Indoor Air Quality Assessment of Campus Spaces with Carbon Dioxide (CO_2) as a Measure of Adverse Health Effects

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Abstract

Indoor air quality (IAQ) is referred to as "the air quality within and around buildings and structures, especially as it relates to the health and comfort of building occupants" (US EPA, 2015). Indoor pollutant levels further determine the quality of indoor air, and one of the indicators used to measure IAQ is carbon dioxide (CO_2). Drawing on data collected from a classroom, auditorium, and gym setting in the Mount Royal University campus, the aim of this report is to determine if CO_2 levels present are within established margins substantial to result in adverse health effects. Environmental factors that are considered in this report include: room size, supply air, and occupant load in the specified spaces on the campus. The results of this study suggest that there are a myriad of factors that may affect IAQ and that CO_2 is merely an indicator of poor air quality. Overall, peak indoor CO_2 levels can further be used to determine appropriate ventilation rates in an indoor space.

1 Introduction

Indoor air quality (IAQ) is a frequent and relevant health and safety concern in many confined environments where human occupancy exists. IAQ is referred to as "the air quality within and around buildings and structures, especially as it relates to the health and comfort of building occupants" (US EPA, 2015). As individuals spend approximately 90 percent of their time indoors (US EPA, 2015) it is important to recognize that adverse health effects can occur from poor air quality. Common indoor air pollutants include formaldehyde, molds, allergens, gas-burning furnaces and appliances, radon gas, and secondhand smoke (CDC, 2014). Hence, IAQ is derived from an array of sources, from which elevated levels of carbon dioxide (CO_2) has historically been considered a proxy indicator of poor air quality (Health Canada, 1989). Numerous studies suggest that CO_2 is an adequate indicator of poor ventilation and can therefore be used as one indicator of poor air quality that results in adverse health effects (Yocom, 1991; Olesen, 1993).

CO_2 is a colorless, odorless and natural chemical component of the atmosphere that is nontoxic in low concentrations. The combustion of fossil fuels is the primary new source of CO_2 in the atmosphere, while metabolic processes serve as the main source within indoor settings (Seppänen, 1999; Apte, 2000). The extent of CO_2 in an occupied and unoccupied indoor space is determined by a variety of factors, which include: efficiency of ventilation, temperature, room volume, and the number of individuals present (Apte, 2000).The maximum indoor CO_2 concentration stated by the American Society of Heating, Refrigerating and Air Conditioning Engineers is 2500 ppm with a recommended target value of 1000 ppm (ASHRAE 2013; Norback 2012). A review of the literature has determined that outdoor environmental CO_2 concentrations vary from 340-370 ppm based on geographical location and local environmental conditions (de Gennaro, 2004; Health Canada, 1987). The amount of CO_2 present in an indoor space can be determined by the combination of the room volume and occupancy load since ASHRAE standards apply to ventilation rates to the "breathing zone".

This study aims to analyze the CO_2 levels in a variety of campus spaces: auditoriums, classrooms and a gym setting and to determine if the CO_2 concentrations exceed levels correlated to adverse health effects. Our main objectives are to analyze CO_2 in an outdoor setting as well as the Mount Royal University Recreation Center weight room during empty, peak and non-peak hours over a period of three days. We will also be analyzing the average CO_2 levels in an auditorium and a classroom setting when it is occupied with students and unoccupied over a period of three sessions.

The purpose of this study is to use CO_2 as a parameter to assess IAQ and to determine if the levels observed exceed the guidelines in the established literature for indoor settings. This study will be considering a variety of factors that could affect the concentration of CO_2 in an indoor space. Parameters that will be observed include: room area, volume of air supplied and occupancy load. It is essential that the chosen Heating, Ventaliation and Air Conditioning (HVAC) system provides adequate ventilation rates for optimal IAQ and that it adheres to IAQ guidelines so that adverse health effects are not consequently induced in humans.

