886.00	0.00	22.90	24.00	6.00
Room 7	Mean	843.00	0.00	22.07	23.17	8.82
	Min	830.00	0.00	21.50	23.00	7.00
	Max	860.00	0.00	22.30	24.00	13.00
Room 6	Mean	764.92	0.00	21.82	22.75	0.014727
	Min	728.00	0.00	21.30	22.00	0.008
	Max	818.00	0.00	22.20	24.00	0.058
Room 4	Mean	893.27	0.00	21.79	26.50	0.009625
	Min	812.00	0.00	21.00	23.00	0.008
	Max	1002.00	0.00	22.30	30.00	0.013

School H

		CO_2 (ppm)	CO (ppm)	TEMPERATURE (°C)	RH (%)	PM_{10} (µg/m^3)
Main Office	Mean	1022.84	0.00	18.53	32.83	13.97
	Min	944.00	0.00	10.80	28.00	6.00
	Max	1102.00	0.00	21.80	50.00	204.00
Room 12	Mean	1031.07	0.00	22.18	27.57	11.00
	Min	1008.00	0.00	21.80	27.00	8.00
	Max	1064.00	0.00	22.50	30.00	17.00
Room 18	Mean	1189.50	0.00	22.63	29.00	12.60
	Min	1078.00	0.00	22.10	27.00	8.00
	Max	1260.00	0.00	22.90	30.00	21.00
Room 17	Mean	1064.67	0.00	22.48	26.72	12.33
	Min	996.00	0.00	22.40	25.00	8.00
	Max	1138.00	0.00	22.60	27.00	24.00
Room 13	Mean	919.40	0.00	22.52	25.00	5.94
	Min	848.00	0.00	21.80	22.00	4.00
	Max	1108.00	0.00	23.00	27.00	10.00
Music Room	Mean	871.58	0.00	21.92	23.40	17.58
	Min	792.00	0.00	21.30	22.00	12.00
	Max	1076.00	0.00	22.90	28.00	30.00
Room 11	Mean	928.11	0.00	22.84	25.78	14.58
	Min	888.00	0.00	21.80	25.00	11.00
	Max	944.00	0.00	23.40	27.00	35.00
Room 10	Mean	859.13	0.00	22.95	25.06	13.61
	Min	846.00	0.00	22.70	25.00	9.00
	Max	882.00	0.00	23.00	26.00	29.00
Room 4	Mean	864.13	0.00	22.41	28.40	12.46
	Min	838.00	0.00	21.50	27.00	8.00
	Max	894.00	0.00	22.70	30.00	17.00
Room 5	Mean	921.43	0.00	21.40	29.50	7.68
	Min	898.00	0.00	21.10	29.00	2.00
	Max	942.00	0.00	21.60	30.00	70.00

School I

		CO_2 (ppm)	CO (ppm)	TEMPERATURE (°C)	RH (%)	PM_{10} ($\mu g/m^3$)
Main Office	Mean	1029.71	0.00	21.17	35.96	7.62
	Min	918.00	0.00	17.30	32.00	3.00
	Max	1552.00	0.00	22.70	49.00	58.00
Room 3	Mean	1415.11	0.00	22.71	47.56	9.18
	Min	1184.00	0.00	22.00	46.00	4.00
	Max	1524.00	0.00	23.00	48.00	32.00
Room 16	Mean	1469.44	0.00	21.61	48.53	5.91
	Min	1356.00	0.00	21.00	47.00	3.00
	Max	1520.00	0.00	22.10	51.00	17.00
Room 4	Mean	1568.77	0.00	21.23	48.60	15.21
	Min	1310.00	0.00	20.39	17.00	5.00
	Max	1710.00	0.00	21.70	52.00	120.00
Room 14	Mean	1549.75	0.00	21.83	49.71	6.56
	Min	1324.00	0.00	20.60	46.00	3.00
	Max	1756.00	0.00	22.30	51.00	15.00
Room 13	Mean	1472.53	0.00	22.73	46.10	5.90
	Min	1440.00	0.00	21.60	44.00	3.00
	Max	1520.00	0.00	23.40	50.00	28.00

School J

		CO_2 (ppm)	CO (ppm)	TEMPERATURE (°C)	RH (%)	PM_{10} (µg/m^3)
Main Office	Mean	602.47	0.00	21.54	25.75	6.37
	Min	562.00	0.00	19.80	24.00	5.00
	Max	668.00	0.00	22.70	28.00	13.00
Room 3	Mean	616.00	0.00	21.31	26.17	6.40
	Min	592.00	0.00	21.00	26.00	6.00
	Max	660.00	0.00	21.50	27.00	7.00
Room 1	Mean	652.89	0.00	22.11	27.28	7.00
	Min	596.00	0.00	20.90	26.00	6.00
	Max	688.00	0.00	22.50	28.00	9.00
Room 2	Mean	699.45	0.00	22.05	27.36	6.67
	Min	688.00	0.00	21.60	26.00	6.00
	Max	716.00	0.00	22.30	28.00	9.00

