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Comparison of indoor air quality in LEED vs non-LEED classrooms at UAH

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COMPARISON OF INDOOR AIR QUALITY IN LEED VS NON-LEED CLASSROOMS AT UAH

by

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A THESIS

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We, the undersigned members of the Graduate Faculty of The University of Alabama in Huntsville, certify that we have advised and/or supervised the candidate on the work described in this thesis. We further certify that we have reviewed the thesis manuscript and approve it in partial fulfillment of the requirements for the degree of Master of Science in Atmospheric Science.

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ABSTRACT

The School of Graduate Studies
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Title Comparison of Indoor Air Quality in LEED vs non-LEED classrooms at UAH

Indoor air quality (IAQ) is important because we spend around 90% of the time in the indoor environment. Newer designs, construction practices, and building materials for "green" buildings and the use of "environmentally friendly" products have the promise of lowering chemical exposure; therefore, they have the potential to improve IAQ. This study examines indoor air pollutants such as carbon monoxide (CO), carbon dioxide (CO_2), formaldehyde (HCHO), and total volatile organic compounds (TVOCs) between non-LEED (NSSTC) and LEED (SWIRLL) certified classrooms with the objective of providing which classroom maintains better indoor air quality. Results from this study indicated that the indoor air pollutants in both classrooms are under the recommended EPA standards. However, ranges of CO_2, CO, HCHO in SWIRLL classroom were well below the ones in NSSTC classroom. The results also indicated that outside temperature, indoor relative humidity, and indoor temperature presented an apparent correlation with indoor air pollutants. In addition, survey results showed that mean satisfaction score of SWIRLL classroom (4.29) was higher than NSSTC classroom (3.93) in the indoor environment. 57.1% of the students participated in the study reported that in both the classrooms temperature is the major disturbing factor. This study recommends UAH that, controlling humidity, and temperature can be a countermeasure of reducing indoor pollutants in both types of classrooms.

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Table of Contents

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE

Introduction

1.1 Purpose and objective of Study

In the mid 1970's, increase in global temperature and climate issues was a major concern worldwide and greenhouse gases were considered as the main cause (Ramanathan & Feng, 2009). Since then, developed countries have reduced greenhouse gas emissions. Among all greenhouse gas (GHG) emission sources, the construction industry was responsible for 30% of greenhouse gas emission (Hirst, 2013). Along with the greenhouse gas emission, the construction industry were also responsible for 45% - 60% of disposed waste in landfills which emitted air pollutants (Yudelson, 2008a); therefore, globally, the control of environmental impacts from the building sector had become a major issue.

The urgency to implement environmental friendly practices across the construction industry resulted in the sustainable building revolution in the 1970's (Erlandsson & Borg, 2003). Initially, sustainable buildings were built to reduce the energy consumption. Later, in the early 1990's, the United States Green Building Council (USGBC) was formed to initiate the practice of green buildings in the United StatesS. By the end of the 20th century, advancement in building technologies, materials and the creation of USGBC promoted the development of sustainable (green) buildings for the efficient use of energy, water, and materials. Global issues such as climate change, population growth, and rapid urbanization have made green buildings a more appealing solution (Butera, 2010). In fact, it is predicted that the green building market growth will rise to 37% by the end of 2020 (World Green building trends, 2016).

Sustainable buildings, also known as green buildings, sustainable construction or high-performance buildings (Yudelson, 2008). There is no single widely accepted definition for green buildings, but the Environmental Protection Agency (EPA) defines green buildings as "a practice of creating structures and process that are environmentally responsible and resource efficient throughout a building's life cycle from siting to design, construction, operation, renovation and deconstruction" (EPA, 2017). Green buildings are usually assessed and certified by third party certification systems. Globally, there are many certification programs for green buildings such as Building Research Establishment Environment Assessment Methodology (BREEAM) in the United Kingdom, Leadership in Energy and Environmental Design (LEED) in the United States, and Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB) in Germany (Doan et al., 2017). Schools, residences, hospitals, offices, industrial and other types of buildings carry out their building innovations and transformations to obtain green building certification. In the United States, USGBC designed the LEED certification for green buildings in late 1990's. Since then, it has gained wide popularity (USGBC, 2017). Currently, forty-one countries have implemented the LEED certification process. As a result, it is one of the fastest-growing assessment methods globally.

The LEED certification is based on a rating system. Constructed buildings can receive points for their environmentally friendly and energy efficiency measures at levels from Certified to Platinum (USGBC, 2017). These points are given to the buildings based on innovation, indoor environmental quality, materials and resources, energy and atmosphere, water efficiency, sustainable sites, location and transportation.

Within LEED, indoor air quality (IAQ) is an integral part of the indoor environmental quality assessment factor. Overall, forty-one contaminants (Table 1) are measured before these points are given to the building; therefore, these buildings play a significant role in supporting indoor air quality. However, from the beginning of the green building certification program, IAQ is not a crucial element for LEED certification. On average, the points allocated for indoor air quality account for 7.5% based on a recent evaluation from thirty countries (Wei, Ramalho, & Mandin, 2015). Since, indoor air quality have direct effects with occupants in the buildings, there is an interest to know whether LEED certification could have an impact on IAQ through its scoring system. Table 1 represents the allowable levels of pollutants in the indoor environment by USGBC.

The points allocated to indoor air quality for green buildings are less. Also, connection between indoor air quality and human well-being is very complex due to inadequate understanding of the links between indoor pollutants and exposure to these pollutants, especially, the indoor air quality in schools and colleges. Indoor air quality plays a vital role in students health as younger people take in roughly twice the air as that of an adult (Bearer, 1995; Bell & Dyment, 2008; Daisey, Angell, & Apte, 2003).

Table 1: Maximum concentration levels allowed for each contaminant in LEED certified buildings (Source: USGBC)

Contaminant			Maximum concentration
Particulates	**PM10** (for all buildings)		50 ug/m3 Healthcare only: 20 ug/m3
	PM2.5 (for buildings in EPA nonattainment areas for PM2.5, or local equivalent)		15 ug/m3
Ozone (for buildings in EPA nonattainment areas for Ozone, or local equivalent)			0.075 ppm
Carbon monoxide (CO)			9 ppm; no more than 2 ppm above outdoor levels
Total volatile organic compounds (TVOCs)			500 ug/m3 Healthcare only: 200 ug/m3
Formaldehyde			27 ppb Healthcare only: 16.3 ppb
Target volatile organic compounds*	1	Acetaldehyde	140 ug/m3
	2	Benzene	3 ug/m3
	3	Carbon disulfide	800 ug/m3
	4	Carbon tetrachloride	40 ug/m3
	5	Chlorobenzene	1000 ug/m3
	6	Chloroform	300 ug/m3
	7	Dichlorobenzene (1,4-)	800ug/m3
	8	Dichloroethylene (1,1)	70 ug/m3
	9	Dimethylformamide (N, N-)	80 ug/m3
	10	Dioxane (1,4-)	3000 ug/m3
	11	Epichlorohydrin	3 ug/m3
	12	Ethylbenzene	2000 ug/m3
	13	Ethylene glycol	400 ug/m3
	14	Ethylene glycol monoethyl ether	70 ug/m3
	15	Ethylene glycol monoethyl ether acetate	300 ug/m3

	16	Ethylene glycol monomethyl ether	60 ug/m3
	17	Ethylene glycol monomethyl ether acetate	90 ug/m3
	19	Hexane (n-)	7000 ug/m3
	20	Isophorone	2000 ug/m3
	21	Isopropanol	7000 ug/m3
	22	Methyl chloroform	1000 ug/m3
	23	Methylene chloride	400 ug/m3
	24	Methyl *t*-butyl ether	8000 ug/m3
	25	Naphthalene	9 ug/m3
	26	Phenol	200 ug/m3
	27	Propylene glycol monomethyl ether	7000 ug/m3
	28	Styrene	900 ug/m3
	29	Tetrachloroethylene (Perchloroethylene)	35 ug/m3
	30	Toluene	300 ug/m3
	31	Trichloroethylene	600 ug/m3
	32	Vinyl acetate	200 ug/m3
	33-35	Xylenes, technical mixture (m-, o-, p- xylene combined)	700 ug/m3
ppb = parts per billion; ppm = parts per million; ug/m^3 = micrograms per cubic meter			

In developed countries, the average length of the school year ranges from 175 to 220 days and the duration of the school day ranges between five and eight hours according to International Network on Climate Change (INCA, 2012). This data reveals that students spend a measurable amount of time both indoors and outdoors, so the air quality inside and outside of the school play a major role in student's health and academic performance (WHO, 2005). The design of today's school buildings and spaces start to reflect the values of green and healthy learning environments, as communities demand more green spaces in educational facility planning and design (Haq, 2011). In the United States, 73% of existing schools were built before 1970; out of all schools in the US, only 2.1% of schools have LEED buildings. If these schools could be transformed to green buildings, the change could reduce 30% of energy, 40% water usage, 35% greenhouse gases, and increase the productivity of the teachers as well as students (Weekes, 2009).

Green buildings has been associated with improving children's mental, physical, and spiritual well-being (Bell & Dyment, 2008; Okcu, Ryherd, & Bayer, 2011). In the last decade, research has emerged to test if LEED certified buildings provide better indoor air quality (Gou & Xie, 2017; Xiong, 2015). The main conclusions from previous studies can be summarized into two categories. On one hand, some studies found that green buildings had better IAQ. A study conducted by Lee, (2011) measured indoor environmental quality and thermal comfort between different classification levels of LEED buildings. The study found that higher LEED classification levels had higher satisfaction rate in indoor air quality and increased the performance among the occupants. Another study measured IAQ parameters like CO_2, and VOC, and concluded that measured parameters were mostly within the recommended standards (Choi & Moon, 2017). On the other hand, some researchers argued that the green buildings did not show better IAQ when compared to non-green buildings. For instance, a study conducted by Altomonte, and Schiavon, (2013) measured IAQ parameters like temperature, humidity, and TVOCs and found that green buildings did not provide better indoor air quality when compared to non-green buildings.

Despite various IAQ studies performed in school and office buildings around the world, comparison of indoor air quality between LEED and non-LEED classrooms in universities are scarce. For example, Hua, Göçer, and Göçer, (2014) measured indoor air pollutants like CO_2, and thermal comfort between LEED and non-LEED campus buildings and found that CO_2 levels were higher in non-LEED building when compared to LEED buildings. Also, few studies used post occupancy survey method to compare the satisfaction rate between LEED vs non-LEED buildings in universities and found LEED buildings had higher satisfaction in IAQ, and thermal comfort (Altomonte & Schiavon, 2013; El Asmar, Chokor, & Srour, 2014).

Taking into consideration, the low number of previous studies in comparing LEED vs non-LEED classrooms in universities, it is imperative to examine how indoor air pollutants differ between LEED and non-LEED classrooms. This study measured CO_2, CO, TVOCs, HCHO, temperature and relative humidity in the classrooms for a period of forty days using indoor air monitors. Along with these measurements, this study also used an online survey questionnaire to understand the satisfaction rate among the students. Investigation of indoor air quality between classrooms using instruments and survey questionnaire offers an improvement over conventional indoor air quality studies that either measured indoor air quality using measurements or a survey. Overall, this study was designed as an investigation to determine which classroom, either LEED or non-LEED classroom has better indoor air quality and a higher satisfaction rate by combining two forms of analysis: measured observations and a survey questionnaire. In particular, this study answers the following questions:

I. Do LEED classrooms have lower levels of pollutants when compared to non-LEED classrooms?

Based on the literature that LEED has the intention of lowering indoor pollution level, we hypothesize that the LEED certified classroom would have lower levels of air pollutants, specifically,

H1: LEED certified classrooms have lower level of pollutants when compared to non-LEED classrooms.

II. Which classrooms have higher satisfaction rate in indoor environmental quality?

Based on the literature, satisfaction of indoor environmental quality between LEED and non-LEED buildings is unclear. However, most literature suggests that LEED certified buildings have a higher satisfaction rate. Therefore, we hypothesize that LEED certified classrooms have higher satisfaction rate in indoor environmental quality, specifically,

H2: LEED certified classroom have a higher satisfaction rate.

III. Do the pollutants vary between day and night?

There is a mounting body of evidence that higher temperatures induce chemical reactions, which increase indoor air pollutants. In addition, it is accepted that average daytime temperature are higher than nighttime temperatures. As a result, we hypothesize that measured pollutants during the day would be higher than at night5 specifically,

H3: Daytime measured pollutants will be higher than nighttime.

This study also attempted to determine if there is a relationship between indoor pollutant levels, temperature, and relative humidity in classrooms. The premise of this research assumes that if LEED certified classrooms are proven to have lower levels of pollutants and a higher satisfaction rate, this knowledge will aid in the implementation of LEED buildings among schools, universities which will improve the indoor quality, and health of the occupants.

CHAPTER TWO

Background on Green Building, LEED certification and its potential health effects

2.1 Green Buildings and LEED

Green buildings are structures that emerged in the late 20th century to improve the efficiency of buildings and to improve the quality of life of people who live inside the building (Environmental Protection Agency, 2017). Today, green buildings are one of the fastest growing building and design concepts around the world (Lu, Wu, Chang, & Li, 2017). Globally, there are many certification schemes available for the assessment of green buildings. The major initiation was started in 1993, when a non-profit organization called the United States Green Building Council (USGBC) was formed to promote sustainability in building design, construction and operation. In 1998, the USGBC created Leadership in Energy and Environmental Design (LEED), a program that provides a third-party verification of green buildings. Within a few years, LEED certification gained popularity and currently is one of the most popular green building certification programs worldwide (Pulselli, 2007). In addition, it is one of the reference systems for design, construction, and operation of green buildings beyond the United States (Wu & Low, 2010).

The LEED certification evaluates buildings using a rating system based on the building usage, construction, operation and maintenance of the building. The LEED green building rating system has evolved in various ways since it was originally introduced in 2000. LEED V4 is the newest version, which represents the most innovative approach to ensure optimal standards in human health and environmental health (Li, Chen, Wang, Xu, & Chen, 2017). LEED projects earn points under seven basic categories: location and transportation, sustainable sites (SS), water efficiency (WE), energy and atmosphere (EA), materials and resources (MR), indoor environmental quality (IEQ), and innovation and design process (Kubba, 2010). Based on the number of points earned by the building they are classified into four LEED rating levels: Certified (40-49 points), Silver (50-59 points), Gold (60-79 points), and Platinum (80+ points). Table 2 summarizes how point allocation has changed since the beginning of the LEED certification. This shows IEQ accounts for 12.6% i.e. 16 points out of 126 points and out of which IAQ accounts for just 7.5% in overall allocation of points. It is, thus, important to assess whether LEED-certified buildings are truly successful in maintaining IAQ irrespective to the less allocation of points.

