Measurement of Carbon Monoxide concentration levels within an underground parking lot throughout the day

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Abstract

Background: During the fall and winter months, people opt to using cars as a mode of transportation to and from work, school, or recreation. The ease of access, comfort, and efficiency of travel prompt an increase in drivers. Underground lots are ideal parking spaces during these months, which see an increase in traffic and subsequent rise in emissions, specifically carbon monoxide (CO) that can be hazardous to health at certain concentrations. This study is to determine the levels of CO in a confined parking space

Methods: Air quality and composition were determined via passive dosi-tubes that were affixed onto columns within the Langara College underground parking lot in the morning and picked up for analysis in the afternoon.

Results: There is an increase in carbon monoxide concentration within the underground parking lot, during peak hours. Traffic within the lot is found to be higher during poor weather conditions which correlate with ease of use and comfort of driving a car. There is also an increase in traffic on Tuesdays and Thursdays, which is likely dictated by class times. Carbon monoxide levels did not fail to meet government regulations during any sampling period.

Conclusions: The air composition in the Langara underground parking lot is safe even during periods of high traffic, for the average person. However, individuals with underlying medical conditions should enter with caution, as the recorded CO levels can aggravate pre-existing cardio-pulmonary diseases.

Keywords: Carbon monoxide, Underground Parking, Dosi-tube, Car Exhaust, Car Emissions, Cardio-pulmonary disease, Langara College

Introduction

This research project involves the measurement of carbon monoxide (CO) gas accumulation in a confined space, specifically Langara College. Currently, there are 22,000 students enrolled in the institution, resulting in its underground parkade receiving a steady volume of traffic throughout the year. Each car emits gasses composed of multiple pollutants that are hazardous to human health such as particulate matters, volatile organic compounds (VOCs), nitrogen oxides, carbon monoxide and greenhouse gasses (CO_2). According to the Canadian Center for Occupational Health and Safety (CCOHS, 2017b), carbon monoxide is specifically considered to be very toxic because it decreases the blood's ability to carry oxygen, therefore, underground ventilation systems must always be properly maintained and in good working order to keep up with influx of gas emissions.

This project is significant to public health because it involves the evaluation of indoor air quality and possible effects on health and safety if regulations are not observed. This project will look at whether different vehicle activity and resulting emissions are properly ventilated by underground parking lots or if CO accumulation is evident. Possible sources of CO are idling, the time that people take to exit the car, traffic within the parking lot itself (such as waiting for an open parking spot), picking up people from the mall entrances, and people that are waiting to pick up another individual. CO will therefore be used as an indicator gas to measure the effectiveness of ventilation in underground parking lots.

Literature and Evidence Review

Carbon Monoxide and Cars

The main focus of this review is carbon monoxide, which is a combustible non-irritant gas that is odorless, tasteless, and colorless. It is produced during the incomplete combustion process of carbon containing substances like gasoline, natural gas, wood, kerosene and coal. CO weighs slightly less than air but is found to equalize within an enclosed space, not accumulating at the ceiling, middle, or floor of a room (Hampson et al, 2012) and mixes freely with the atmosphere, easily forming explosive mixtures in the air. According to the WHO (Penney et al, 2010), human activities are responsible for roughly two-thirds of CO released into the atmosphere. In the US specifically, vehicle emissions are the largest contributors. The United States Environmental Agency (USEPA, 2016) records that as much as 75% of CO emissions are released by motor exhaust due to fuel combustions. However, there is a lack of data that breaks down the actual amount of CO released by burning a liter of gasoline. Prolonged exposure to as little as 150 ppm or 0.015% in the air is enough to cause symptoms for healthy individuals. Low temperatures can contribute to higher than average concentrations of CO. This is due to emissions control equipment within cars not functioning as efficiently when cold. Air-to-fuel ratios are lower which result in incomplete combustions that form higher concentrations of CO. This can be a problem in underground parking lots, especially during the winter months due to lower temperatures, increased traffic, and long idling periods to warm up the car (National Academies Press, 2002)

Morbidity Statistics of Carbon Monoxide

The detrimental health effects of carbon monoxide depend on the concentration of CO and the length of exposure. From 1 to 70 ppm, most people will not experience any symptoms of prolonged exposure, but those with cardiovascular diseases may start to experience chest pain (CPSC, 2019). If exposed to low levels of CO for extended periods or to high levels for a short time (70 ppm and above), flu-like symptoms manifest such as tiredness, headaches, shortness of breath, muscle weakness, or even partial to total loss of function of a body part (U.S. Consumer Product Safety Commission, 2019). Sustained concentrations of 150 ppm and above, result in symptoms such as chest pain, poor vision, difficulty thinking, convulsions, coma, or even death (Government of Canada, 2019). This results in many cases of individuals suddenly getting light headed, passing out, or dying in their sleep from carbon monoxide poisoning.