School K

		CO_2 (ppm)	CO (ppm)	TEMPERATURE (°C)	RH (%)	PM_{10} (µg/m^3)
Main Office	Mean	929.58	0.00	20.61	20.49	7.44
	Min	748.00	0.00	18.70	17.00	2.00
	Max	1120.00	0.00	21.40	25.00	76.00
Room 20	Mean	1224.42	0.00	21.18	25.21	12.61
	Min	1022.00	0.00	21.00	22.00	4.00
	Max	1328.00	0.00	21.70	27.00	52.00
Room 19	Mean	1385.67	0.00	21.35	25.83	6.08
	Min	1116.00	0.00	21.00	22.00	4.00
	Max	1516.00	0.00	21.50	27.00	14.00
Room 18	Mean	1113.58	0.00	21.53	21.38	7.75
	Min	646.00	0.00	20.50	16.00	5.00
	Max	1308.00	0.00	21.90	23.00	14.00
Room 4	Mean	485.71	0.02	20.77	15.95	6.74
	Min	444.00	0.00	20.39	15.00	4.00
	Max	628.00	1.00	21.30	16.00	12.00
Room 3	Mean	421.67	0.00	21.57	15.06	6.58
	Min	412.00	0.00	21.30	15.00	5.00
	Max	438.00	0.00	21.70	16.00	8.00
Room 7	Mean	409.00	0.00	21.67	15.39	6.70
	Min	396.00	0.00	21.10	15.00	5.00
	Max	418.00	0.00	21.80	16.00	23.00
Room 1	Mean	646.05	0.00	21.84	17.62	6.67
	Min	412.00	0.00	20.60	15.00	5.00
	Max	758.00	0.00	22.20	19.00	12.00
Room 8	Mean	545.11	0.00	21.45	16.33	6.42
	Min	508.00	0.00	20.80	15.00	5.00
	Max	660.00	0.00	22.10	18.00	9.00
Room 9	Mean	776.22	0.06	22.29	17.39	6.55
	Min	686.00	0.00	21.90	17.00	5.00
	Max	836.00	1.00	22.50	18.00	9.00
Room 10	Mean	851.54	0.08	22.04	18.00	12.25
	Min	840.00	0.00	22.00	18.00	8.00
	Max	862.00	1.00	22.10	18.00	26.00

School L

		CO_2 (ppm)	CO (ppm)	TEMPERATURE (ºC)	RH (%)	PM_{10} ($\mu g/m^3$)
Main Office	Mean	1526.19	0.12	21.64	25.56	6.93
	Min	1370.00	0.00	19.89	22.00	4.00
	Max	1892.00	1.00	22.50	30.00	17.00
Room 8	Mean	1218.50	0.06	22.67	21.97	6.87
	Min	1086.00	0.00	21.70	20.00	5.00
	Max	1504.00	1.00	23.10	28.00	26.00
Room 17	Mean	1553.67	0.13	23.03	25.42	7.57
	Min	1492.00	0.00	21.60	23.00	5.00
	Max	1572.00	1.00	23.60	27.00	13.00
Room 18	Mean	1085.86	0.10	23.09	21.79	6.22
	Min	972.00	0.00	22.70	21.00	5.00
	Max	1326.00	1.00	23.20	25.00	19.00
Room 9	Mean	1227.22	0.28	22.79	23.00	6.18
	Min	1176.00	0.00	22.30	22.00	5.00
	Max	1288.00	1.00	23.30	24.00	12.00
Room 10	Mean	1358.33	0.25	23.41	24.08	5.38
	Min	1304.00	0.00	23.20	23.00	5.00
	Max	1410.00	1.00	23.70	25.00	6.00
Room 11	Mean	1428.50	0.42	23.53	24.42	5.57
	Min	1412.00	0.00	22.90	23.00	5.00
	Max	1486.00	1.00	23.90	27.00	7.00
Room 12	Mean	1378.58	0.23	22.81	23.90	10.88
	Min	1208.00	0.00	20.50	23.00	6.00
	Max	1538.00	1.00	23.40	26.00	34.00
Room 2	Mean	1789.17	0.42	21.88	30.13	12.60
	Min	1274.00	0.00	21.30	27.00	7.00
	Max	1936.00	1.00	22.00	31.00	55.00
Room 3	Mean	1952.17	0.50	22.08	30.75	11.43
	Min	1920.00	0.00	21.70	29.00	6.00
	Max	2082.00	1.00	22.20	33.00	21.00
Room 4	Mean	1717.57	0.32	22.02	28.11	9.50
	Min	1216.00	0.00	20.90	22.00	6.00
	Max	2408.00	1.00	22.90	35.00	14.00