Table 2: Allocation summary of LEED points

Assessment area	**LEED v2.2**	**LEED 2009**	**LEED v4**	**Percent change**
Location and transportation	N/A	N/A	32(25.39%)	N/A
Sustainable sites	14(20.3%)	26(23.6%)	10(7.9%)	-15.7%
Water efficiency	5(7.3%)	10(9.1%)	11(8.7%)	-0.4%
Energy and atmosphere	17(24.6%)	35(31.8%)	33(26.2%)	-5.6%
Material and resources	13(18.8%)	14(12.7%)	13(10.3%)	-2.4%
Indoor environmental quality	15(21.7%)	15(13.6%)	16(12.6%)	-1%
Innovation	5(7.3%)	6(5.5%)	6(4.7%)	-0.8%
Regional priority credits	N/A	4(3.7%)	4(3.2%)	-0.5%
Total points available	69(100%)	110(100%)	126(100%))	

Source: USGBC

2.2 LEED, Non-LEED and Indoor air quality (IAQ)

Green buildings have become popular in recent years and many assessment tools have evolved to evaluate them. Green buildings are expected to use resources efficiently and to provide a conductive indoor environmental quality to its occupants. To fulfill its requirement, unique features are considered within the design to distinguish from a conventional building. Some of these unique features are the provision of natural ventilation, day lighting, energy efficient fixtures and fittings, personal control of ambient conditions, use of nontoxic paints and recycled materials (Paul & Taylor, 2008).

Indoor air quality plays a key role in a person's life, since people spend majority of their time in a closed space. On average, American adult spends 90% of their time indoors, while children younger than three years old spend up to 100% of their time in indoor environments (The EPA, 2011). As we spend most of our time in indoor environment, exposure to indoor air pollution is high. Exposure to these pollutants can affect the well-being of the people in a different manner based on the age group who occupies the buildings (Dionisio, 2017).

Several studies have been conducted to identify IAQ in both LEED and non-LEED buildings. In a study, Lee and Guerin, (2009) measured IEQ parameters in 15-LEED certified green buildings. They concluded that apart from acoustics and thermal quality, other IEQ variables like office layout, furnishings, air quality, lighting, cleanliness and space, scored higher satisfaction ratings. In addition, they found a positive correlation between IEQ and respondents' perceived performance. Irga and Torpy, (2016) measured CO_2, $PM_{2.5}$, CO, and TVOCs in non-green buildings and found that the ventilation type in the buildings affected indoor air quality and also increased levels of CO_2, CO levels.

Lee and Kim, (2008) compared seven IEQ criteria related to occupant's satisfaction and performance between LEED-certified buildings and non-LEED certified buildings. Their findings indicated that occupants in LEED certified buildings have higher satisfaction rate with office furnishings quality, IAQ, cleanliness, and maintenance quality than non-LEED-certified buildings. However, non-LEED-certified buildings presented higher occupant's satisfaction with office layout quality, lighting quality, and acoustic quality than LEED-certified buildings. In another study, Newsham et al., (2013) compared nine pairs of green and conventional office buildings in Canada and U.S. using an occupant survey and physical measurements of key IEQ parameters like IAQ, acoustics, ventilation, noise. The building pairs were selected by controlling size, age, climate zone, owner, and the occupants' work activity. This quasi-experimental research design helped the researchers establish a direct link between the IEQ satisfaction and attributes of the green buildings. The large sample size of 2,545 responses to the questionnaire along with 974 points of physical measurements showed that green buildings had better IEQ performance compared to similar conventional buildings. This was due to better speech privacy, less background noise, higher illumination, greater access to windows, better thermal conditions, and less airborne particulates. One study compared the productivity and differences between satisfaction levels of employees who moved from a conventional building to a green building and found the move to be very satisfactory with improved IAQ, which led to self-reported improvements in productivity and less absenteeism (Singh, 2010). In another study, Lee and Guerin, (2010) found that

IAQ enhanced workers' job performance in private spaces when compared to shared cubicles. Additionally, they found that the LEED office had higher satisfaction with the amount of light and visual comfort.

Even though some studies showed that LEED buildings maintained better indoor air quality and improved the productivity among the people who utilized the buildings, several other studies comparing LEED and non-LEED certified buildings showed that LEED buildings do not outperform non- LEED buildings (El Asmar et al., 2014; Liang et al., 2014). The study by Altomonte and Schiavon, (2013) surveyed 21,477 individuals (10,129 from LEED buildings) and found that the mean satisfaction scores of LEED building are 6% lower than non-LEED buildings. They concluded that LEED certification does not influence IAQ satisfaction among occupants. Similarly, in a study by Scofield, (2013) regarding the comparison of energy performance in 953 office buildings in New York City (21 LEED certified), energy consumption and GHG emission were not lower in LEED building as compared to non-LEED buildings; however, the Gold certified buildings showed 20% more GHG reduction. In a comparative analysis of conventional and green buildings, researchers used a post occupancy evaluation survey and concluded that there was no difference between LEED and non-LEED buildings with respect to IEQ (Gou, Lau, & Zhang, 2012).

There have always been contradicting results when evaluating IEQ in LEED and non-LEED buildings using a survey method. Most of the studies assessing IAQ utilized post-occupancy surveys while a few studies are based on measurements, such as measuring the pollutants, ventilation, etc. In a study by Liang et al., (2014) he adopted post occupancy evaluation using survey and on-site measurements to evaluate the satisfaction of the occupants and pollutants influence in IAQ. He concluded that green buildings provided a better quality in CO_2, TVOCs and had higher satisfaction rate among occupants when compared to conventional building. In another study Almeida measured indoor PM and CO_2 in three classrooms and found that physical activity of students highly contributed to increase in PM and CO_2 in classrooms (Almeida et al., 2011). Another study measured HCHO, TVOCs, CO_2, CO, and NO_2 in five different classrooms in a conventional building using instruments and found that two classrooms had higher level of pollutants when compared to outdoor pollutants and formaldehyde was higher in all the classrooms than the recommended value (Jovanović, Vučićević, Turanjanin, Živković, & Spasojević, 2014). Despite the consistencies in research, a research gap persists in comparing IAQ in LEED and non-LEED buildings.

2.3 Indoor Air Quality and Health

There is growing public awareness of the risk associated with poor indoor air quality, which emphasizes the importance to maintain good indoor air quality inside of buildings. Various pollutants are present in the indoor environment, and they have varying effect times. The most common types of indoor air pollutants are particulate matter (PM), gases such as ozone (O_3), nitrogen dioxide (NO_2), carbon monoxide (CO), carbon dioxide (CO_2) and sulfur dioxide (SO_2); microbial and chemical volatile organic compounds (VOCs), and passive smoke. A major limitation of understanding the adverse health effects of these specific air pollutants is the inability to directly relate measurable ambient air concentrations to personal exposure (Bernstein, 2008). This review attempts to provide a summary of the potential health effects caused by the indoor air pollution.

Specific Indoor Air Pollutants and Their Effects

a) Indoor Particulate Matter (PM)

PM is one of the major pollutants, which has adverse effects on human life and can remain in the atmosphere for a long time (Kim, Kabir, & Kabir, 2015). The adverse effects of indoor PM are dependent on deposition in the respiratory tract. For example, coarse PM generated indoors (2.5-10 μm) tends to deposit in the nasal, pharyngeal, and laryngeal regions of the respiratory system, whereas fine (0.1-2.5 μm) and ultrafine (< 0.1 μm) PM generated indoors and outdoors tends to deposit in the tracheobronchial region and alveoli.(Madureira et al., 2015). Indoor PM has been associated with an increase in admittance to hospitals (Li, Wen, & Zhang, 2017) and an increase in respiratory problems. Indoor PM also classified according to its sources, which includes Environmental Tobacco Smoke (ETS), cooking, heating, consumer products, building materials, house dust, particle suspension from human activity such as vacuuming and foot traffic, outdoor particle infiltration, and secondary organic aerosols (Li et al., 2017).

b) Ozone (O_3)

Major sources of indoor ozone are from outdoor ozone as well as air purifiers (electrostatic precipitation, negative ion generators, and ozone generators), which are marketed to the public to provide relief from numerous respiratory ailments, reduce odors, and destroy microbes. These devices increase indoor O_3 concentrations in the range of 16 to 453 ppb (Hubbard, 2005). Ozone exposure produces decrements in pulmonary function and exercise capacity and induces airways inflammation in both healthy individuals as well as those with pre-existing airways disease (e.g. asthma, chronic obstructive pulmonary disease) (Nuvolone, Petri, & Voller, 2018). O_3-induced health effects are dependent on the dose and concentration of Ozone deposited in the lung, individual's ventilation rate, and duration of exposure (Glas, Stenberg, Stenlund, & Sunesson, 2015) . Furthermore, interactions between ozone and particulate matter in office settings creates discomfort (Li, Wen, & Zhang, 2017).

c) Nitrogen dioxide (NO_2)

The primary source of indoor NO_2 is gas fueled cooking and heating appliances. One study suggests that children with atopy or asthma, infants who are at risk of developing asthma, and female adults are more sensitive to the respiratory effects of NO_2 exposure (Faustini, Rapp, & Forastiere, 2014). Indoor NO_2 exposure also enhances asthmatic reactions to inhaled allergens (Heinzerling, Hsu, & Yip, 2016). Nitrogen oxides' acidic nature makes it capable of causing respiratory damage leading to respiratory symptoms in patients with asthma at concentrations of 650 ppb over 3 hours (Wu et al., 2016).

d) Sulfur dioxide (SO_2)

Sulfur dioxide is a primary combustion product of fossil fuels that can be grouped together with acid aerosols and particles to form a complex group of distinct air pollutants associated with a wide array of adverse health effects, including short term respiratory morbidity and mortality (Goudarzi et al., 2016). Exposure to SO_2 will intensively irritate eyes and mucosa of respiratory passage. A large amount inhalation of SO_2 will result in pneumonedema and throat swelling, dramatically impairing lung function or even causing suffocation (Schlesinger, 2017).

e) Carbon monoxide (CO)

Carbon monoxide is a tasteless, odorless, colorless and non-irritating gas (Liu et al., 2016). The main sources of indoor CO are gas appliances, burning of wood and environmental tobacco smoke. CO can impair the oxygen binding capacity of hemoglobin, which can cause headaches, nausea, dizziness, breathlessness and fatigue, and with high exposures can lead to coma and death (Sönmez et al., 2018).

f) Volatile organic compounds (VOCs)

Formaldehyde is a common VOC; which is familiar among the public. The major sources of formaldehyde are from paints, adhesives insulations, wallboard, ceiling tile and workstations (Tong et al., 2019) . The sum of all individual VOCs is known as total volatile organic compounds (TVOCs). When TVOCs levels are 3,000 ug/m3 and higher it causes suffocation and uneasiness in breathing among a group of people (Mečiarová, Vilčeková, Burdová, & Kiselák, 2017). Building occupants emit Benzene from tobacco smoke (ETS) and attached garages, limonene (a terpene) and various siloxane compounds (e.g, decamethylcyclopentasiloxane) from personal care products including antiperspirants and deodorants, tetrachloroethylene from dry-cleaned clothing, C12 to C16 alkanes from lotion, moisturizing soaps, and other cosmetics (Tang, Misztal, Nazaroff, & Goldstein, 2016). Table 3 lists some of the common sources of VOCs in buildings.

Table 3: VOCs and their indoor sources

Sources	VOCs
Adhesives and sealants	Formaldehyde, butyl ether, vinyl cyclohexane,2-propenoic acid, propylene glycol
Carpet	4-Phenylcyclohexene, vinyl acetate styrene, odecanol, acetaldehyde
cleaning chemicals	Limonene, isopentane, isopropanol, butoxyethanol, 1,4 dichlorobenzenes
office furniture	formaldehyde, acetaldehyde butyl acetate, hexanal, cyclohexanone
Paints	Toluene, propylene glycol, ethylene glycol butyl propionate, methyl propanol
Printers/ Copiers	Styrene, ethylbenzene, xylenes benzene, 2-ethyl-1-hexanol
Window shades	Ethyl hexanoic acid, decanol dodecane, ethyl hexanol, naphthalene

Source: EPA (2018)

g) Carbon dioxide (CO_2)

Humans produce and exhale CO_2. Natural concentrations of CO_2 in occupied indoor spaces are higher than outdoor concentrations. The acceptable level of CO_2 in indoor environment is 1000 ppm. When the concentrations of CO_2 increases above the acceptable level, people tend to lose their concentration and feel drowsy (Hong, Kim, & Lee, 2018). Also, when CO_2 concentration level goes beyond 20,000 ppm it leads to shortening of breath among humans which affects the nervous system (Tillett, 2012). Furthermore, findings reflected that elevated CO_2 levels can cause sleepiness

(Vehviläinen, 2016).

2.3.1 Indoor air quality in schools

Indoor air quality has been recognized as a cause of occupant discomfort, adverse health effects, increased absenteeism from work or school, and degraded cognitive performance (Tham, 2016). The most common health manifestation or poor IAQ is via non- specific symptoms such as headaches, eye or nasal irritations, skin rashes or itches, malaise or difficulty in concentrating (Allen et al., 2016). Such symptoms are often described as "sick building syndrome" (Lu, Lin, Chen, & Chen, 2015). Children are a sub-population of special interest for many environmental exposures (Belanger, Gent, Triche, Bracken, & Leaderer, 2006); therefore, air quality inside school buildings can play a crucial role in affecting student's health. Children take in roughly twice as much air by volume compared to their body mass as adults, resulting into twice as many the pollutants taken in through respiration (Bearer, 1995). In addition, children are more active, and breathe in the lower level of ground that accumulates more pollutants.

Several studies compared IAQ in schools and universities. For instance, in a study, Jovanović, (2014) used a mixed type analysis in five classrooms. He found that in three classrooms, indoor pollutant concentrations were less than outdoor pollutants. Additionally, for the remaining classrooms he found that indoor pollutant concentrations were higher than outdoor concentration levels. In another study Ashmore and Dimitroulopoulou, (2009) measured personal exposure of children both in their school and in their houses, and found variations in exposure to indoor pollutants between home and schools. The authors concluded that these variations are caused by differences in building design, indoor and outdoor sources, and activity patterns which was higher at home in terms of personal exposure. Researchers measured CO_2, indoor temperature and relative humidity in university classrooms and found that indoor temperature, and CO_2 were higher during summer due to improper ventilation (Vilčeková, Kapalo, Mečiarová, Burdová, & Imreczeová, 2017).