2 Methodology

2.1 Collection of data

Colorimetric gas detection tubes (CO_2 300-5000 ppm) and a hand held pump were used to gather CO_2 concentrations in specified indoor spaces on MRU campus. The sampling occurred in a classroom, auditorium and a weight room in the fitness center for three separate days spaced out over a three-week time frame. For each specified classroom and auditorium setting, a baseline sample was taken at the beginning of the class session (prior to being occupied with students) with the doors closed. Another reading was taken after the class has ceased its session (before the students exited). For the weight room in the fitness center, a baseline sample was taken at opening hour (i.e. 06:00) prior to being occupied with students. Another reading obtained on the same day was taken at peak occupancy hour at 18:30. A non-peak occupancy was taken at closing hour (i.e. 23:00). A reading of the outdoor CO_2 levels was taken each day the indoor data was collected. Three days within a three-week time frame during the month of October and November were chosen for data collection. Locations were chosen based on varying room size and supplied air volume with varying occupancy load with the dates determined by convenience.

2.2 Collection of technical data

Technical data of the specified room area and the volume of air supplied to the room and the type of HVAC system used were collected by a Certified Engineering Technologist, James Dyck at Mount Royal University. Peak occupancy data of the weight room was provided by the MRU Recreation Center. All samples were collected from the same location in the selected areas, following the recommended procedures on the colorimetric packs. The colorimetric tubes were within the expiration period and stored in a cool dark location as per the recommended guidelines. Peak times were determined based on various staff inputs and information available on the MRU Recreation website. Prior to field analysis, a leak test was performed to ensure that the instrument was optimized and appropriate for data collection.

2.3 Data Analysis

The data obtained is referenced to established ASHRAE standards and the scientific literature.

3 Results

3.1 Assessment of parameters

Table 1: Detailed physical and numerical parameters of specific locations on MRU campus.

	Weight room	Auditorium	Classroom
Floor Area (m^2)	770.7	194.4	74.3
Supply Air (L/s)	7830	1320	426
Peak Student Count	32	50	24
Non-peak Student Count	23	/	/
Duration Occupied (hrs)	18	6	6

Table 2: Summary of the mean CO_2 concentrations (ppm) of various locations on MRU campus.

	Baseline	Peak Occupied	Non-peak Occupied
Auditorium	683	1150	/
Classroom	700	850	/
Weight Room	517	1150	817
Outdoor	300	300	300

*Non-peak occupied indicates the closing hour (i.e. at 23:00)

4 Discussion

4.1 Synthesis of key findings

The average indoor CO_2 concentrations detected in the selected indoor spaces were below the established 2500 ppm ASHRAE threshold levels; hence, it is not likely to pose any long term health risks to students. However, the average CO_2 levels at peak occupancy are above the 1000 ppm recommendation by ASHRAE guidelines for indoor comfort and within the range for short term effects (Satish et al, 2012). The results obtained in this study indicate that the ventilation rates in these specific locations are in compliance with the standards as the supply air is above the minimum ventilation rates in the breathing zone for acceptable indoor air quality. It is notable that supply air volumes are usually much higher due to ventilation (outdoor) air being mixed with room air (ASHRAE, 2013); thus, the results obtained in our study suggest that the ventilation system is sufficient in supplying outdoor air to these selected occupied zones.

The CO_2 levels during peak occupancy had a tendency to increase or remain constant, with the exception of the weight room (U135). There was a general increase in CO_2 in Y224 ranging from 1000 to 1200 ppm. The sampling on 11/10/15 in the auditorium (Y224) was analyzed the class after an examination session, which could explain the decreased attendance and corresponding CO_2 levels. A similar trend was observed for the classroom (Y314), with peak CO_2 levels increasing over the month of November. This is likely a result of the examination that took place in the class on 11/10/15. The peak CO_2 levels may not have had enough time to reach equilibrium in the indoor system due to the short session resulting in lower than normal concentrations. There was a slight decrease in peak CO_2 over the course of the sampling period for U135 with a maximum of 1200 ppm and a minimum of 1100 ppm.