School M

		CO_2 (ppm)	CO (ppm)	TEMPERATURE (°C)	RH (%)	PM_{10} ($\mu g/m^3$)
Main Office	Mean	1215.03	0.00	17.43	31.44	3.86
	Min	1142.00	0.00	10.70	26.00	1.00
	Max	1272.00	0.00	20.90	40.00	26.00
Room 14	Mean	1196.08	0.00	20.04	25.54	1.81
	Min	1164.00	0.00	19.70	24.00	1.00
	Max	1238.00	0.00	21.00	26.00	7.00
Room 12	Mean	1210.52	0.00	22.03	24.60	3.75
	Min	1136.00	0.00	21.10	23.00	1.00
	Max	1442.00	0.00	22.60	30.00	22.00
Room 11	Mean	1692.93	0.00	22.44	29.50	4.32
	Min	1308.00	0.00	21.90	20.00	1.00
	Max	1878.00	0.00	22.60	32.00	13.00
Room 9	Mean	1077.44	0.00	22.09	19.89	3.33
	Min	948.00	0.00	21.60	19.00	2.00
	Max	1266.00	0.00	22.20	21.00	8.00
Room 10	Mean	1310.87	0.00	22.71	27.50	4.82
	Min	960.00	0.00	21.40	24.00	1.00
	Max	1536.00	0.00	23.40	30.00	15.00
Room 4	Mean	1135.88	0.00	21.94	27.94	4.36
	Min	1108.00	0.00	21.70	27.00	2.00
	Max	1154.00	0.00	22.10	30.00	22.00
Room 1	Mean	1432.42	0.00	22.76	29.33	2.71
	Min	1108.00	0.00	21.40	24.00	2.00
	Max	1644.00	0.00	23.40	31.00	8.00

School N

		CO_2 (ppm)	CO (ppm)	TEMPERATURE (°C)	RH (%)	PM_{10} (µg/m^3)
Main Office	Mean	931.08	0.00	21.47	22.65	5.74
	Min	692.00	0.00	20.20	18.00	3.00
	Max	1098.00	0.00	22.30	27.00	27.00
Room 17	Mean	1121.22	0.00	22.51	23.22	5.50
	Min	974.00	0.00	22.30	23.00	3.00
	Max	1240.00	0.00	22.90	24.00	25.00
Room 16	Mean	856.08	0.00	22.96	19.25	3.38
	Min	738.00	0.00	22.70	18.00	3.00
	Max	1224.00	0.00	23.30	22.00	5.00
Room 14	Mean	844.80	0.00	23.00	20.50	5.41
	Min	776.00	0.00	21.10	19.00	3.00
	Max	884.00	0.00	23.70	26.00	11.00
Room 4	Mean	889.56	0.00	21.71	26.78	81.58
	Min	798.00	0.00	19.39	26.00	4.00
	Max	1030.00	0.00	22.40	30.00	26.00
Room 2	Mean	981.00	0.00	20.92	29.17	14.18
	Min	956.00	0.00	19.89	28.00	7.00
	Max	1002.00	0.00	21.20	30.00	45.00
Room 1	Mean	805.69	0.00	20.77	27.62	7.83
	Min	732.00	0.00	19.80	27.00	4.00
	Max	950.00	0.00	21.20	28.00	14.00

School O

		CO_2 (ppm)	CO (ppm)	TEMPERATURE (ºC)	RH (%)	PM_{10} ($\mu g/m^3$)
Main Office	Mean	770.77	0.00	21.94	24.21	14.17
	Min	670.00	0.00	21.20	23.00	9.00
	Max	1272.00	0.00	22.40	27.00	32.00
Room 2	Mean	1234.50	0.00	21.28	32.50	16.31
	Min	938.00	0.00	20.80	26.00	12.00
	Max	1368.00	0.00	21.50	36.00	27.00
Room 3	Mean	1058.17	0.00	21.33	25.83	14.14
	Min	980.00	0.00	20.90	25.00	8.00
	Max	1198.00	0.00	21.40	26.00	41.00
Room 4	Mean	849.00	0.00	21.35	24.23	12.22
	Min	788.00	0.00	20.80	23.00	8.00
	Max	956.00	0.00	21.50	27.00	18.00
Room 18	Mean	886.17	0.00	21.36	27.08	14.65
	Min	822.00	0.00	21.10	27.00	10.00
	Max	908.00	0.00	21.60	28.00	34.00
Room 19	Mean	892.17	0.00	21.22	27.50	15.13
	Min	872.00	0.00	20.30	27.00	10.00
	Max	918.00	0.00	21.80	30.00	20.00
Room 17	Mean	1132.00	0.00	21.28	31.11	14.22
	Min	938.00	0.00	20.39	22.00	10.00
	Max	1382.00	0.00	21.90	36.00	21.00
Library	Mean	776.11	0.00	21.26	22.28	13.33
	Min	640.00	0.00	20.70	21.00	11.00
	Max	1058.00	0.00	21.70	30.00	19.00
Room 11	Mean	1349.33	0.00	21.78	30.00	13.20
	Min	1242.00	0.00	21.30	26.00	8.00
	Max	1416.00	0.00	22.00	31.00	20.00
Room 10	Mean	1415.17	0.00	22.16	31.58	13.38
	Min	1362.00	0.00	21.30	27.00	8.00
	Max	1494.00	0.00	22.50	33.00	19.00
Room 8	Mean	1105.36	0.00	21.73	27.43	12.00
	Min	760.00	0.00	20.70	24.00	8.00
	Max	1902.00	0.00	22.20	34.00	22.00