Several studies showed that indoor air quality will improve the students' performance and reduces absenteeism in schools. For example, in a study by Sarbu & Pacurar (2015), they measured CO_2, indoor temperature, relative humidity and their association with student's performance and found that the classrooms in university had pollution levels below the recommended standards. Also, relative humidity was higher in summer when compared to winter season, Further, they also said that student's performance was higher when indoor temperature was around 27^{o} Celsius. In a review, Stafford (2015) concluded that indoor air quality determines well-being, attitude of students, and staff, which can ultimately affect the learning and teaching process.

Although air quality in schools has important health implications both inside and outside of the classroom, the research conducted on LEED building in schools is mostly about energy consumption (Figueiro & Rea, 2010) and the cost to build the green schools (Gabay, 2014; Liu, Guo, & Hu, 2014b; Rehm & Ade, 2013). A majority of the literature focused on air pollution outside schools (Hwang, 2006; McConnell, 2010), yet students spend most of the time inside the classroom. Green buildings have positive effects on indoor air quality. A study by Zuhaib et al., (2018) revealed that indoor pollution exposure in conventional buildings lead to asthma and other respiratory problems;

whereas, LEED certified buildings tend to have fewer pollutants (Hedge, Miller, & Dorsey, 2014). However, there is not enough evidence about the impact of LEED building on health.

While there have been different studies related to IAQ in LEED and non-LEED buildings, most of the studies focus on office buildings rather than schools. Additionally, there are few comparisons in literature between LEED and non-LEED certified buildings. Out of the existing literature on LEED certified office buildings, the majority have a survey-oriented research design. These studies though provide an opportunity to see what conclusions have been already found related to performances among the buildings while not all the conclusions are done by comparison of the two buildings. This study will contribute to research in LEED buildings' impact in IAQ, as well as provide evidence for schools to advocate for green buildings on their campuses. Furthermore, it will also contribute to empirical research in indoor air quality and green schools.

CHAPTER THREE

Data and Methodology

Data used for this study is divided into two main categories: observational data and survey data. The observational data is measured using Graywolf instruments, to determine the indoor air pollutants between the classrooms for a period of forty days. The survey data, consisting of a set of questionnaires prepared with google forms to determine the satisfaction rate between the classrooms among the students. This section discusses the instruments used and the methodology adopted to analyze the observed data. This section also covers how the questionnaire was prepared and the methodology used to analyze the data obtained from the survey.

3.1 Measurements and instrumentation

Indoor air pollutants were measured using the instruments acquired from gray wolf sensing solutions[1]. The complete setup of the instrument is shown in Figure 1. The instrument consists of one probe, which measured TVOCs, CO_2, CO, indoor temperature and humidity. The probe takes in the flow of air from the indoor environment and Non-Dispersive infrared (NDIR) sensors in the probe measures TVOCs, CO_2, CO, temperature and relative humidity from the air. Along with this, we had a formaldehyde meter, which measures HCHO in indoor environment. The formaldehyde meter has a reusable sensor cartridge that employs the chemical reaction between formaldehyde and ß-diketone in a porous glass. The yellowing that results from this reaction is measured via photoelectric

[1] Gray Wolf sensing solutions is a company that is dealing with IAQ measuring instruments (https://graywolfsensing.com)

photometry with accuracy of +/- 4ppb. The parameters, ranges, accuracy of the instruments are listed in table 4.

To measure the indoor pollutants, we selected the rooms inside NSSTC and SWIRLL buildings and finalized with NSSTC 2076 (non-LEED classroom) and SWIRLL 103 (LEED-Silver certified) as both classrooms were 500 +/- 20 square feet in size. Once the classrooms are selected, one set of Graywolf instruments was installed in each classroom and the measurements were carried out for a period of forty days from September 6^{th}, 2018 to October 14^{th}, 2018. Pollutants are continuously monitored (live reading) with an average interval of five minutes, which are logged using advanced sense pro and laptop. During this period calibrations are checked regularly. Along with this, the number of students in the classroom was also monitored. At the end of observation period, the data stored in PC or advanced sense pro was converted to csv format using Graywolf sense software.

Table 4: Indoor air quality parameters range and accuracy

Indoor Air Quality Meters			
Pollutants	**Range**	**Precision Level**	**Accuracy level**
Carbon Monoxide	0 to 500 ppm	0.01 ppm	+/- 2 ppm
Carbon Dioxide	0 to 10000 ppm	+/- 10 ppm	+/-3 % rdg
VOC's	5 to 20,000 ppb	> 0.6 ppb	N/A
Temperature	-25° C to +70°C	+/- 0.11° C	+/- 0.3° C
Humidity	0 to 100%	+/- 1.4%	+/- 2%
Formaldehyde	<10 ppb to 1000ppb	1 ppb	+/- 4ppb

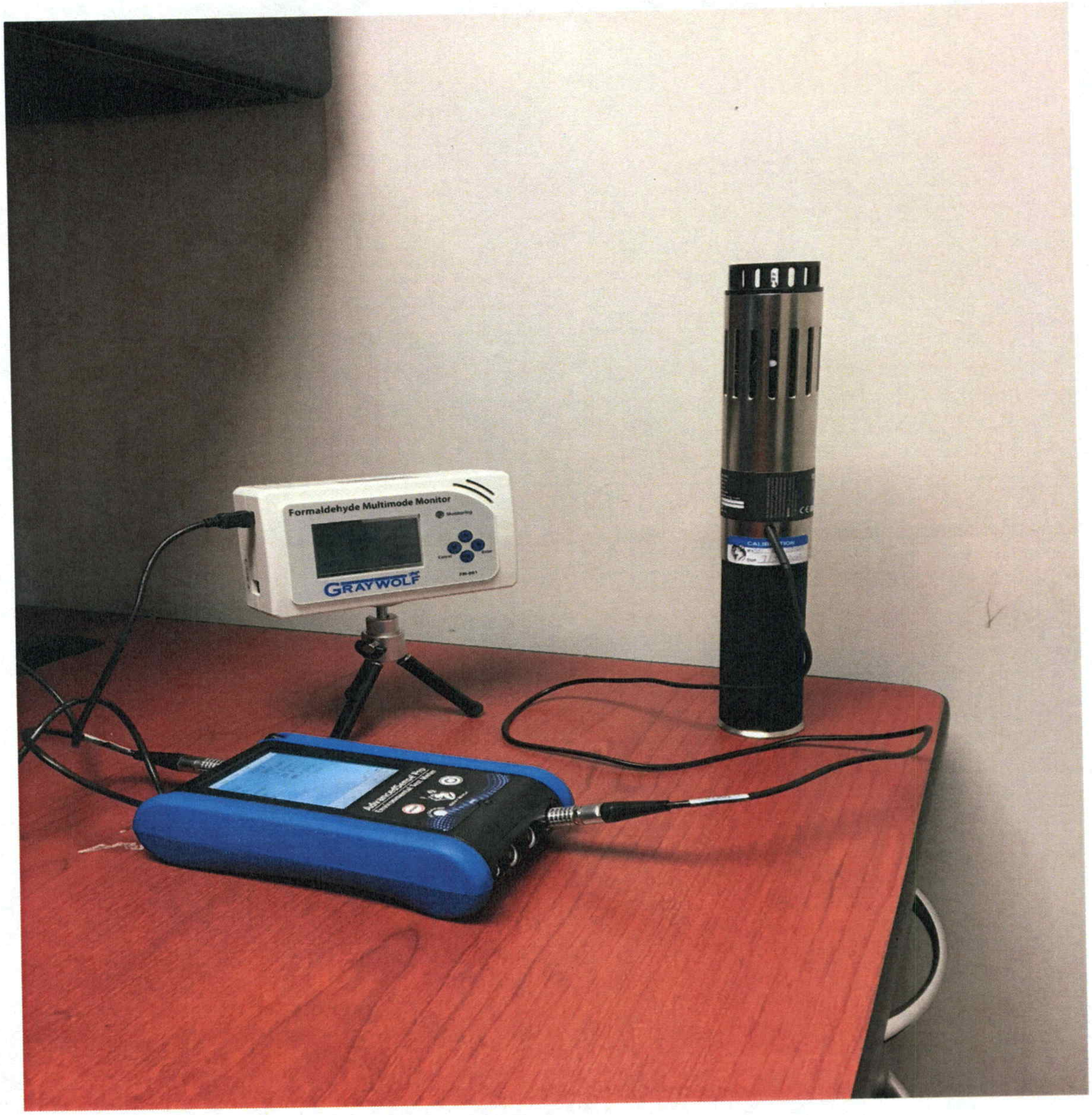

Figure 1: Instrument set up

Analyses of air pollutants, humidity, and temperature

The data obtained from the instruments undergoes two phases of processing: 1) preprocessing phase and preparation of the data 2) analysis of the data. First, the obtained data is averaged into hourly basis using pivot table in Microsoft Excel. Then, the data is segregated based on daytime and nighttime, and the day averages. The extracted data are merged with the average outside temperature, which is obtained from Iowa State University[2].

Pollutants over time between LEED and non-LEED classrooms are obtained and differences in TVOCs, CO_2, CO, HCHO, temperature, and humidity of NSSTC and SWIRLL classrooms is compared. We utilized tableau and Microsoft Excel software to make graphs to find the difference between two classrooms. From these graphs we identified the overall differences between the pollutants across the classrooms and also we measured the differences in pollutants when equal number of people present inside the classrooms which provided a better understanding about the pollutants between the buildings.

In the initial analysis, we identified the different levels of pollutants between two classrooms, but we could not identify what causes the change in pollutants. For that, we must identify the relationship between the environmental variables measured and the pollutants. So, the environmental variables like indoor temperature, indoor humidity, outdoor temperature, and outdoor humidity were tested with respect to pollutants.

First, we identified the mean, median, standard deviation and the range of all the pollutants and variables, from which we understood the overall distribution of pollutants. Second, we identified the association of environmental variables and pollutants using Pearson's Correlation analysis. There are two major characteristics of correlation. The correlation coefficient is bounded by -1 and 1. These bounding values describe the linear association between two variables. A perfect, linear relationship would have a value 1,

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[2] The data is obtained from https://mesonet.agron.iastate.edu/request/download.phtml?network=AL_ASOS

meaning that the values of one variable will always increase when the value of other variable increases or the value of one variable will decrease when other variable decreases. Likewise, a negative correlation coefficient of -1 indicates value of one variable will always increase in relation to a decrease of other variables or if the values of a variable were to decrease, and then the other values in variables will increase. Secondly, correlation is often represented by r or r^2. This value indicates the quantitative relationship how strongly one variable explains the other variable. We used guide of Evans to describe the correlation (Wuensch & Evans, 1996). In our study, correlation was used to determine the relationship between pollutants and the independent variables like temperature and humidity. Once the association is identified next step was to identify which variables contribute significantly for the increase in indoor pollutants. For this, we conducted multiple regression analysis. Multiple regression analysis is an extension of linear regression and this method is used when we want to predict the value of a variable based on the value of two or more variables. Multiple regression analysis is expressed mathematically as follows:

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 +..\beta_i x_i + \epsilon_{i,} ,\quad i = 1, \ldots..n$$

Where Y is the dependent variable x_1 , x_2 , x_i are independent variables. In our analyses, levels of emissions of pollutants (VOC, CO, CO_2, HCHO) are the dependent variable and indoor temperature, indoor humidity, outdoor temperature, outdoor humidity are independent variables.

Finally, we performed independent t-tests (Sedgwick, 2010; Ugoni & Walker, 1995) to assess the means of measured pollutants in two groups during day time and night time. This test compared the means between two unrelated groups on the same continuous, dependent variable. From which, we identified which pollutants drastically differed between two classrooms during the day and nighttime.

3.2 Survey data and analysis

Most of the studies about indoor air quality used survey questionnaire (Abbaszadeh, 2006; Altomonte & Schiavon, 2013; Brown & Cole, 2009). Majority of the studies used software developed by CBE (Center for the Built Environment) in the University of California Berkeley (1997), to distribute the survey and to obtain results. These studies have relatively large sample sizes. In this study, as our sample size is small, we prepared the questionnaire from samples obtained from CBE[3] and compiled the questions using Google forms.

The questionnaire designed for this study is intended for a general understanding of indoor air quality among the students and to identify the satisfaction rate among students between NSSTC and SWIRLL classrooms. Along with this purpose, the survey also intended to answer questions like satisfaction in ventilation, indoor air quality, carpet used, dust between NSSTC and SWIRLL. A complete set of the questionnaire prepared for this survey can be found in Appendix B. Once the questionnaire is prepared, the first task was to select the participants. The selected participants for this study are the students who have classes in either NSSTC or SWIRLL as the observations on air pollution levels takes place in the classrooms.

[3] The link to obtain sample questions https://www.cbe.berkeley.edu/

The questionnaire consists of three sections: The first section was to gather personal information of the students and a consent form is used to protect the confidentiality about the information that is being provided. The second section has questions about building and the classroom environment. The third section has questions related to health status inside the building and concerning factors inside the building. Instructions to fill out the survey is added along the Google forms so that students can easily answer the questions. The duration taken to fill the survey was estimated to be ten minutes. Once the questionnaire is ready, it is distributed to the students during the last week of October with a one-week time duration to complete and submit the forms online.

After a week, the forms are downloaded in csv format from google forms. The collected data undergoes cleaning process where data was divided based on the amount of time spent inside the buildings so that we can make comparisons of the satisfaction factor between NSSTC and SWIRLL classrooms. Once the data is ready, statistical analysis was performed on the difference between the two classrooms with respect to students' choices. First, as the survey has questions related to the environment of classrooms, we utilized that data and perform an independent t-test. The independent t-test is also called two-sample t-test or student's t-test. This test is an inferential statistical test that determines whether there is statistically significant difference between the means in two groups. The variables that are compared in this test are ventilation, flooring, dust, concentration, and illumination. From this analysis, we inferred which building maintains better indoor environment and which can be utilized to support the results obtained from the observations. The next analysis that we performed using the data is crosstab statistics. In this analysis, relationship between variables like temperature, air quality, odor, improper ventilation with respect to NSSTC and SWIRLL was studied. This provided a better understanding about which factors inside the classroom affect the concentration of the students and how much it contributes in both the buildings based on student's responses.

A large part of this study analyzed the difference between pollutants in LEED versus non-LEED certified classrooms and to identify how the environmental variables alter the indoor air pollutants. To perform statistical analysis, we used IBM SPSS Version 25 software and Tableau. Excel are used to create graphs.