A correlation efficient of 0.70 suggests that there is a correlation between the number of occupants in a confined space (Figure 2 in Appendix) and CO_2 levels. This supports the literature stating that humans are the greatest source of indoor CO_2 generation (Prill, 2000). Discrepancy in this correlation could be a result of varying gender ratios of the sampled populations over the course of November. Males generate CO_2 at greater active and passive rates then females (Aitken, 1986), this could account for situations where a lower number of individuals generates a higher CO_2 concentration and vice versa. Other factors that affect CO_2 generation include height, fitness, and weight (Aitken, 1986).

4.2 Hazardous effects corresponding to increased CO_2

67 percent of samples taken during the peak occupation had values greater than 1000 ppm CO_2 (Satish et al, 2012) which is has been identified as a threshold for cognitive effects. At these levels relative to the baseline data collected, it can be expected that there will be short-term mental impairments such as: task orientation, information usage and applied activity (Satish et al, 2012). Levels above baseline CO_2 levels may increase the prevalence of conditions such as headaches, lower respiratory issues and eye irritations (Apte, 2000). A more

recent study suggests that in conjunction with the negative effects, the ability to concentrate on individual tasks increases with elevated CO_2 levels; peaking at 2500 ppm relative to the 600 ppm baseline (Satish et al, 2012).

4.3 Human respiration

Respiration of indoor occupants is the primary source of elevated CO_2 in indoor settings (Seppänen, 1999; Apte, 2000), and the average adult breath respires about 35,000 to 50,000 ppm of CO_2 (Prill, 2000). Rooms that have poor ventilation can lead to concentrations of approximately 3000 ppm CO_2 solely from human respiration (Health Canada, 1989). Furthermore, it is advised that CO_2 levels do not exceed 700 ppm above outdoor ambient air, which is usually around 340 – 370 ppm CO_2 (ASHRAE, 2013; Health Canada, 1989). Levels between 600 and 10,000 ppm CO_2 indicate a poorly circulated room (Table 3 in Appendix); however, these levels suggest that it is tolerable to healthy individuals (Indoor Air Quality Handbook, 2013). However, these levels may affect younger children, as they are more vulnerable to indoor air pollutants in terms of their developmental stage and physical structure (Ferng & Lee, 2002).

4.4 Limitations

There are many compounding factors associated with this experiment that must be taken into account. Due to the nature of the experiment it was important to allow human movement in and out of the test locations in order to achieve a representative result. Having doors opened or closed within the indoor space would change the status of the system, therefore affecting the amount of air exchange between the room and hallways. This would result in varying air circulation rates over the course of the testing periods. Over a longer period with a greater number of samples, a representative average could be attained. With the limited number of samples (n=3) gathered for each room, coupled with the limited time frame, it is difficult to determine whether the information collected is representative of long-term CO_2 concentrations within these spaces. The inability to keep conditions controlled between sampling periods and other incalculable sources of CO_2may occur. These factors may include varying sex ratios, body size & height, and the fitness differences in occupants. The low precision offered by the colorimetric gas detection tubes inhibits the ability to reproduce data as reading the values between the gradations is relatively subjective at low concentrations.

4.5 Future research recommendations

This study stipulates that there is a strong relationship between elevated indoor CO_2 levels with the number of occupants present in an indoor setting. Drawing from the results of this study, appropriate ventilation levels that would decrease the risk for adverse health effects can be indicated by the concentration of CO_2 in a fully occupied space. However, CO_2 is only one parameter to determine the quality of indoor air; hence, other parameters should be measured to get the overall air quality of the indoor space of interest. These parameters include: temperature, humidity, air movement and flow of the space, ventilation, bioaerosols and the various particulates in the air (ASHRAE, 2013). Appropriate corrective action can further be determined based on the values of these parameters, i.e. whether or not they adhere to ASHRAE guidelines or any other applicable standards. CO_2 levels can be sufficiently managed within a confined indoor space by considering a combination of factors including the buildings ventilation rate, outdoor CO_2 levels, and the number of occupants in a selected space (Indoor Air Quality Handbook, 2013).