School P

		CO_2 (ppm)	CO (ppm)	TEMPERATURE (°C)	RH (%)	PM_{10} (µg/m^3)
Main Office	Mean	1033.76	0.00	22.24	27.05	13.21
	Min	908.00	0.00	20.80	26.00	8.00
	Max	1114.00	0.00	23.00	30.00	20.00
Room 6	Mean	1042.80	0.00	22.65	28.00	11.24
	Min	1028.00	0.00	22.30	28.00	8.00
	Max	1058.00	0.00	22.70	28.00	14.00
Room 5	Mean	1135.08	0.00	21.67	29.92	18.15
	Min	1032.00	0.00	21.10	28.00	14.00
	Max	1186.00	0.00	22.00	31.00	23.00
Room 3	Mean	1144.00	0.00	21.90	30.17	11.24
	Min	1092.00	0.00	21.70	29.00	13.00
	Max	1246.00	0.00	22.20	32.00	24.00
Room 2	Mean	1212.83	0.00	22.23	31.92	18.14
	Min	1182.00	0.00	22.00	31.00	12.00
	Max	1240.00	0.00	22.30	32.00	24.00
Room 1	Mean	1264.93	0.00	22.60	30.73	17.89
	Min	1188.00	0.00	22.30	30.00	8.00
	Max	1486.00	0.00	22.80	33.00	23.00

School Q

		CO_2 (ppm)	CO (ppm)	TEMPERATURE (°C)	RH (%)	PM_{10} (µg/m^3)
Main Office	Mean	863.16	0.00	19.54	36.20	4.78
	Min	690.00	0.00	14.60	33.00	2.00
	Max	1026.00	0.00	21.20	43.00	24.00
Room 11	Mean	868.75	0.00	21.41	35.75	6.42
	Min	790.00	0.00	21.10	34.00	3.00
	Max	912.00	0.00	21.60	37.00	25.00
Room 12	Mean	827.83	0.00	21.34	35.33	3.25
	Min	810.00	0.00	20.60	34.00	2.00
	Max	848.00	0.00	21.70	41.00	5.00
Room 14	Mean	858.50	0.00	21.67	36.58	5.40
	Min	810.00	0.00	21.40	36.00	2.00
	Max	904.00	0.00	21.80	38.00	14.00
Room 15	Mean	1015.11	0.00	22.11	36.83	5.46
	Min	924.00	0.00	21.40	36.00	3.00
	Max	1054.00	0.00	22.40	38.00	17.00
Room 16	Mean	785.32	0.00	21.61	33.85	4.20
	Min	738.00	0.00	15.30	32.00	3.00
	Max	980.00	0.00	22.80	41.00	5.00

School R

		CO_2 (ppm)	CO (ppm)	TEMPERATURE (°C)	RH (%)	PM_{10} (µg/m^3)
Room 9	Mean	574.50	0.00	20.00	28.83	6.44
	Min	540.00	0.00	19.80	28.00	5.00
	Max	628.00	0.00	20.50	31.00	11.00
Room 7	Mean	676.00	0.00	20.48	28.63	8.48
	Min	552.00	0.00	19.89	28.00	5.00
	Max	732.00	0.00	20.60	33.00	35.00
Room 24	Mean	576.86	0.00	21.83	26.71	6.29
	Min	522.00	0.00	20.10	26.00	4.00
	Max	618.00	0.00	22.90	29.00	14.00
Room 22	Mean	514.40	0.00	20.99	27.40	5.70
	Min	472.00	0.00	20.70	27.00	5.00
	Max	546.00	0.00	21.40	28.00	8.00
Room 19	Mean	552.17	0.00	21.72	27.25	7.18
	Min	548.00	0.00	21.50	27.00	5.00
	Max	556.00	0.00	22.10	28.00	9.00
Room 16	Mean	602.00	0.00	21.55	28.50	7.71
	Min	552.00	0.00	21.30	28.00	6.00
	Max	980.00	0.00	22.20	30.00	11.00
Main Office	Mean	647.80	0.00	22.07	27.27	8.10
	Min	594.00	0.00	21.50	27.00	5.00
	Max	964.00	0.00	22.40	29.00	13.00