CHAPTER FOUR

Results

The goal of this study was to determine which classroom, LEED certified or non-LEED certified classroom has better indoor air quality and higher satisfaction rate by combining observations and survey questionnaire. This chapter is organized into two sections. The first section describes the findings from observational data and second section is about results from the survey data. In the first section the findings are organized into two broad categories. The first category explains the variations in pollutants levels across two classrooms by graphing the day averages. Also, we compared the pollutants when the same number of people are present in both the classrooms. In the second category we used Pearson correlation and Multiple regression analysis to identify the association and contribution between environmental variables (temperature, relative humidity) and pollutants. Finally, independent t-test was used to compare the means of day and night variations in pollutants in order to determine whether there is statistical evidence that the associated population means are significantly different. The second section used the survey data obtained from students to identify which building has higher satisfaction rate and what are the factors that affect their concentration between the two classrooms using statistical analysis.

4.1 Observational Data

4.1.1 Indoor air quality difference between LEED and non-LEED classrooms

Descriptive Statistics

In this study, air pollutants, indoor temperature, and indoor relative humidity are measured using instruments and outdoor temperature, outdoor relative humidity, are derived from nearby weather station. Out of twelve parameters, eight parameters measure pollutant levels and other four measure temperature and humidity. Table 5 provides the descriptive statistics for the sample population. A total of 936 observations for every indoor air pollutant were collected from both the classrooms. The report of the measured pollutants indicated that that mean TVOCs was higher in SWIRLL (128.41 ppb) when compared to NSSTC (66.95 ppb) by 94% which is, TVOCs in SWIRLL is nearly doubled the amount when compared to NSSTC. Also, the mean of CO_2, CO, and HCHO are higher in NSSTC classroom, which are almost doubled when compared to SWIRLL classroom. Overall, most of the mean values of pollutants were lower in SWIRLL classroom when compared to NSSTC classroom.

Additional information regarding temperature and humidity were measured. The range and mean columns indicated that even though outside temperature and outside humidity fluctuated, both buildings maintained constant temperature and humidity with +/- 5 ^{o}C and +/-25% fluctuations.

Table 5:Descriptive statistics of pollutant concentrations for NSSTC and SWIRLL classrooms and indoor, outdoor temperature and humidity measurements

Descriptive Statistics						
	N	Range	Minimum	Maximum	Mean	Std. Deviation
Avg outside RH (%)	936	71.01	28.99	100.00	76.57	16.30
CO in NSSTC (ppm)	936	0.51	0.29	0.80	0.49	0.09
CO in SWIRLL (ppm)	936	0.40	0.10	0.50	0.22	0.08
CO_2 in NSSTC (ppm)	936	805.08	433.92	1239.00	604.41	175.89
CO_2 in SWIRLL (ppm)	936	779.83	209.42	989.25	314.77	106.24
HCHO in NSSTC (ppb)	936	43.08	10.50	53.58	28.89	8.39
HCHO in SWIRLL (ppb)	936	37.25	10.00	47.25	13.57	5.12
RH in NSSTC (%)	936	24.26	34.90	59.16	48.04	5.13
RH in SWIRLL (%)	936	24.83	30.24	55.07	45.29	4.07
T Outside (°C)	936	27.56	8.22	35.78	24.10	4.60
T in NSSTC (°C)	936	4.83	22.15	26.98	24.75	1.36
T in SWIRLL (°C)	936	6.53	22.68	29.20	25.40	1.36
TVOCs in NSSTC (ppb)	936	222.83	40.17	263.00	66.95	27.66
TVOCs in SWIRLL (ppb)	936	240.17	38.83	279.00	128.41	22.61

Paired T-Test

To respond to the first research question, "Does LEED classroom have lower level of pollutants when compared to non-LEED classrooms?" this study used paired t-test to determine whether there is any difference between the mean levels of pollutants measured in NSSTC classroom and SWIRLL classroom. Table 6 indicated significant differences of TVOCs, CO_2, CO, and HCHO between NSSTC classroom and SWIRLL classroom. In general, the results show there's a significant difference between mean levels of all pollutants. Most of the pollutants (i.e. HCHO, CO, CO_2) are lower in SWIRLL classroom, but TVOCs is significantly lower in NSSTC classroom. Based on the results we find SWIRLL (LEED) classroom has lower level of pollutants when compared to NSSTC (non-LEED) classroom except TVOCs. This suggests H1 is supported in most of the pollutants measured except TVOCs.

Table 6: Summary of t-test comparison of pollutants

Paired T-test		
Pollutant Comparison	t	Sig. (2-tailed)
TVOC in NSSTC (ppb) - TVOC in SWIRLL (ppb)	-59.520	0.000
CO_2 in NSSTC (ppm) - CO_2 in SWIRLL (ppm)	49.499	0.000
CO in NSSTC (ppm) - CO in SWIRLL (ppm)	78.884	0.000
HCHO in NSSTC (ppb) - HCHO in SWIRLL (ppb)	61.254	0.000

Graphical Analysis

The relationship between the weather and human health is heterogenous; the association varies by geography with varying cold related and heat related diseases (Bhaskaran, 2009; Ye, 2012). Studies have proven that there is a strong relationship between temperature and generation of pollutants (Lepeule, 2018). Also, a study by Nguyen, Schwartz, and Dockery, (2014), showed that there is a strong correlation between outdoor temperature and indoor temperature. Therefore, outdoor temperature plays an important role in variations of emission levels of pollutants. We compared the indoor air pollutants with respect to outdoor temperature.

TVOCs

Figure 2 summarizes the TVOCs measured across NSSTC and SWIRLL classrooms obtained during the study period. The relationship of TVOCs during weekdays and weekends based on outside temperature is studied. It can clearly be seen that in both NSSTC and SWIRLL classrooms during weekdays, TVOCs increase or decrease in consistent with outside temperature. During weekends, irrespective to increase or decrease in temperature TVOCs decreased in both the classroom. We speculate that TVOCs' variation is related to temperature variation and human activities inside the classroom.

To support this observation, we analyzed TVOCs when equal number of people are present inside the classroom. From figure 3 we find that when outside temperature decreases TVOCs in SWIRLL and NSSTC classroom decreased. Taken together, these results suggest temperature variation is associated with increased levels of TVOCs inside the classroom. Also, SWIRLL classroom emitted higher levels of TVOCs when compared to NSSTC classroom because the average indoor temperature inside SWIRLL classroom was higher when compared to NSSTC classroom (table 5).

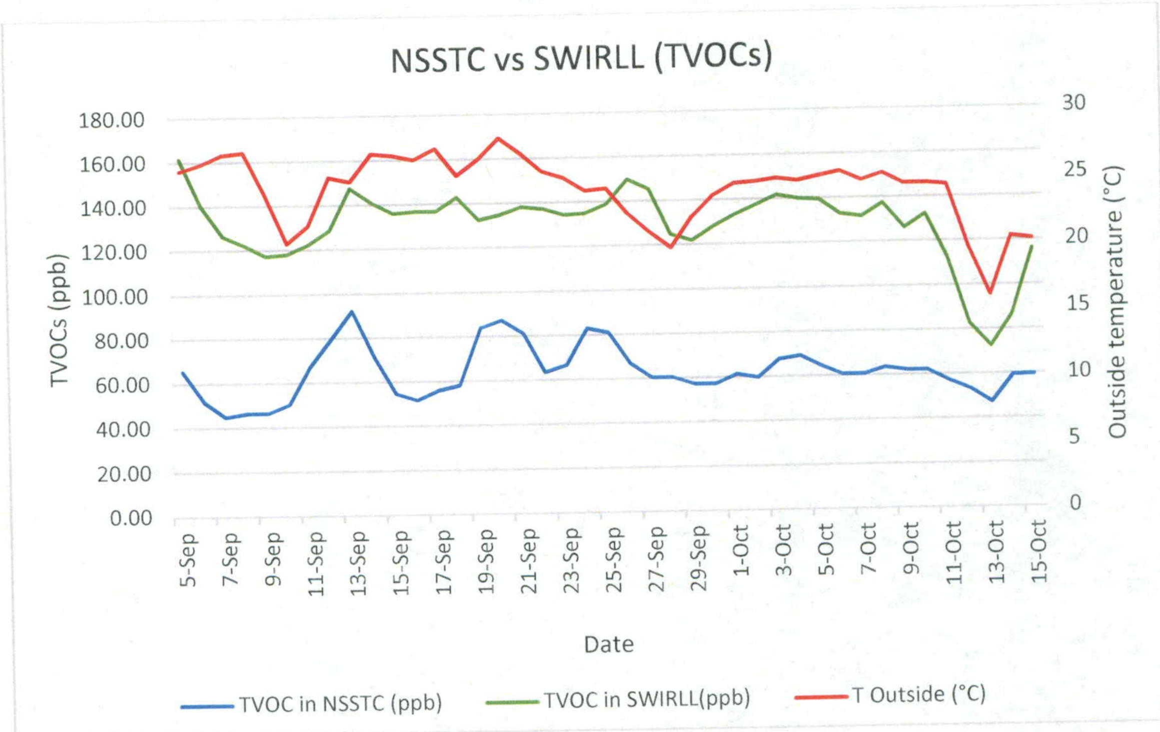

Figure 2 : Comparison of TVOCs between NSSTC and SWIRLL in respect to outside temperature

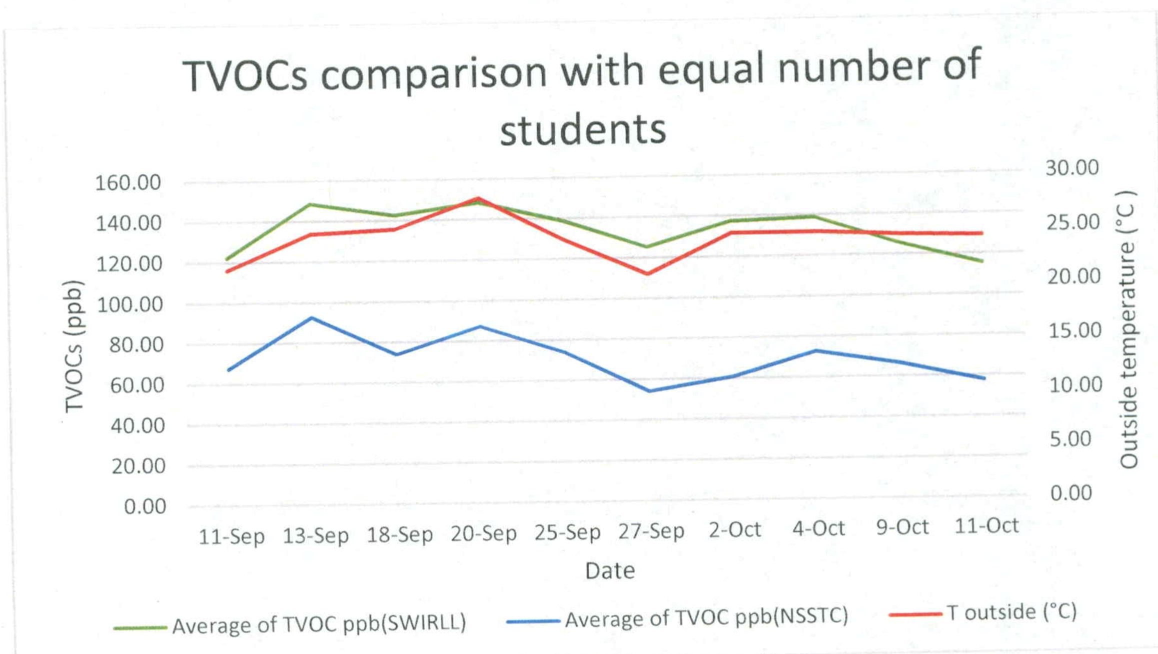

Figure 3: TVOCs comparison with equal number of students in respect to outside temperature

CO_2

Figure 4 summarizes the CO_2 measured across NSSTC and SWIRLL classrooms obtained during the study period. The relationship of CO_2 during weekdays and weekends based on outside temperature is studied. It can clearly be seen that in both NSSTC and SWIRLL classrooms outside temperature does not have any effect on CO_2. However, in general the graph showed that CO_2 levels in NSSTC was much higher compared to SWIRLL. From figure 4, we also found that CO_2 increases in the classrooms during weekdays i.e. when students were present. The ups and downs in the graph represent weekdays and weekend variations.

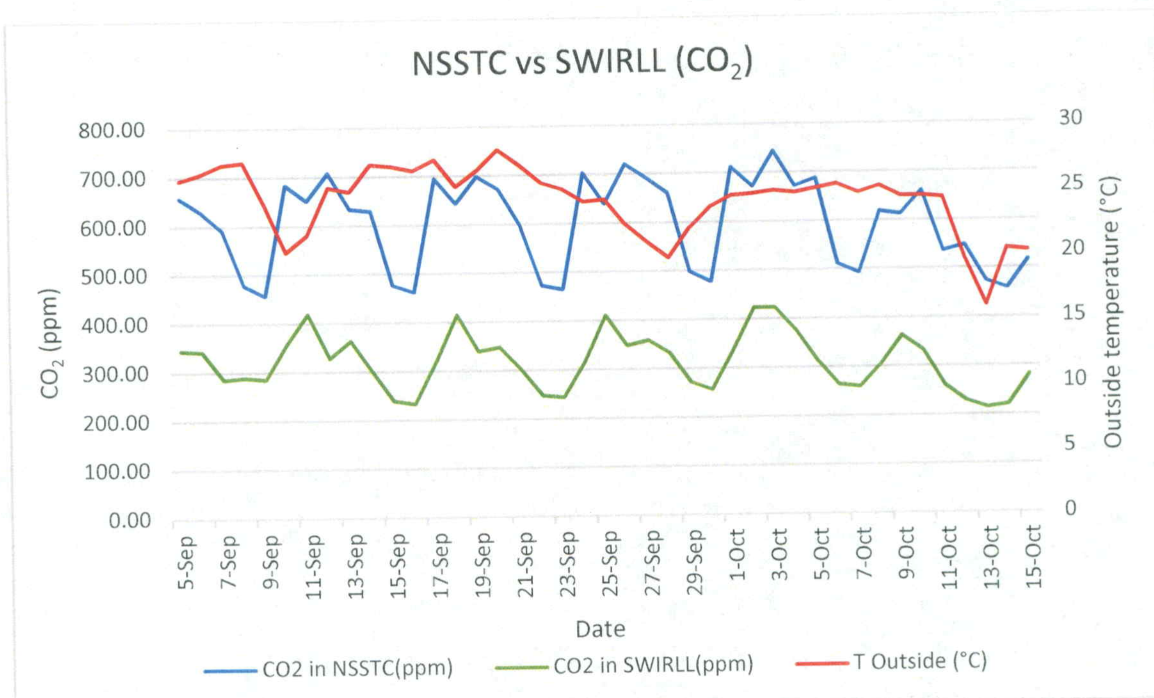

Figure 4: Comparison of CO_2 between NSSTC and SWIRLL in respect to outside temperature

In addition, we also compared the CO_2 concentrations between NSSTC and SWIRLL with equal number of students and the plot is represented in Figure 5. The average CO_2 concentrations were 644.25 ppm and 375.27 ppm in NSSTC and SWIRLL respectively. Taken together, these results suggest that SWIRLL (LEED) classroom maintained lower levels of CO_2 inside the classrooms when compared to NSSTC (non-LEED) classroom.