5 Conclusion

The results drawn from this study indicate that we can obtain a general illustration of CO2 levels in a variety of indoor spaces. Furthermore, fine-tuned adjustments can be made to the HVAC systems so as to increase the airflow in a confined indoor space. Other suggestions include using portable ventilation systems, ensuring that adequate maintenance is established, and retrofitting applicable indoor spaces where necessary. The results further entail that a suitable monitoring program be established in order to obtain statistics that can be used to aid in building regulations and standards. Incorporating the other recommended parameters that are used to measure IAQ is important to ensure that the HVAC systems in buildings are providing adequate airflow that would reduce these adverse health effects.

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6 Appendix

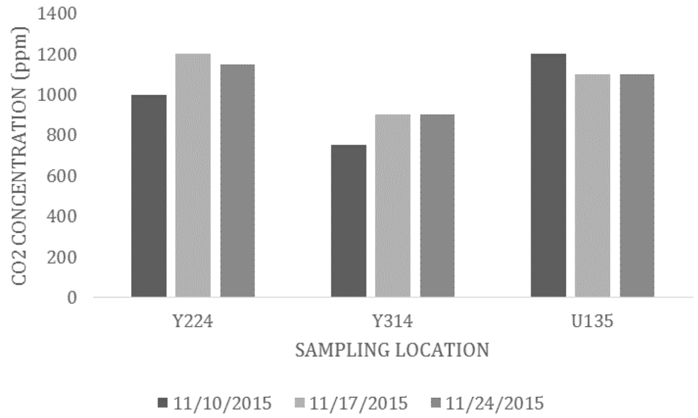

Figure 1: Peak CO_2 values for the selected locations on the days specified over a three week period

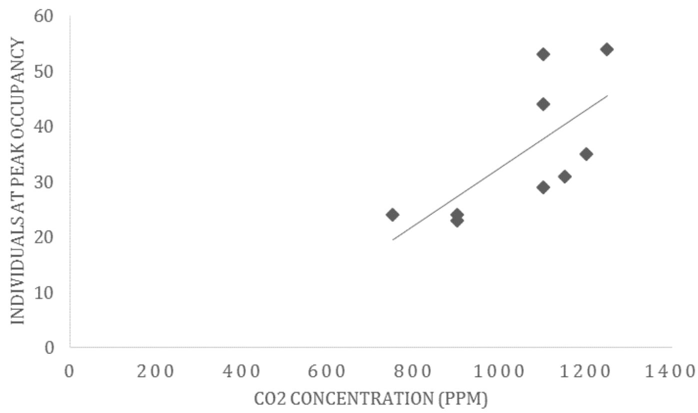

Figure 2: Plot of the relationship between the occupants in selected indoor spaces and the resulting CO_2 concentrations.

sitemap.png

Table 3: Typical CO_2 concentrations and their environments (MRU ENVS 3307, 2015)

Concentration(ppm)	Concentration(%)	Setting
400	0.04	Outside Air
600	0.06	A poorly circulated room
10,000	1.00	A large full auditorium with no windows. At this level some people wills start to feel drowsy
20,000	2.00	A room with a gas leak or a garage with a running car exhaust. At this level some people may feel faint and sick.
30,000	3.00	Fainting, blood acidosis. Breathing rate doubles from low oxygen
50,000	5.00	Acute toxicity, unconscious and eventual death such as a coal mine collapse

	Baseline (ppm)	Peak Occupation (ppm)	Non-Peak Occupancy (ppm)	Peak Occupants	Non-Peak Occupants
Auditorium (Y224)					
Reading 1	700	1100	/	44	/
Reading 2	750	1100	/	53	/
Reading 3	600	1250	/	54	/
Classroom (Y314)					
Reading 1	700	750	/	24	/
Reading 2	650	900	/	23	/
Reading 3	750	900	/	24	/
Weight Room (U135)					
Reading 1	400	1150	750	31	18
Reading 2	450	1200	800	35	29
Reading 3	400	1100	900	29	22
Outdoors	300	300	300	/	/

Figure 3: The raw data recorded for various locations on MRU campus.