School S

		CO_2 (ppm)	CO (ppm)	TEMPERATURE (°C)	RH (%)	PM_{10} (µg/m^3)
Main Office	Mean	1261.20	0.00	20.47	44.17	6.75
	Min	1202.00	0.00	19.70	41.00	3.00
	Max	1304.00	0.00	21.00	54.00	11.00
Room 8	Mean	1074.11	0.00	19.83	54.28	37.36
	Min	1000.00	0.00	19.20	51.00	2.00
	Max	1198.00	0.00	20.50	57.00	379.00
Room 7	Mean	1158.17	0.00	20.69	49.33	4.40
	Min	1094.00	0.00	20.20	48.00	1.00
	Max	1198.00	0.00	21.10	50.00	15.00
Room 6	Mean	1125.53	0.00	20.91	49.00	6.44
	Min	1104.00	0.00	20.50	48.00	1.00
	Max	1156.00	0.00	21.10	50.00	33.00
Room 5	Mean	1233.50	0.00	20.81	49.54	3.36
	Min	1132.00	0.00	20.39	47.00	2.00
	Max	1612.00	0.00	21.30	54.00	6.00
Room 4	Mean	1744.29	0.00	21.43	51.90	7.92
	Min	1550.00	0.00	21.10	50.00	1.00
	Max	1800.00	0.00	21.50	53.00	33.00
Room 12	Mean	1453.48	0.00	21.73	47.78	4.34
	Min	1412.00	0.00	21.40	44.00	1.00
	Max	1636.00	0.00	23.30	50.00	15.00
Room 13	Mean	1637.00	0.00	22.03	45.89	4.93
	Min	1504.00	0.00	20.70	37.00	1.00
	Max	1710.00	0.00	24.80	50.00	17.00
Room 14	Mean	1048.94	0.00	21.15	42.81	3.00
	Min	644.00	0.00	19.30	38.00	1.00
	Max	1500.00	0.00	22.00	48.00	5.00

School T

		CO_2 (ppm)	CO (ppm)	TEMPERATURE (ºC)	RH (%)	PM_{10} (µg/m^3)
Main Office	Mean	900.60	0.00	19.01	32.80	16.00
	Min	722.00	0.00	17.10	32.00	9.00
	Max	1124.00	0.00	20.39	36.00	25.00
Room 5	Mean	803.57	0.00	20.43	34.96	4.43
	Min	728.00	0.00	20.00	32.00	1.00
	Max	832.00	0.00	21.30	36.00	12.00
Room 6	Mean	821.17	0.00	20.96	32.75	4.50
	Min	810.00	0.00	20.00	32.00	2.00
	Max	838.00	0.00	21.60	34.00	13.00
Room 28	Mean	911.27	0.00	20.22	33.23	3.36
	Min	852.00	0.00	19.70	32.00	1.00
	Max	958.00	0.00	20.90	37.00	11.00
Room 31	Mean	999.00	0.00	21.04	34.83	6.70
	Min	906.00	0.00	20.30	33.00	2.00
	Max	1048.00	0.00	21.30	36.00	22.00
Room 38	Mean	799.39	0.00	20.67	32.13	43.83
	Min	768.00	0.00	20.20	32.00	3.00
	Max	888.00	0.00	20.80	34.00	472.00
Room 40	Mean	1037.60	0.00	20.98	39.08	4.89
	Min	774.00	0.00	20.60	35.00	1.00
	Max	1158.00	0.00	21.20	40.00	21.00
Room 39	Mean	1079.22	0.00	21.11	36.67	3.19
	Min	860.00	0.00	20.30	30.00	1.00
	Max	1190.00	0.00	21.50	40.00	6.00
Room 19	Mean	871.83	0.00	21.53	33.08	6.00
	Min	860.00	0.00	21.30	31.00	3.00
	Max	884.00	0.00	21.70	34.00	10.00
Room 20	Mean	753.05	0.00	21.68	30.67	5.46
	Min	684.00	0.00	20.80	30.00	3.00
	Max	852.00	0.00	22.00	32.00	13.00