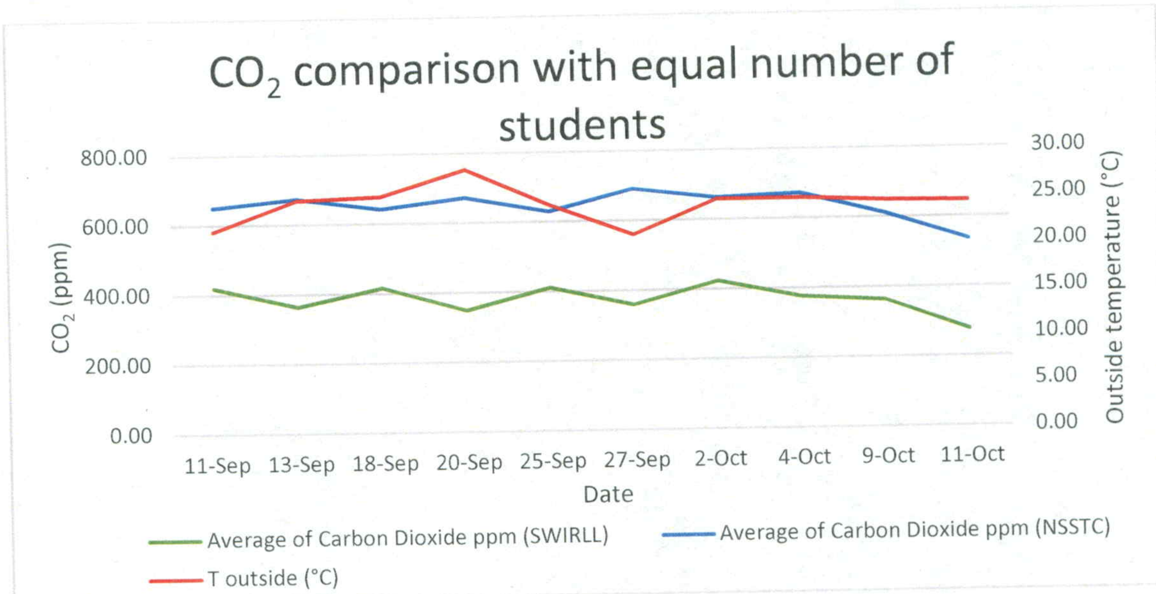

Figure 5: CO_2 comparison with equal number of students in respect to outside temperature

CO

Figure 6 summarizes the CO measured across NSSTC and SWIRLL obtained during the study period. The relationship of CO during weekdays and weekends based on outside temperature is studied. It can clearly be seen that in both NSSTC and SWIRLL classrooms outside temperature does not have any effect on CO. However, in general the graph showed that CO levels in NSSTC was much higher compared to SWIRLL. From figure 4, we also found that CO was higher during weekdays and lower during weekends.

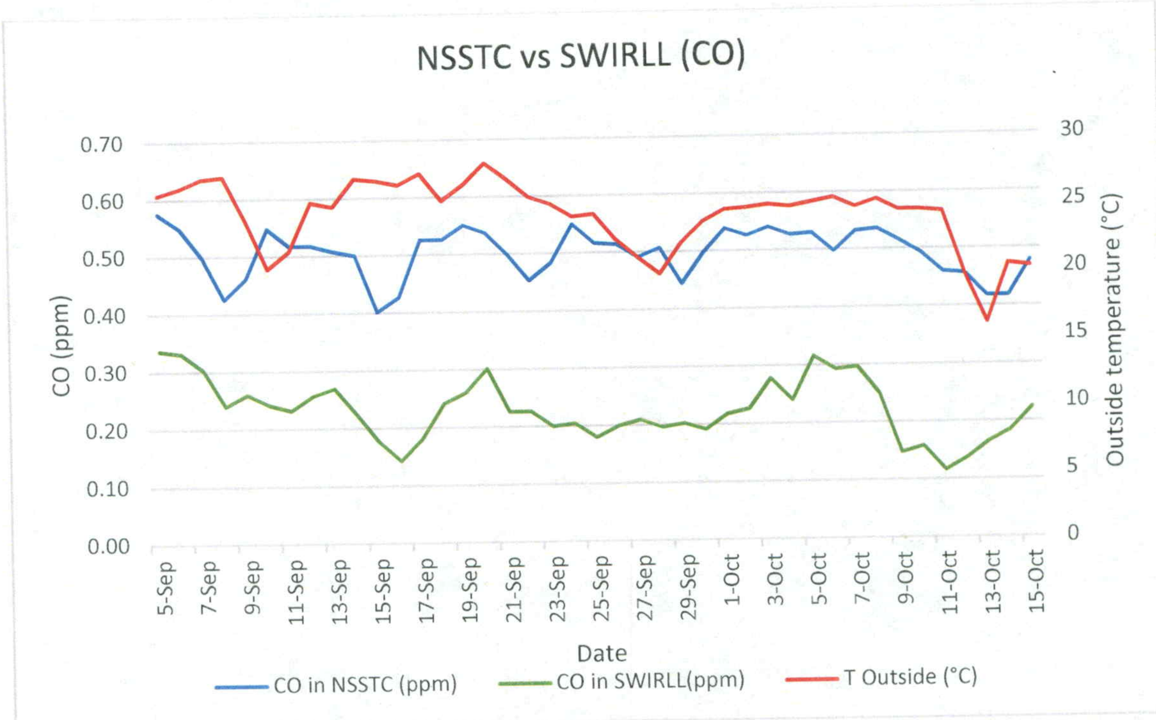

Figure 6: Comparison of CO between NSSTC and SWIRLL in respect to outside temperature

Figure 7 summarizes the changes in CO concentrations when equal number of students was present. The average CO concentrations in NSSTC and SWIRLL was 0.58 ppm and 0.26 ppm. This clearly indicated that the average of CO concentrations with equal number of students was higher when compared to the overall average. This shows that human presence inside the buildings will increase the CO concentrations. However, the limits are within allowable limits and SWIRLL maintained better CO when compared to NSSTC.

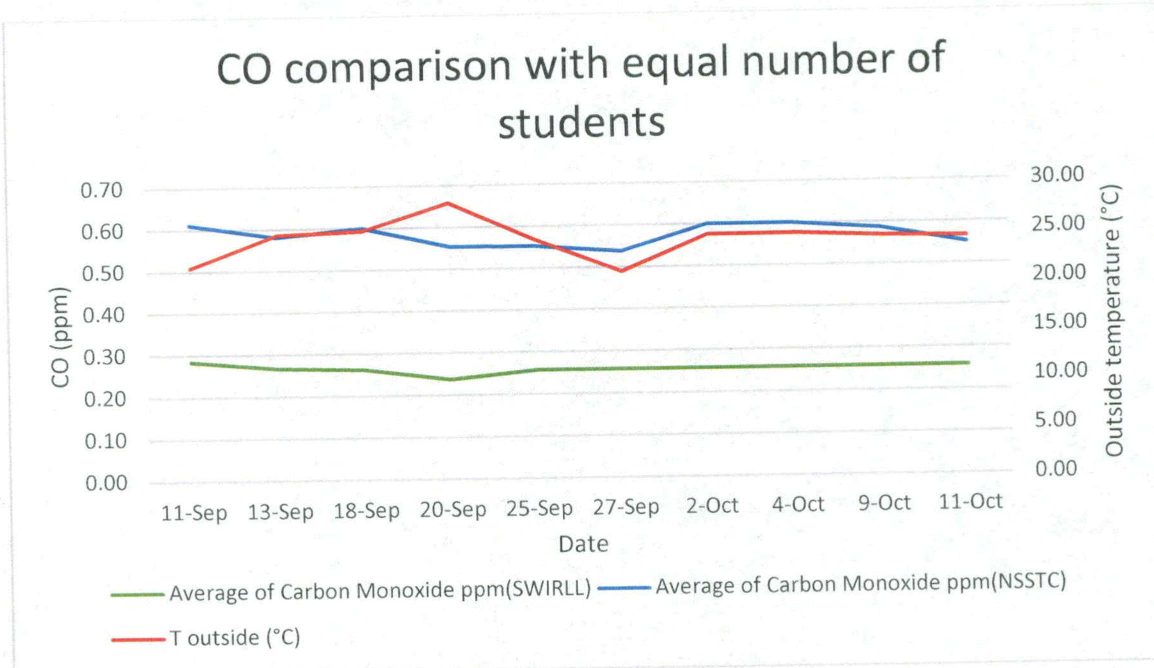

Figure 7: CO comparison with equal number of students in respect to outside temperature

HCHO

Figure 8 summarizes the HCHO between NSSTC and SWIRLL obtained during the study period. Two differences were found when HCHO relationship is studied with outside temperature. First, in both NSSTC and SWIRLL classrooms when outside temperature increased HCHO also increased. Second, when outside temperature decreased HCHO decreased only in NSSTC classroom, whereas HCHO remained constant in SWIRLL classroom.

To support this argument, we analyzed HCHO when equal number of people are present inside the classroom. From figure 9 we find that when outside temperature decreases HCHO in NSSTC decreased but SWIRLL maintained constant HCHO. Taken together, these results suggest that along with temperature some other variables contribute for HCHO concentration levels in both classrooms. But overall, SWIRLL has lower HCHO levels when compared to NSSTC classroom.

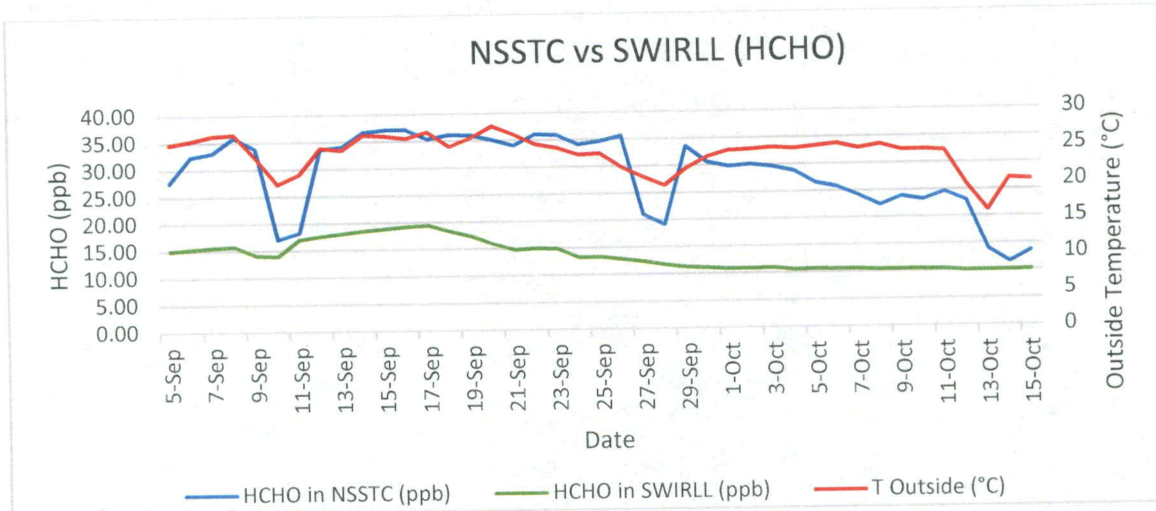

Figure 8:Comparison of HCHO between NSSTC and SWIRLL in respect to outside temperature

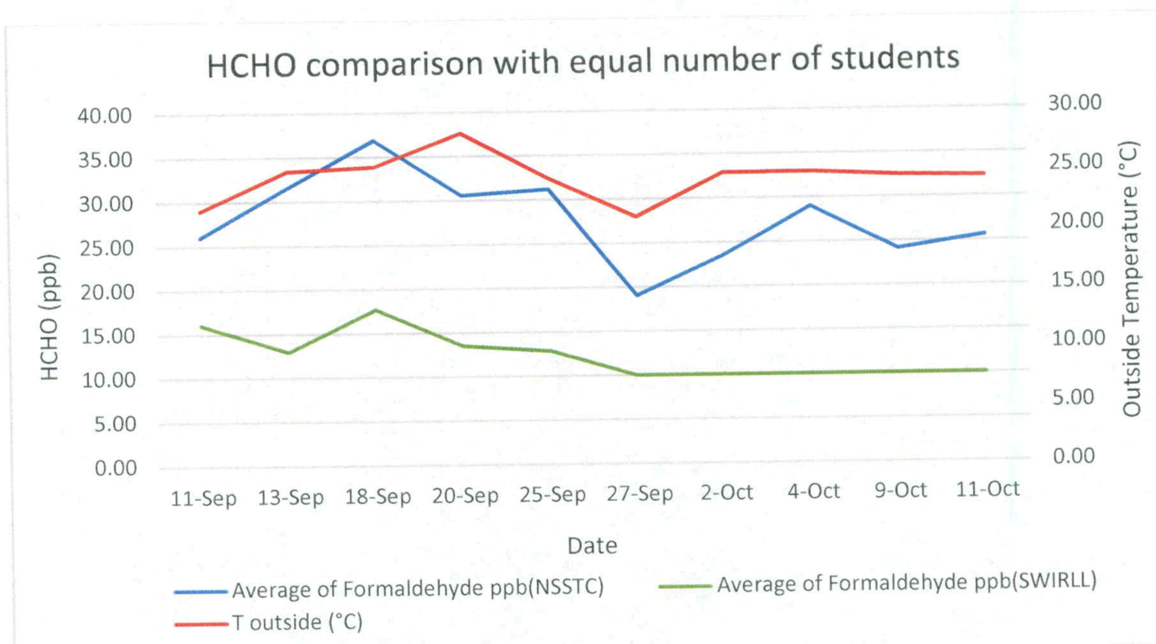

Figure 9: HCHO comparison with equal number of students in respect to outside temperature

The first research question was "Does LEED classroom have lower level of pollutants when compared to non-LEED classrooms?" and the hypothesis assumed is

"LEED classrooms have lower level of pollutants when compared to non-LEED classrooms". Based on the results from t-test and graphical analysis we conclude that except TVOCs, other pollutants are lower in SWIRLL (LEED classroom) than NSSTC (non-LEED classroom). This shows my hypothesis is partially supported.