Adequate monitoring of this gas is very important due to it being colorless, odorless, and tasteless, therefore is easily overlooked. In developed countries, emissions from faulty, incorrectly installed, poorly maintained or poorly ventilated cooking or heating appliances that burn fossil fuels are the largest cause of carbon Monoxide poisoning (Penney et al, 2010). From 2000 to 2013, there were a total of 4,990 deaths associated to carbon monoxide poisoning with 1,125 deaths having no underlying cause of death (Cohen et al., 2017). Quebec, Alberta, and BC have the highest occurrences of these deaths. In Canada alone, more than 300 deaths and 200 hospitalizations occur from carbon monoxide-related poisoning each year. Between 2002 and 2016, a total of about 3000 hospitalization cases were linked to carbon monoxide poisoning (Cohen et al., 2017). When it comes to vehicles, it does not take a completely enclosed space for fatal accumulation of carbon monoxide to occur. Cases of fatal carbon monoxide poisoning can come from insufficient ventilation of car exhausts from something as trivial as parking with the exhaust pipe facing a guard rail, leaving garage doors half open while idling a car, or faulty exhaust system components within the cars that allow carbon monoxide to enter the vehicle (The Canadian Press, 2019). Vehicle-related carbon monoxide poisoning are also weather influenced, as it is more common for people to idle their cars to warm up during the winter time.

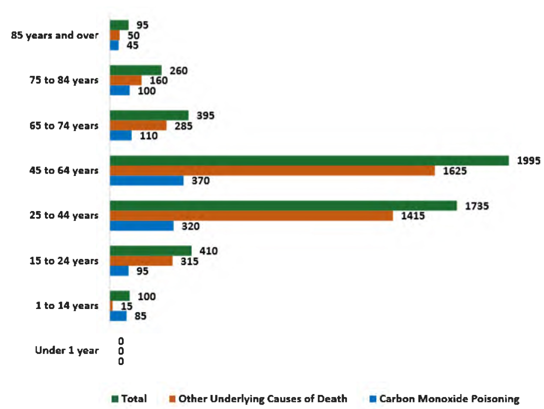

Figure 1: Age ranges for carbon monoxide-related deaths in Canada between 2000 to 2013 (N = 4990). (Cohen et al., 2017)

As previously mentioned, only 1125 deaths occur solely from carbon monoxide poisoning without underlying causes, while 3865 deaths are linked to carbon monoxide with underlying causes. Data gathered by Statistics Canada (Cohen et al, 2017) from 2000 to 2013 show that the majority of deaths come from the 45 to 64 year olds age group, with a total of 1995 deaths (40% of the total cases). From that group, 1625 deaths are linked to carbon monoxide poisoning but have underlying causes, while only 370 are a direct result of carbon monoxide poisoning (figure 1).

Health implications of exposure to Carbon Monoxide

To understand these underlying causes and determine the population most at risk, we look at data gathered in 2012 by the American Heart association (figure 2), in which U.S. adults within the age group of 40-59 include 40.5% of males and 35.5% of females with cardiovascular disease. As we move up in age groups, cardiovascular disease becomes more prevalent. The age of 60-79, show that an average of 68% of males and females manifest cardiovascular diseases, while strokes occur in 6.1% of men and 5.2% of women.

According to the American Heart Association (American heart Association, 2016), carbon monoxide affects the blood’s ability to carry oxygen in the body, causing permanent damage to organs such as the brain and the heart if insufficient air quality is not provided. Carbon monoxide will readily bind to hemoglobin to form Carboxyhemoglobin (COHb), reducing the oxygen carrying capacity of blood, causing hypoxic stress to even the healthiest individuals.

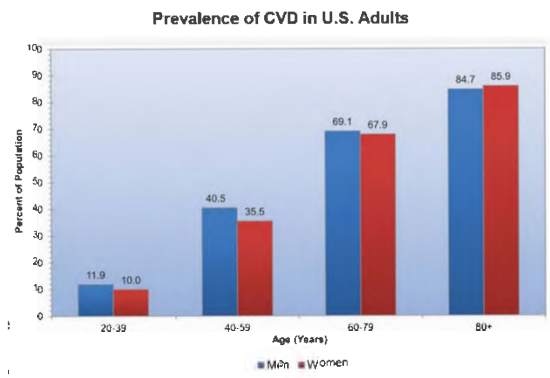

Figure 2: Prevalence of Cardiovascular disease in U.S. Adults (American Heart Association, 2016)

Those most at risk would be older individuals with pre-existing cardiopulmonary diseases that can easily be aggravated by low levels of carbon monoxide in the air. This is because the body will increase in cardiac output to the brain or heart due to lack of oxygen. When the heart is overburdened by the need for oxygen or goes over its limit, tissue injury can occur (Center for Disease Control, 2011). Myocardial ischemia, for example, is the lack of oxygen going to the heart and is often felt alongside angina chest pains. Carbon monoxide poisoning can be misdiagnosed as symptoms that are non-specific, due to these underlying conditions, which can result in people not knowing that locations they visit are hazardous to their health and subsequently return to these areas again (Sircar et al, 2015). Carbon monoxide is also a significant risk to pregnant women, because CO is classified as a developmental hazard for unborn children, which can result in low birth weights, learning disabilities, and miscarriage (CCOHS, 2017b).