School U

		CO_2 (ppm)	CO (ppm)	TEMPERATURE (°C)	RH (%)	PM_{10} ($\mu g/m^3$)
Main Office	Mean	1106.41	0.00	17.72	32.65	12.80
	Min	672.00	0.00	13.70	29.00	8.00
	Max	2328.00	0.00	20.50	36.00	23.00
Room 32	Mean	958.50	0.00	20.67	34.42	12.80
	Min	942.00	0.00	20.50	33.00	8.00
	Max	1004.00	0.00	20.80	35.00	26.00
Room 31	Mean	872.17	0.00	20.55	35.06	10.27
	Min	770.00	0.00	20.30	32.00	6.00
	Max	1020.00	0.00	21.10	36.00	21.00
Room 29	Mean	746.08	0.00	21.85	30.47	12.78
	Min	720.00	0.00	21.10	28.00	8.00
	Max	788.00	0.00	22.20	32.00	52.00
Room 30	Mean	825.67	0.00	22.12	32.04	10.29
	Min	792.00	0.00	20.90	30.00	7.00
	Max	836.00	0.00	22.50	33.00	27.00
Room 28	Mean	857.33	0.00	21.29	31.83	6.92
	Min	828.00	0.00	20.60	31.00	5.00
	Max	890.00	0.00	21.50	32.00	8.00
Room 26	Mean	847.70	0.00	21.30	29.89	13.81
	Min	722.00	0.00	20.50	27.00	10.00
	Max	890.00	0.00	21.60	31.00	22.00
Room 3	Mean	848.67	0.00	21.06	30.11	14.92
	Min	724.00	0.00	20.60	29.00	12.00
	Max	896.00	0.00	21.30	31.00	23.00
Room 5	Mean	856.50	0.00	21.24	30.13	14.58
	Min	828.00	0.00	20.80	30.00	12.00
	Max	950.00	0.00	21.40	31.00	21.00

School V

		CO_2 (ppm)	CO (ppm)	TEMPERATURE (ºC)	RH (%)	PM_{10} ($\mu g/m^3$)
Main Office	Mean	826.05	0.00	20.24	33.44	11.06
	Min	548.00	0.00	5.20	30.00	8.00
	Max	956.00	0.00	22.70	66.00	29.00
Room 3	Mean	819.33	0.00	22.27	30.08	10.85
	Min	802.00	0.00	22.20	30.00	8.00
	Max	840.00	0.00	22.30	31.00	14.00
Room 4	Mean	793.17	0.00	22.33	29.67	9.13
	Min	770.00	0.00	22.00	29.00	8.00
	Max	806.00	0.00	22.50	31.00	11.00
Room 5	Mean	973.00	0.00	22.41	30.28	13.00
	Min	754.00	0.00	22.30	29.00	8.00
	Max	1090.00	0.00	22.50	31.00	29.00
Room 6	Mean	914.00	0.00	22.30	31.00	17.29
	Min	818.00	0.00	20.90	30.00	8.00
	Max	1022.00	0.00	22.80	33.00	65.00
Room 12	Mean	778.33	0.00	22.29	29.50	10.70
	Min	766.00	0.00	21.70	29.00	8.00
	Max	808.00	0.00	22.50	31.00	19.00
Room 11	Mean	770.67	0.00	22.29	30.17	8.78
	Min	764.00	0.00	21.80	30.00	7.00
	Max	780.00	0.00	22.60	31.00	10.00
Room 10	Mean	793.22	0.00	22.21	29.67	9.88
	Min	780.00	0.00	21.60	29.00	8.00
	Max	802.00	0.00	22.40	30.00	12.00
Room 16	Mean	776.56	0.00	22.21	30.00	9.32
	Min	768.00	0.00	21.60	30.00	7.00
	Max	784.00	0.00	22.40	30.00	19.00
Room 15	Mean	763.60	0.00	22.35	29.75	9.09
	Min	756.00	0.00	21.20	28.00	7.00
	Max	776.00	0.00	23.20	31.00	19.00