4.1.2 Relationship between environmental variables and indoor air pollutants

Pearson Correlation

Based on the graphs we found that in general, SWIRLL maintains better indoor air quality (except TVOCs) when compared to NSSTC. This study examined any potential correlational relationships between environmental variables and pollutants, a Pearson correlation was used to assess the relationship between the measured pollutants (TVOCs, CO2, CO, HCHO) and environmental variables. The environmental variables were indoor temperature, indoor relative humidity, outdoor temperature and outdoor relative humidity.

As indicated in table 7, all the variables reported weak, moderate and strong correlations with levels of air pollutants except CO_2, and TVOCs. Ten of the correlations were positive, while three were negative. Overall, TVOCs had a positive correlation with outside temperature, indoor relative humidity and indoor temperature i.e. when outside temperature, indoor relative humidity, indoor temperature increased TVOCs also increased. Outside relative humidity is not significant which means it has no impact on TVOCs.

HCHO had a positive correlation with outside temperature, outside relative humidity, indoor temperature and indoor relative humidity i.e. when outside temperature, indoor relative humidity, indoor temperature increased it also increased HCHO.

CO_2 had a positive correlation with outside temperature, indoor relative humidity and negative correlation with indoor temperature i.e. when outside temperature indoor relative humidity increases it also increases CO_2. Whereas when indoor temperature increased it decreased CO_2 levels. Outside relative humidity is not significant which means it has no impact on CO_2.

Table 7: Pearson correlation between variables and pollutants

Pearson Correlation					
		CO (ppm)	CO_2 (ppm)	HCHO (ppb)	TVOCs (ppb)
Outside Temperature	Correlation coefficient	.337**	.211**	.242**	.341**
	Sig. (2-tailed)	0.0	0.0	0.0	0.0
Outside RH	Correlation coefficient	-.123*	-.052	.141**	.042
	Sig. (2-tailed)	0.016	0.107	0.0	0.195
Indoor RH	Correlation coefficient	.360**	.493**	.360**	.596**
	Sig. (2-tailed)	0.0	0.0	0.0	0.0
Indoor Temperature	Correlation coefficient	-.196**	-.404**	.262*	.204**
	Sig. (2-tailed)	0.0	0.0	0.025	0.0
**. Correlation is significant at the 0.01 level (2-tailed).					
*. Correlation is significant at the 0.05 level (2-tailed). Total observations = 956					

CO had a positive correlation with outside temperature, indoor relative humidity and negative correlation with outside relative humidity, indoor temperature i.e. when outside temperature and indoor relative humidity increased it also increased CO. Whereas, when indoor temperature and outside relative humidity increased it decreased CO levels.

Multiple Regression

In order to determine the contribution made by temperature and relative humidity to indoor pollutant levels a regression model was used to predict the dependent variable by examining the set of independent variables. The dependent variables were TVOCs, CO_2, HCHO, and CO. The predictor or independent variables were indoor temperature, indoor relative humidity, outside temperature and outside relative humidity. Based on the number of dependent variables four models were constructed. Model 1 examines the relationship between each predictor variables and the dependent variable (TVOCs). Similarly, Model 2,3, and 4 examines the relationship between each of the predictor variables with levels of HCHO, CO_2, CO respectively.

For Model 1(TVOCs) based on the results of beta coefficients all the four predictor variables showed significance. The result indicates that for every unit increase in outdoor relative humidity there is 0.235 ppb increase in TVOCs. For every unit increase in outdoor temperature there is 0.628 ppb increase in TVOCs. For every unit increase in indoor relative humidity there is a 2.090 ppb increase in TVOCs. For every unit increase in indoor temperature there is 2.369 ppb increase in TVOCs. Looking over the beta coefficients indoor temperature ($\beta = 2.369$, $p=0.000$) has higher impact to TVOCs.

Table 8:Multiple regression Output showing contribution of predictor variable to the dependent variable of all the pollutants

Predictors		**TVOC (ppb)**	**HCHO (ppb)**	**CO2 (ppm)**	**CO (ppm)**
Outside RH	Beta Coefficient	0.235*	0.168*	-0.398	0.003*
	Sig. (2-tailed)	0.000	0.000	0.243	0.000
Outside temperature	Beta Coefficient	0.628*	0.357*	-0.97	0.001*
	Sig. (2-tailed)	0.000	0.000	0.899	0.015
Indoor RH	Beta Coefficient	2.090*	1.584*	12.039*	0.02*
	Sig. (2-tailed)	0.000	0.023	0.000	0.025
Indoor temperature	Beta Coefficient	2.369*	-0.582*	-39.103*	-0.16*
	Sig. (2-tailed)	0.000	0.036	0.000	0.000
R Squared		0.372	0.216	0.309	0.187
*– denotes p value < 0.05					

For Model 2 (HCHO) based on the results of the beta coefficients all the four predictor variables showed significance. The result indicates that for every unit increase in outdoor relative humidity there is 0.168 ppb increase in HCHO. For every unit increase in outdoor temperature there is 0.357 ppb increase in HCHO. For every unit increase in indoor relative humidity there is 1.584 ppb increase in HCHO. For every unit decrease in indoor temperature there is -0.582 ppb increase in HCHO. Looking over the beta coefficients indoor relative humidity ($\beta = 1.584$, $p=0.023$) has higher impact to HCHO.

For Model 3(CO_2) based on the results of the beta coefficients only two of the four predictor variables showed significance. The result indicates that for every unit increase in indoor relative humidity there is 12.039 ppm increase in CO_2. For every unit decrease in indoor temperature there is 39.103 ppm increase in CO_2. Based on beta coefficient indoor temperature (β = -39.103, p=0.000) has higher impact to CO_2.

For Model 4(CO) based on the results of the beta coefficients all the four predictor variables showed significance. The result indicates that for every unit increase in outdoor relative humidity there is 0.003 ppm increase in CO. For every unit increase in outdoor temperature there is 0.001 ppm increase in CO. For every unit increase in indoor relative humidity there is 0.02 ppm increase in CO. For every unit decrease in indoor temperature there is -0.16 ppm increase in CO. Based on beta coefficient values indoor relative humidity (β = -0.16, p=0.000) has higher impact to CO.

In summary, to examine the potential correlational relationships between environmental variables and pollutants regression and Pearson correlation analysis were used. Pearson correlation results indicated that all the environmental variables and pollutants have correlational relationship. From regression analysis we find indoor temperature has higher impact for change in TVOCs, CO_2, and CO and indoor relative humidity has higher impact for change in HCHO in indoor classrooms.

4.1.3 Day and Night differences

From the above analysis we showed the contribution and relationship between predictor variables with respect to the pollutants. But we couldn't explain about the differences in pollutants with respect to day and night. To respond to the third research question "Do pollutants vary between day and night?" independent t-tests were conducted. To do this analysis the data is separated into day and night, then, this data is fed into SPSS software and t-test is run for the data and the results are shown in the below tables.

Table 9: Group statistics for pollutants using independent sample t-test

Measured parameters		Mean	Std. Deviation	Std. Error Mean
TVOCs (ppb)	Day	98.43	32.54	1.5
	Night	98.78	21.7	1
CO (ppm)	Day	0.37	0.08	0
	Night	0.35	0.09	0
CO_2 (ppm)	Day	465.42	209.38	9.68
	Night	453.59	121.63	5.62
HCHO (ppb)	Day	22.74	7.88	0.36
	Night	21.96	8.15	0.38
Outside RH (%)	Day	67.35	15.89	0.73
	Night	84.28	9.73	0.45
Outside T (^oC)	Day	26.53	4.47	0.21
	Night	21.67	3.25	0.15
Indoor T (^oC)	Day	24.98	1.45	0.07
	Night	25.14	0.77	0.04
Indoor RH (%)	Day	47.4	5.52	0.26
	Night	45.88	3.56	0.16

Table 9 provides the descriptive statistics for the sample population. There were 468 cases in both day and nighttime measured data respectively. The report indicated that indoor relative humidity, outside temperature, HCHO, CO_2, CO had higher day time means when compared to nighttime. Whereas, TVOCs, indoor temperature, outside temperature had higher nighttime mean than daytime.

Table 10: Independent sample t- test result that shows the average mean differences between day and nighttime measurements

Independent Samples Test		
	t-test for Equality of Means	
	t	Sig. (2-tailed)
TVOCs (ppb)	-0.286	0.775
CO (ppm)	5.165	0.000
CO_2 (ppm)	1.593	0.112
HCHO (ppb)	3.861	0.000

The purpose of the t-test is to identify whether there is any difference between day and nighttime measured pollutants. The t-test indicated significant differences in HCHO and CO regarding measured pollutants in day and nighttime. But TVOCs and CO_2 does not show any significant differences between day and night. Based on the results, we can state that there was a significant difference in means between day and night in HCHO (t (936) = 3.861, p = 0.000) and CO (t (936) = 5.165), p= 0.000). From table 10 we found that daytime means was higher for CO, CO_2, and HCHO than nighttime, whereas, for TVOCs nighttime mean was higher. The reason for higher nighttime means for TVOCs can be explained from table 9 and table 8. Since indoor temperature were higher during nighttime and TVOCs have positive correlation with indoor temperature, this increased the mean of TVOCs in nighttime. The results from independent t-test partially supports H3 that daytime measured pollutants were higher than night time except TVOCs.

4.2 Survey Data

The maintenance of indoor air quality in schools and universities is key to the well-being and productivity of the occupants (Altomonte & Schiavon, 2013). Occupant satisfaction over buildings have been studied vigorously (Abbaszadeh, 2006; Agha-Hossein, 2013; Kweon, 2017) and there is always contradiction between various factors like ventilation, lighting, acoustics, dust, etc. especially when it comes to green and non-green buildings contradiction becomes wider (Gou, Prasad, & Siu-Yu Lau 2013; Huizenga, 2006; Pei, 2015). Overall these studies provided a good understanding of the awareness and satisfaction among the occupants in the buildings. In this section we evaluated satisfaction among students between NSSTC and SWIRLL classrooms using statistical methods and graphical representations.

Descriptive Statistics

In this study, the survey questionnaire aimed to understand the satisfaction among students and to identify the disturbing factors in NSSTC and SWIRLL classrooms. The questionnaire was developed referencing CBE survey. The survey questions can be found in Appendix B. During the actual survey, a paper copy of the questionnaire was also distributed to the students who could not complete the survey online. As summarized in table 12 and figure 11, the total number of participants for this survey was 56 students out of which 56% of the students attended classes in only NSSTC and 38% of students attended in both NSSTC and SWIRLL and remaining 6% attended only in SWIRLL building.

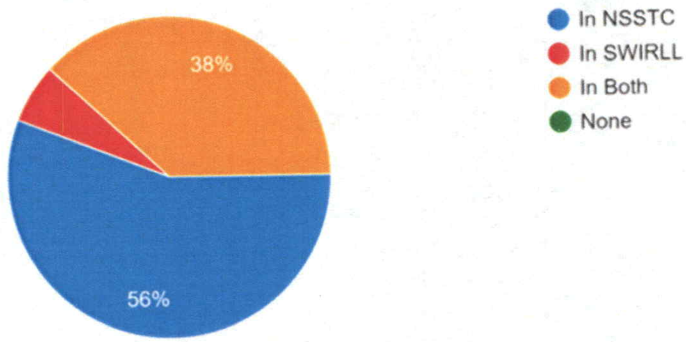

Figure 10: Responses showing where students attend their classes

Independent sample T-test

To respond to our second research question "Which classroom has higher satisfaction rate in indoor environmental quality?" this study employed the use of independent t-test. The participants were asked to rate their satisfaction in ventilation, flooring, dust, concentration and illumination, the votes are categorized in an increasing order of "Poor" (1) to "Excellent" (5). There were forty-two responses for NSSTC classroom and 14 responses for SWIRLL classroom. The group statistics indicated except condition of flooring the mean satisfaction rate was higher in NSSTC when compared to SWIRLL classroom.

In table 12 the data shows where there are significant differences between NSSTC and SWIRLL classroom as related to the variables of participation as measured by ventilation, condition of flooring, dust, concentration and illumination. Based on the results, we can state that there was a significant difference in satisfaction means between NSSTC and SWIRLL in ventilation ($t = 2.663$, $p = 0.01$) and concentration ($t = 2.259$, p

= 0.028). Also, from table 11 we find except condition of flooring, NSSTC classroom had higher mean satisfaction score in illumination, concentration, dust and ventilation when compared to SWIRLL classroom.

Table 11: Group statistics from independent sample t-test

Longer in NSSTC or SWIRLL		N	Mean	Std. Deviation
How will you rate the Ventilation (Air circulation) of the classroom?	NSSTC	42	3.64	1.008
	SWIRLL	14	2.86	0.770
How would you rate the condition of flooring?	NSSTC	42	3.71	0.995
	SWIRLL	14	4.00	0.877
How would you rate the dust inside the classroom?	NSSTC	42	3.60	0.939
	SWIRLL	14	3.36	1.082
How will you rate your concentration during class hours?	NSSTC	42	3.71	0.835
	SWIRLL	14	3.14	0.770
How would you rate the illumination (lighting) inside the classroom?	NSSTC	42	4.10	0.958
	SWIRLL	14	3.93	0.829

In another question, the participants were asked to rate the overall satisfaction rate between the two classrooms. The result from table 13 indicated overall mean satisfaction rate for SWIRLL classroom was higher when compared to NSSTC classroom. This result support our H2 where LEED certified (SWIRLL) classroom has a higher satisfaction rate.