School W

		CO_2 (ppm)	CO (ppm)	TEMPERATURE (ºC)	RH (%)	PM_{10} ($\mu g/m^3$)
Main Office	Mean	1031.52	0.00	20.86	26.48	6.33
	Min	884.00	0.00	19.89	23.00	4.00
	Max	1094.00	0.00	21.30	29.00	11.00
Room 21	Mean	832.92	0.00	21.08	23.25	5.36
	Min	810.00	0.00	21.00	23.00	3.00
	Max	876.00	0.00	21.30	24.00	9.00
Room 22	Mean	870.83	0.00	21.18	24.00	5.83
	Min	848.00	0.00	20.90	24.00	4.00
	Max	884.00	0.00	21.30	24.00	9.00
Room 19	Mean	821.41	0.00	21.11	23.24	5.41
	Min	808.00	0.00	20.80	23.00	3.00
	Max	844.00	0.00	21.20	25.00	7.00
Room 20	Mean	886.56	0.00	21.36	26.17	62.86
	Min	816.00	0.00	20.80	26.00	4.00
	Max	936.00	0.00	21.80	27.00	9.00
Room 15	Mean	990.83	0.00	21.97	25.25	9.00
	Min	950.00	0.00	21.70	23.00	6.00
	Max	1020.00	0.00	22.20	26.00	17.00
Room 16	Mean	878.33	0.00	21.90	22.75	8.60
	Min	820.00	0.00	21.20	22.00	5.00
	Max	970.00	0.00	22.10	27.00	25.00
Room 11	Mean	860.33	0.00	22.11	24.42	10.33
	Min	834.00	0.00	21.80	24.00	6.00
	Max	892.00	0.00	22.30	25.00	15.00
Room 12	Mean	991.89	0.00	22.33	25.67	6.67
	Min	904.00	0.00	20.50	25.00	5.00
	Max	1068.00	0.00	23.10	27.00	10.00
Room 2	Mean	625.07	0.00	20.74	24.71	6.70
	Min	1076.00	0.00	22.20	25.00	4.00
	Max	1142.00	0.00	22.70	26.00	11.00
Room 1	Mean	1061.11	0.00	21.63	25.00	7.20
	Min	1048.00	0.00	12.70	25.00	5.00
	Max	1088.00	0.00	22.80	25.00	11.00

School X

		CO_2 (ppm)	CO (ppm)	TEMPERATURE (°C)	RH (%)	PM_{10} ($\mu g/m^3$)
Main Office	Mean	541.17	0.00	19.79	23.63	0.01
	Min	534.00	0.00	18.89	22.00	0.01
	Max	566.00	0.00	21.50	24.00	0.02
Room 13	Mean	611.75	0.00	21.41	23.21	0.01
	Min	572.00	0.00	20.90	22.00	0.01
	Max	680.00	0.00	21.90	29.00	0.02
Room 6	Mean	902.50	0.00	22.10	29.13	0.01
	Min	722.00	0.00	21.90	27.00	0.01
	Max	978.00	0.00	22.30	31.00	0.02
Room 3	Mean	1099.81	0.00	22.41	27.43	0.01
	Min	986.00	0.00	21.40	27.00	0.01
	Max	1154.00	0.00	22.70	29.00	0.02
Room 2	Mean	915.64	0.00	21.20	25.05	0.01
	Min	814.00	0.00	20.60	25.00	0.01
	Max	1058.00	0.00	21.70	26.00	0.02

APPENDIX II
RADON RESULTS

Average Radon Concentrations Measured

Location		Radon Concentration (Bq/m³)
School Y	Room 101-B	24.4
	Room 102	24.3
	Room 103	28.9
	Room 104	28.8
	Room L1	33.3
	Room - L2	31.1
	Room - L3	24.2
	Room - L4	28.6
	Room - L5	19.7
	Room - L6	21.9
	Room - L7	31.0
	Room - L8	24.3
School Z	Room - 101	70.1
	Room - 102	24.3
	Room - 103	69.5
	Room - 104	69.9
	Room - 105	53.9
	Room - 106	61.0
	Room - 107	49.2
	Room - 108	61.0
	Room - 109	51.6
	Room - 110	58.2
School X	Room - 7	26.1
	Room - 8	21.9
	Room - 9	10.5
	Room - 10	10.4
	Speech Office	38.0
	Staff Room	56.5
	Custodian Office	67.6

Average Radon Concentrations Measured Cont.

Location		Radon Concentration (Bq/m³)
School AA	Room - B11	23.9
	Room - Basement 456	26.5
	Boiler Room	31.2
	Cafeteria	21.9
	Canteen	29.0
School E	Tech Lab	29.2
	Theatre	29.8
School BA	Cafeteria	181.6
	Cardio Room	97.3
	Custodian Office	76.5
	HVAC Room	143.7
	Kitchen	80.9
	Weight Room	77.0
School CA	Basement PE/Health	48.7
	Cafeteria	60.5
	Crawlspace	129.8
	Kitchen	44.4
School V	Music Room	67.8
School DA	Cafeteria	15.2
	Kitchen	24.3
	Work Room	28.6
School P	Custodian Office	56.7
	Music Room	27.7
	Resource	28.6
	Staff Room	69.0

APPENDIX III

SURVEY AND CONSENT FORM

[redacted]

Principal Investigator
Heather Swail
[redacted]

Research Supervisor
Dr. Shauna Mallory-Hill
[redacted]

Consent Form

Assessing Indoor Air Quality and Lost Work Time in the [redacted] School Division

This consent form, a copy of which will be left with you for your records and reference, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.

What is the study?
The [redacted] School Division is participating in a University of Manitoba Master's Thesis. The study is performing an indoor air quality analysis in all elementary schools in the division. Several classrooms and offices have been randomly selected for testing. Locations will be tested for common air quality parameters and be compared to government standards.

This research will also compare air quality and absenteeism within the school division. We are interested in learning if poor air quality can lead to lost work time through absenteeism. Many studies do suggest this but few have proven this hypothesis. We are receiving staff absenteeism data through human resources. However, please keep in mind that this data is only generalized and anonymous. The only information being collected is the number of staff absent each day.

What will you be asked to do?
We are asking staff to participate in a survey so we can compare perceived air quality to actual air quality. We are interested in learning how you feel about the air quality in your workplace.

The survey is a brief multiple choice form that should take less than five minutes to complete. The survey is completely anonymous and confidential. If you have the time and would like to contribute to the study we would greatly appreciate your help.

Potential harms/ inconveniences/ benefits
There are no known potential risks in participating in this survey. By participating in this survey you will not benefit directly, but you will contribute to the development of knowledge about how to improve indoor air quality in schools.

Privacy and Confidentiality
This survey is completely anonymous and confidential. Only the principal researcher, Heather Swail, will have access to your survey and consent form. Both forms will be stored separately in a secure manner at the University of Manitoba.

All of surveys and consent forms will be destroyed three months after the completion of the thesis, July 2013. The data collected will only be used for the purpose of this study.

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[redacted]

Principal Investigator
Heather Swail
[redacted]

Research Supervisor
Dr. Shauna Mallory-Hill
[redacted]

Can I change my mind?
Because this survey is anonymous, once submitted it cannot be withdrawn from research. If you have any hesitations about completing this survey please keep in mind that it is completely voluntary.

Receiving results and feedback
Schools will receive an email from [redacted] the Health and Safety Officer, in May 2012 regarding the results of testing and the survey. Suggestions for improvement in air quality will be provided if necessary.

Copies of the thesis will be submitted to [redacted] upon completion in April 2013. [redacted] will provide electronic copies to the participating schools. If you would like an individual copy please contact Heather Swail at the above information.

If you would like to receive the results in a form other than email please contact Heather Swail for alternative methods.

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate as a subject. In no way does this waive your legal rights nor release the researchers, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time, and /or refrain from answering any questions you prefer to omit, without prejudice or consequence. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation.
The University of Manitoba Research Ethics Board(s) and a representative(s) of the University of Manitoba Research Quality Management / Assurance office may also require access to your research records for safety and quality assurance purposes.
This research has been approved by the Joint Faculty Research Ethics Board. If you have any concerns or complaints about this project you may contact any of the above-named persons or the Human Ethics Coordinator (HEC) at 474-7122. A copy of this consent form has been given to you to keep for your records and reference.

Participant's Signature ________________________ Date ____________

Researcher Signature __________________ Date _______

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[redacted]

Principal Investigator
Heather Swail
[redacted]

Research Supervisor
Dr. Shauna Mallory-Hill
[redacted]

Indoor Air Quality and Lost Work Time in the [redacted] School Division

Please review and sign the consent form before completing the following questions. If this survey cannot be completed upon delivery, it may be dropped off in the main office for pick up by the end of the school day. For confidentiality purposes please submit surveys and consent forms in a sealed envelope addressed to Heather Swail or [redacted] For questions, comments, or concerns please see the contact information at the top of the consent form.

1. Work Location:
   School ________________________

2. Circle any of the following that are true for your workplace:
   a) unusual odours
   b) stuffy air
   c) dry air
   d) dust
   e) shocks from static electricity
   f) too warm
   g) too cold
   h) temperature varies from room to room
   i) drafts

3. Have you experienced any of the following symptoms (circle all)?
   a) Headache
   b) Nausea
   c) Dizziness
   d) Tiredness/fatigue
   e) Irritation of eyes, nose, throat
   f) Breathing Problems
   g) Wheezing
   h) Coughing
   i) Blurred Vision
   j) Sinus Congestion
   k) Difficulty concentrating
   l) Pain or discomfort of back and/or neck
   m) Pain/discomfort of hands and/or wrists
   n) Sneezing
   o) Shortness of Breath

   *If you have not experienced any symptoms disregard questions 4-9 and proceed to #10.

4. Do you have any other health conditions that may make symptoms worse (allergies, respiratory disease, chronic cardiovascular disease, etc.)?
   a) yes b) no

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[redacted]

5. Have you seen a doctor for these symptoms?
   a) yes b) no

6. On average, how long have you been at work when you notice symptoms?
   a) Less than 1 hour
   b) 2-4 hours
   c) 1 day
   d) Multiple days

7. When do the symptoms go away?
   a) overnight
   b) after a week
   c) rarely/never

8. Has the pain or discomfort caused you to take time off work?
   a) yes b) no

9. Are you aware of coworkers with similar symptoms or concerns?
   a) yes b) no

10. Do you think your school has adequate air quality?
    a) yes b) no

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