Table 12: Independent sample t-test results that shows the satisfaction rate between NSSTC and SWIRLL

Independent Samples Test			
	t-test for Equality of Means		
	t	df	Sig. (2-tailed)
How will you rate the Ventilation (Air circulation) of the classroom?	2.663	54	0.01
How would you rate the condition of flooring?	-0.957	54	0.343
How would you rate the dust inside the classroom? (Furniture)	0.791	54	0.432
How will you rate your concentration during class hours?	2.259	54	0.028
How would you rate the illumination (lighting) inside the classroom?	0.582	54	0.563

Table 13: Descriptive statistics of overall satisfaction in NSSTC and SWIRLL

Descriptive Statistics					
	N	Minimum	Maximum	Mean	Std. Deviation
How will you rate the overall satisfaction of classroom in NSSTC?	56	1	5	3.93	0.970
How will you rate the overall satisfaction of classrooms in SWIRLL?	49	1	5	4.29	0.890
Valid N (listwise)	49				

The crosstab results are shown table 14. We inferred from the table that out of all the factors asked, temperature was the major factor that affected students in both NSSTC and SWIRLL classrooms. Overall, 57.1% of the participants said temperature was a major concern and the next affecting factor was odor which accounted for 14.3% respondents. Figure 12 represents the number of counts(respondents) voted for every disturbing factor inside the classrooms. This showed that thirty-two participants voted temperature as a major disturbing factor. Eight participants reported odor as a disturbing factor inside the classroom. Three participants reported air quality as a concern inside the classroom. Eight participants reported illumination inside the classroom as a concern. Eight participants reported other factors such as noise, health issues disturb them inside the classroom.

Table 14: Crosstab result showing the factors that affect in NSSTC and SWIRLL classrooms

Out of these factors, which one disturb your concentration most in the classroom? * NSSTC or SWIRLL Crosstabulation					
			NSSTC or SWILL		Total
			NSSTC	SWIRLL	
Out of these factors, which one disturb your concentration most in the classroom?	Temperature	Count	25	7	32
		% of Total	44.6%	12.5%	57.1%
	Air quality	Count	2	1	3
		% of Total	3.6%	1.8%	5.4%
	Odor	Count	6	2	8
		% of Total	10.7%	3.6%	14.3%
	Improper ventilation	Count	2	3	5
		% of Total	3.6%	5.4%	8.9%
	Other	Count	7	1	8
		% of Total	12.5%	1.8%	14.3%
Total		Count	42	14	56
		% of Total	75.0%	25.0%	100.0%

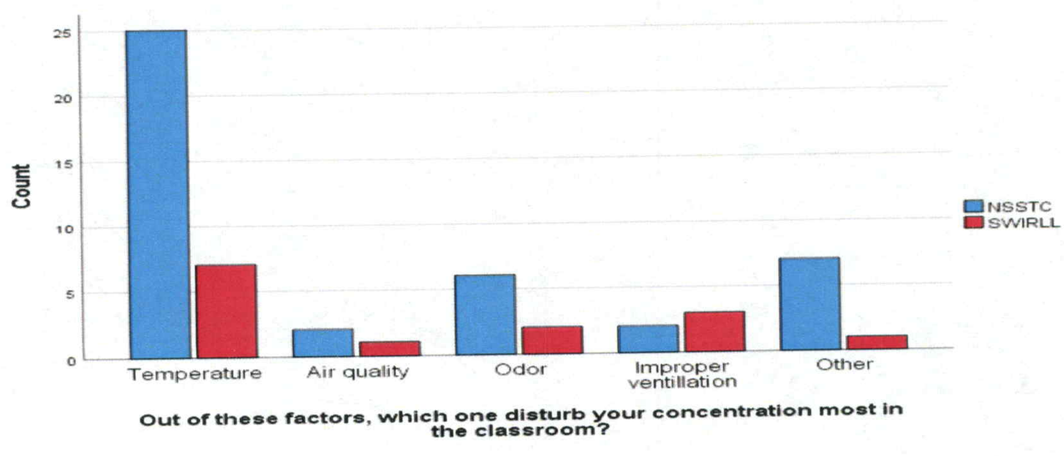

Figure 11: Factors affecting in NSSTC and SWIRLL

CHAPTER FIVE

Discussion and Concluding Remarks

We spend most of our time in confined spaces. In developed countries an average adult spends around 90% of the time in indoor environment. Therefore, indoor air quality (IAQ) is a significant problem that needs to be addressed (Dionisio, 2017). IAQ have received considerable attention from the public as well as from researchers. After homes, schools are the most important indoor environment for students, who spend over 1000 hours each year at school (Tham, 2016). Students represent a potentially vulnerable population, one that may be especially susceptible to pollutant exposure. Changes in school buildings and spaces start to reflect the values of green and healthy learning environments, as an influence from communities that demand more green spaces in educational facility planning and design (Haq, 2011). These changes created the importance of understanding the differences in indoor air pollutants between LEED and non-LEED buildings.

This study sought to examine the differences in TVOCs, CO_2, CO and HCHO in LEED (SWIRLL) classroom and non-LEED (NSSTC) classroom and, the satisfaction among the students between the two classrooms. The rest of this chapter will discuss the findings and limitations of the study, identify areas in need of future research, and draw conclusions for consideration by university administrators.

5.1 Discussion

This study was designed as an investigation to determine which classroom, either LEED or non-LEED classroom has better indoor air quality and higher satisfaction rate using observations and survey questionnaire. The first hypothesis "Whether LEED classroom have lower level of pollutants when compared to non-LEED classroom" was tested using paired t-test and graphs. From paired t-test, significant differences were found in all the pollutants in both the classrooms. However, from the means of TVOCs, CO_2, CO and HCHO it was found that except TVOCs, SWIRLL had lower level of pollutants when compared to NSSTC classroom. In order to understand about the lower levels of TVOCs in NSSTC, TVOCs of NSSTC and SWIRLL are plotted against outside temperature. The graph showed that TVOCs increased when outside temperature increased, which shows TVOCs are temperature dependent as mentioned in previous studies (Zhong, Su, & Batterman, 2017). Also, in a study by Nguyen, Schwartz, and Dockery (2014) they showed that there is a strong correlation between outdoor temperature and indoor temperature. In this study, we found the average indoor temperature in SWIRLL was higher than NSSTC classroom which explains the reason for the higher TVOCs in SWIRLL classroom.

As TVOCs showed dependency with temperature, all the pollutants were examined to find whether any relationship exist between pollutants (TVOCs, CO_2, CO and HCHO) and environmental variables (temperature, relative humidity). In order to examine the potential correlational relationships between environmental variables and pollutants regression and Pearson correlation analysis were used. The results from Pearson correlation analysis indicated that all the environmental variables had either weak or moderate correlational relationship with the pollutants.

TVOCs had a positive correlation with outside temperature, indoor relative humidity and indoor temperature i.e. when outside temperature, indoor relative humidity, indoor temperature increased it also increased TVOCs. In order to determine which environmental variable has a major impact on TVOCs regression models were used. The result showed that indoor temperature had higher impact and for every unit increase in indoor temperature there is 2.369 ppb increase in TVOCs. Also, when indoor temperature increases furniture's emit more TVOCs (Mečiarová et al., 2017) this explains the reason why SWIRLL classroom has higher TVOCs. Furthermore, in a study by Ho, Kim, Sohn, Oh, & Ahn, (2011) showed that older furniture's tend to emit lower TVOCs when compared to newer ones. As SWIRLL classroom is just three years old when compared to NSSTC which is eighteen years old, this also explains the reason of higher TVOCs in SWIRLL classroom.

From table 5 we find that NSSTC (28.89 ppb) classroom had higher mean of HCHO when compared to SWIRLL (13.57 ppb) classroom. To understand the higher levels of HCHO in NSSTC we compared the correlational relationship of HCHO and environmental variables. The results showed that HCHO had a positive correlation with outside temperature, outside relative humidity, indoor temperature and indoor relative humidity i.e. when outside temperature, indoor relative humidity, indoor temperature increased it also increased HCHO. In order to determine which environmental variable has a major impact on HCHO regression models were used. The result showed that indoor relative humidity had higher impact and for every unit increase in indoor relative humidity there is 1.584 ppb increase in HCHO. The higher impact of indoor relative humidity on HCHO reflexes what Zhong et al., (2017) reports that relative humidity acts as a promoter that increases the catalytic activity of the formaldehyde oxidation reaction. From table 5 we find that indoor relative humidity for NSSTC classroom was higher when compared to SWIRLL classroom which explains the reason of higher HCHO in NSSTC classroom.

From table 5 we find that NSSTC (604.11 ppm) classroom had higher mean of CO_2 when compared to SWIRLL (314.77 ppm) classroom. To understand the higher levels of CO_2 in NSSTC we compared the correlational relationship of CO_2 and environmental variables. The results showed CO_2 had a positive correlation with outside temperature, indoor relative humidity and negative correlation with indoor temperature i.e. when outside temperature, indoor relative humidity increased it also increased CO_2. Whereas when indoor temperature increased it decreased CO_2 levels. In order to determine which environmental variable has a major impact on CO_2 regression models were used. The result showed that indoor temperature had higher impact and for every unit increase in indoor temperature there is 39.103 ppm decrease in CO_2. A study by Yang Razali et al., (2015) showed indoor temperature and CO_2 has negative relationship. From table 5 we find indoor temperature of NSSTC lower than SWIRLL classroom which explains the reason why CO2 levels are higher in NSSTC classroom.

From figure 6, CO levels inside the classroom increased during weekdays and decreased during weekend. This fluctuations showed human activity increases CO concentration inside the classrooms similar to a study by Liu et al., (2016). Also, CO had a positive correlation with outside temperature, indoor relative humidity and negative correlation with outside relative humidity, indoor temperature i.e. when outside temperature and indoor relative humidity increased it also increased CO. Whereas, when indoor temperature and outside relative humidity increases it decreases CO levels. As indoor temperature in NSSTC is lower than SWIRLL, NSSTC classroom had higher CO concentration levels. The negative relationship found in this study between temperature and CO levels is also explained by Yang Razali et al., (2015). Overall, the findings in this study showed that SWIRLL (LEED) classroom has lower levels of pollutants than NSSTC (non-LEED) classrooms except TVOCs.

To answer our second question, survey questionnaire was prepared, and responses were collected from the participants. A total of 56 individual responses were collected using a web-based survey and paper in LEED and non-LEED certified classrooms. The data obtained from the survey are cleaned and segregated to test our hypothesis LEED certified classroom has higher satisfaction rate in indoor environmental quality.

The hypothesis is tested using independent sample t-test. The independent sample t-test tested are there differences in satisfaction rate in ventilation, flooring, dust, illumination, and concentration between SWIRLL and NSSTC classrooms. The results showed that there was a significant difference in satisfaction means in ventilation and concentration. The mean satisfaction score showed that NSSTC classroom is better than SWIRLL classroom in ventilation and concentration. As mentioned in Chapter 2, this may explain the reason for higher satisfaction in NSSTC for ventilation, and concentration. Also, the other three variables did not show any significant difference, which means, there is no difference in satisfaction score for dust, illumination and condition of flooring. Past literature has reported, there is no differences in occupant's satisfaction between LEED and non-LEED buildings (El Asmar et al., 2014). However, in an overall satisfaction rate SWIRLL (LEED) classroom had a higher satisfaction rate of 4.29 when compared to NSSTC (non-LEED) classroom. Higher satisfaction score of LEED classroom in this study reflexes what Altomonte & Schiavon, (2013) reportes that even though there is not a significant difference in IEQ between LEED and non-LEED buildings, overall satisfaction votes revealed LEED building tends to be slightly more satisfied. Also, we identified the most disturbing factors in both the classrooms among temperature, air quality, odor, and ventilation. The results showed 57.1% of students responded that temperature was a major concern in both the classrooms which disturbed their concentration.

To respond to the third research question, the data from the observations are separated based on day and nighttime. The separated data is used to test our hypothesis daytime measured pollutants will be higher than nighttime. The hypothesis is tested using independent sample t-test. The t-test identified whether there is any difference between day and nighttime measured pollutants. The results showed significant differences in HCHO and CO between day and nighttime. Also, we found HCHO, CO, and CO_2 had higher day time mean when compared to nighttime. The reason for higher day time means can be explained from table 5. Average indoor relative humidity during day time was higher which explains the reason why HCHO was higher during day time, as higher relative humidity promotes formation of HCHO (Zhong et al., 2017). Also, indoor temperature was lower during daytime, and CO_2, CO had negative relationship with temperature, (Yang Razali et al., 2015) this explains the reason why CO_2, and CO had higher day time mean when compared to nighttime. From table 9 we find the mean of

TVOCs were higher in nighttime. This is because indoor temperature was higher in night time and TVOCs increases when temperature increases (Zhong et al., 2017). Overall, except TVOCs all other pollutants were higher in daytime.

5.2 Future Research

It is important to continue the research of indoor air pollutants and their relationship with temperature, humidity and various other factors. Based on the findings of this study, the following recommendations are suggested for future research:

1. Continue further research on indoor air pollutants in schools which will promote green buildings.
2. Continue further research by increasing the survey sample size which will promote in better understanding of satisfaction rate between LEED and non-LEED buildings.
3. Continue further research on measuring other indoor air pollutants to have an understanding about its differences between LEED and non-LEED classrooms.

While this study specifically examined the indoor air pollution in classroom level as it directly relates to the students within the classroom, building level examination of indoor air pollutants can be researched which will give an understanding about the distribution of pollutants in different levels of building. Acknowledging the limited research on indoor air pollutants between LEED and non-LEED buildings there is much to be learned regarding the behavior of indoor air pollutants. For instance, additional research could focus on observing the indoor air pollutants for a prolonged period so that the indoor air pollutant variations can be studied based on seasons. This will give a better understanding of how buildings react to different seasons and how the indoor pollutants are maintained by the buildings. In this study the average age of the participants in survey was twenty-three years. By distributing the questionnaire to all the people inside the building will give us a large sample size and to gain a better understanding how the satisfaction scores vary between different age groups.

5.3 Limitations

In this study, one of the major limitations is that we did not measure or consider all the variables that can alter the indoor air pollutants. Also, while selecting classrooms use and presence of electronics were not considered. Another major limitation in this study is we could not keep track of the activities taking place when classrooms being used apart from the classroom hours. Also, we couldn't monitor the number of times the main door of the classrooms was opened in a day. Similar to the current study, most quantitative data were observed just from measurements because tracking down all the parameters emitting indoor air pollutants is difficult. It is also difficult to generalize the results of this study to other indoor air pollutant comparisons. Most of the studies focused on post occupancy evaluation of indoor air quality and some studies quantitatively measured indoor air pollutants in offices and large buildings, thus limiting generalizability (El Asmar et al., 2014; Gou et al., 2012; Scofield, 2013). However, given the limited time and resource of a master thesis, the study maintains its rigor by selecting a comparable classroom setting by taking account of a similar size and the location of the two classrooms. Also, the number of students in both the classrooms remained below ten which also provided a better result for this study.

5.4 Conclusion and Recommendations

Previous literatures on indoor air quality between LEED and non-LEED buildings showed LEED buildings enhances indoor air quality. The findings presented in this study also showed, SWIRLL (LEED) classroom had lower indoor air pollutants when compared to NSSTC (non-LEED) classroom throughout the study period. Therefore, LEED-certified buildings maintain better indoor air quality than non-LEED buildings. Several studies indicated strong association of temperature and humidity in generation of pollutants. Even this study showed indoor temperature and indoor relative humidity had a strong relationship with TVOCs, CO_2, CO, and HCHO. So, control of temperature and humidity will aid in reducing indoor air pollutants. This study recommends UAH that humidity control and consistent indoor temperature can be considered as a counter measure to control of indoor air pollutants in buildings. Also, this data can be utilized while designing the buildings by giving appropriate weightage to indoor environmental quality like ventilation, illumination etc... Finally, from the survey data, we found that indoor temperature is a major affecting factor among students. So, based on the end-user response indoor temperature should be controlled in UAH classrooms which will increase the concentration among the students as well as improve their performance (B. S. Kweon, Ellis, Lee, & Jacobs, 2017). Construction of LEED buildings in educational institutions could be costly; nonetheless, they enhance indoor air quality and improves student's health and performance.

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APPENDIX A

Comparison graphs of Temperature and relative humidity

Temperature:

Error! Reference source not found. summarizes the inside temperature maintaind by NSSTC and SWIRLL. According to Center for the Built Environment (CBE), the optimal indoor temperature is when the buidling maintains between 23^0 to 25^0 (^{0}C) (Frontczak, 2012). The average temperature measured inside NSSTC vs SWIRLL was 24.76 ^{0}C and 25.49 ^{0}C respectively. However, from this measured value we cannot come to a conclusion because the air conditioning unit is being shut off in both the buildings from 6.00 pm-7.00 am. So, we compared the inside tempreature during daytime to find out which building mainatined the tempereature. Based upon that we find measured temperature inside NSSTC and SWIRLL was 24 ^{0}C and 25.9 ^{0}C respectively. Therefore, NSSTC maintained the recommened temperature when compared to SWIRLL. However, from the plot for temperature we can find that inside temperature in NSSTC had lot of variations, whereas, SWIRLL mainited the inside temperature constantly.

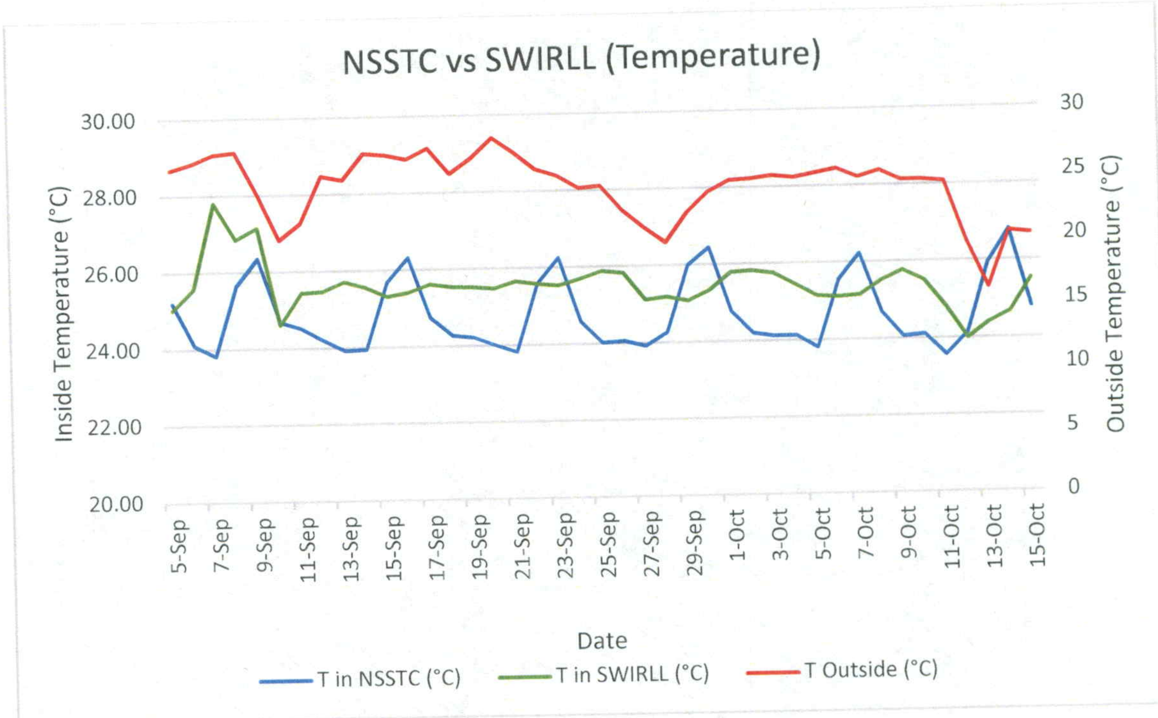

Figure 12:Comparison of Temperature between NSSTC and SWIRLL

Relative Humidty:

Error! Reference source not found. summarizes the inside relative humidity (RH) maintaiend by NSSTC and SWIRLL. Various studies have indicated that optimal RH in indoor environment is around 40% and when RH in indoor environment increased above 50% or decreased below 30% significant health effects have been observed (Fang, 1998; Wolkoff and Kjærgaard, 2007). Therefore, in our study we find which classroom maintained better RH.

The average RH measured in NSSTC and SWIRLL was 47.9% and 44.4% respectively. This shows that SWIRLL maintains better RH when compared to NSSTC. From the plot we can also infer that outside temperature plays an important role in maintaining indoor RH. We can see that there are lot of fluctuations in indoor RH maintanence between both the buidings. So, we compare the range of RH maintained and we find that NSSTC had a range from 35-53% and SWIRLL had a range of 33-49%. This further proves that SWIRLL maintain better RH when compared to NSSTC classroom.

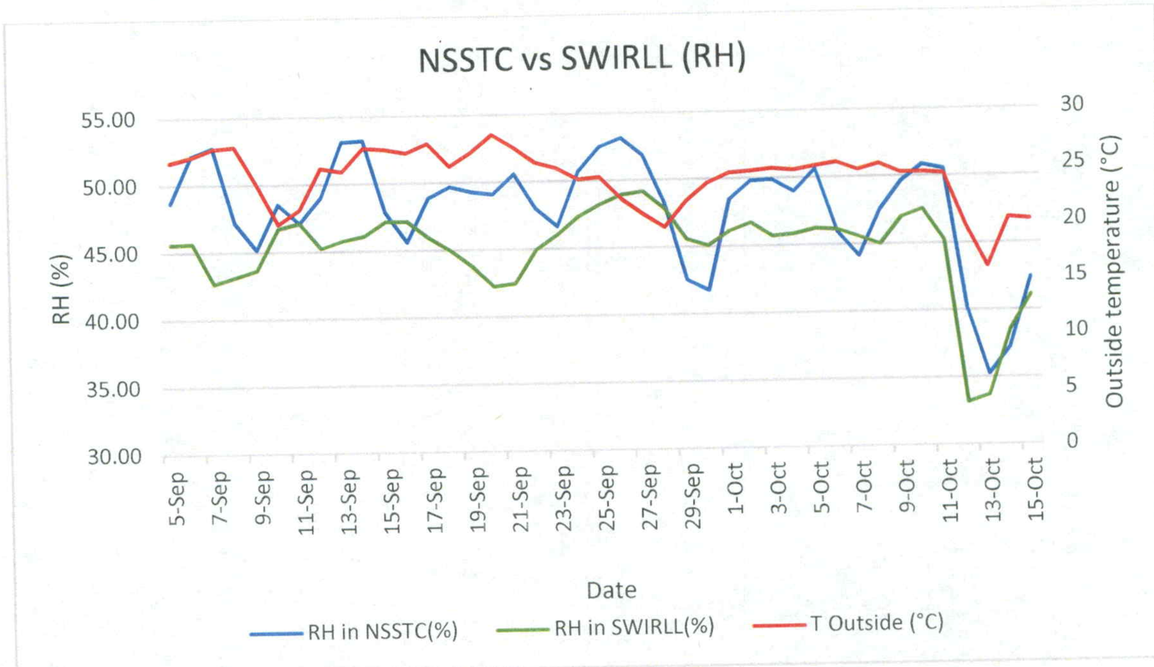

Figure 13:Comparison of relative humidity between NSSTC and SWIRLL

APPENDIX B

Indoor air quality and Health survey

This survey is to identify the Indoor air quality inside NSSTC and SWIRLL classrooms

1. Email address ____________________

Consent Form

We are inviting you to participate in a research study. Participation is completely voluntary. There are no negative consequences, whatever you decide. This survey will help us to understand the distribution of indoor air pollution across NSSTC and SWIRLL buildings and how much time students spend inside these buildings and to understand whether they had any health concerns when they are physically present inside the building. This Survey will have general questions about your background, your knowledge about your surroundings(classrooms), concerns about the classrooms. Also, this survey has general health questions. It might take around 10 minutes to complete the survey. The information that you provide will be held confidential and won't be revealed on any social media. If you are interested, we will share the finally general findings with you per your request.

2. This survey is completely Voluntary If you agree please click the button and continue the survey *

Mark only one oval.

◯ I Agree ◯ I disagree

3. Name ______________________________

4. Age ______________________________

5. Sex ◯ Male ◯ Female ◯ Other

6. Race ◯ White ◯ Black or African American ◯ Asian ◯ American Indian or Alaskan Native ◯ Native Hawaiian or Other Pacific Islander ◯ Other

Building and Classroom Environment

This section identifies how students recognize the Environment of classroom and Building

1. Do you Smoke? ◯ Yes ◯ No ◯ Occasionally

2. Where do you attend your classes? ◯ In NSSTC ◯ In SWIRLL ◯ In both

3. How many classes do you take in NSSTC?

◯ One ◯ More than One ◯ None

4. How many classes do you take in SWIRLL?

◯ One ◯ More than One ◯ None

5. How long is your class session approximately in a day in NSSTC?

◯ Less than 2 hours ◯ 2 -3 hours ◯ More than 3 hours

6. **How long is your class session approximately in a day SWIRLL?**

◯ Less than 2 hours ◯ 2-3 hours ◯ More than 3 hours

7. **How much time do you spend at NSSTC in a day?**

◯ Less than 2 hours ◯ 2-3 hours ◯ More than 3 hours ◯ none

8. **How much time do you spend at SWIRLL in a day?**

◯ Less than 2 hours ◯ 2-3 hours ◯ More than 3 hours ◯ none

9. **When do you attend your classes?**

◯ Morning (AM) ◯ Afternoon /Evening (PM) ◯ Mixed

10. **How would you rate the illumination (lighting) inside the classroom?**

	1	2	3	4	5	
Poor	◯	◯	◯	◯	◯	Excellent

11. **How will you rate the Ventilation (Air circulation) of the classroom?**

	1	2	3	4	5	
Poor	◯	◯	◯	◯	◯	Excellent

12. **How would you rate the condition of flooring?**

	1	2	3	4	5	
Poor	◯	◯	◯	◯	◯	Excellent

13. How would you rate the dust inside the classroom? (Furniture)

	1	2	3	4	5	
Poor	◯	◯	◯	◯	◯	Excellent

14. Please indicate if you work near

	Yes, Often	yes, Sometimes	Never
Typewriter	◯	◯	◯
Scanner	◯	◯	◯
Computer	◯	◯	◯
Photocopier	◯	◯	◯

15. Number of days you are absence in the classroom in a week

One ◯ ◯ More than one

20. How will you rate your concentration during class hours?

	1	2	3	4	5	
Poor	◯	◯	◯	◯	◯	Excellent

21. Out of these factors, which one disturb your concentration most in the classroom?

◯ Temperature ◯ Air Quality ◯ Unpleasant Odor ◯ Improper ventilation

22. Have you been bothered during the last two months by any of the following factors inside the classroom?

	Yes, Often	Yes, Sometimes	Never
Dryness	☐	☐	☐
Varying room temperatures	☐	☐	☐
Room temperature too high	☐	☐	☐
Room temperature too low	☐	☐	☐
Moist or humid conditions	☐	☐	☐
Unpleasant odor	☐	☐	☐

23. How do you scale the use of projector and marker inside the classroom?

1 2 3 4 5

Never ◯ ◯ ◯ ◯ ◯ Always

24. How will you rate the overall satisfaction of classroom in NSSTC?

1 2 3 4 5

Poor ◯ ◯ ◯ ◯ ◯ Excellent

25. How will you rate the overall satisfaction of classroom in SWIRLL?

1 2 3 4 5

Poor ◯ ◯ ◯ ◯ ◯ Excellent

Health Status inside the classroom/Building

This section is used to understand whether students face any health changes when they are present inside the building or classroom

26. Have you ever had asthma attack in last two months?

Yes ◯ No ◯ Never ◯

27. Have you ever had Sinusitis attack in last two months?

◯

Yes ◯ No ◯ Never

28. **Have you ever had any breathing problems in the past two months when you were inside the building?**

Yes ◯ No ◯ Never ◯

29. **Do you have any of the following symptoms when you are inside the building**

	NSSTC	SWIRLL	Yes	No	Never
Headache	◯	◯	◯	◯	◯
Feel heavy-headed	◯	◯	◯	◯	◯
Drowsiness	◯	◯	◯	◯	◯
Dizziness	◯	◯	◯	◯	◯
Nausea/Vomiting	◯	◯	◯	◯	◯
Cough	◯	◯	◯	◯	◯
Irritated/Stuffy Nose	◯	◯	◯	◯	◯
Hoarse/Dry Throat	◯	◯	◯	◯	◯
Skin rash/Itchiness	◯	◯	◯	◯	◯
Irritation in Eyes	◯	◯	◯	◯	◯

30. **Specify if you felt anything different rather than the specified above symptoms**

31. **After leaving the building do you recover from these symptoms?**

Yes ◯ No ◯ Maybe after few hours ◯

32. **When do these symptoms occur?**

Morning ◯ Afternoon ◯ Evening ◯ Other: ◯

33. Which part of the season you feel uncomfortable in the building (NSSTC/SWIRLL)

Fall ◯ Winter ◯ Spring ◯ Summer ◯ None ◯

34. How well do you scale yourself about the knowledge you have about Indoor air quality?

	1	2	3	4	5	
None	◯	◯	◯	◯	◯	Excellent