BC legislation and guidelines for Carbon Monoxide

To control the limits of exposure, the Canadian Center for Occupational Health and Safety (CCOHS) establish the standard for air contaminant safety in Canada. CCOHS states that carbon monoxide has a short-term exposure limit of 400ppm for 15 minutes (which they based off of regulations by the American Conference of Governmental Industrial Hygienists (ACGIH)). For daily, 8-hour exposure, ACGIH states that a threshold limit value (TLV) and time weighted average (TWA) of 25 ppm is necessary for healthy individuals, but specifically to protect those that have underlying cardiovascular diseases (CCOHS, 2019) due to their higher risk of serious cardiovascular injury. The National Institute for Occupational Safety and Health (NIOSH) on the other hand, argues that a TWA of 35 ppm is sufficient for those that have chronic heart disease. Following the CCOHS regulations, the TLV of 25 ppm of carbon monoxide is equivalent to 4 percent of Carboxyhemoglobin (COHb) levels in the blood. However, saturations of 3 to 5 percent of COHb in the blood is enough to impair cardiovascular function in those with underlying diseases and even in healthy individuals (Center for Disease Control, 2011). This means that prolonged exposure to even lower levels of carbon monoxide is enough to cause negative health effects to the body.

Figure 3: A full underground parking lot in Langara College

In British Columbia, the BC building code (BC Government, 2018a) contains the regulations that govern building safety for small-scale and large-scale buildings, be it small private homes or commercial establishments. Underground parking lot ventilation is covered by part 6 of the BC building code, section 6.3.1.4. , “Ventilation of Storage Garages”. The BC building code classifies parking areas and storage garages into one category, therefore, section 6.3.1.4. can be applied to parking areas such as mall parking lots. It states that for enclosed garages that can house five or more motor vehicles (figure 3), there shall be a mechanical ventilation system that is controlled by carbon monoxide and Nitrogen dioxide monitoring devices that will limit concentration of air contaminant accumulation. The legislation requires that carbon monoxide in the air is limited to 100 ppm or less, Nitrogen dioxide to no more than 3 parts per million or less, or the provision of a continuous supply of outdoor air at a minimum rate of 3.9 L/s for each square meter of floor area, during operational hours. This regulation would apply directly to the mall underground parking, which includes multiple underground levels that are not directly open to outside air. Only the first level of underground parking lots usually have the entryways for cars to enter or exit from the main road, thus having the best ventilation. Carbon monoxide is also an extremely flammable gas that is easily combustible at room temperature. Section 3.3.1.20. , "Exhaust Ventilation and Explosion Venting", requires that the ventilation system is designed to conform section 6.3.1.4 (BC government 2018b).

Policy 4 of section 6.3.1.4, states that storage garages covered by the aforementioned guidelines can reduce their ventilation requirements by one half if motor vehicles are parked by mechanical means. This is logical if the regulation only concerns garages where cars will be parked for long periods of time (i.e. storage for when an individual is leaving the country) and will not be have constant human traffic. However, this regulation contradicts the purpose of ventilation in busy commercial parking lots where many cars are constantly moving and engines are left idle in confined spaces. Unfortunately, the legislation doesn't specify the difference between storage garage and underground parking lots, which can easily be confused with and result in reduction of ventilation in busy confined parking lots.

Materials and Methods

Complete Description of Materials Used

The procedure utilised Gastec 1DL carbon monoxide measuring Dosimeter tubes (dosi-tubes for short), which passively measures CO at the range of 0.4 to 400 ppm. The 1DL tubes have a sampling time of 0.5 to 24 hours and turns from pale yellow to dark brown in the presence of carbon monoxide (Gastec, 2019). This occurs when carbon monoxide from the atmosphere reacts with the detecting agent within the tube, Dipotassium disulfitopalladate (II) monohydrate, as shown by figure 4 below. The resulting reaction produces Palladium, Carbon Dioxide, Sulfur Dioxide, and Sodium Sulfite.

$$CO + Na_2Pd(SO_3)_2 \rightarrow Pd + CO_2 + SO_2 + Na_2SO_3$$

Figure 4: The reaction between carbon monoxide and the dosi-tube's detecting agent

At the end of the sampling period, the peak CO level detected is divided by the amount of hours of sampling time to determine the time weighted average (TWA) that a regular person will be exposed to in the parking lot.

Description of Methods used

Thirty tubes were used in a span of 10 consecutive business days during the month of

January, beginning on the 14th until the 28th of the month. On each day of the procedure, three Dosi-tubes were placed in the parking lot for 8 hours to represent a standard work period. Every morning at roughly 7:30 am, one tube was taped to a column in the upper, middle, and lower levels of the parking lot (figure 5).

Figure 5: A Dosi-tube secured to a column.

Each tube was placed at the center of each level, a meter above ground, and broken at the breaking line to create an orifice for passive diffusion. The tubes were secured with electrical tape to the column and had the instrument's orifice pointed to towards the traffic. All three tubes were then collected after a minimum of 8 hours.

Statistical Analyses and Results

Description of Data Collected

Data collected is numerical continuous because the scale of measurement has an absolute zero point (which means no carbon monoxide detected). Concentration is measured in ppm, which falls under the ratio scale and is measured on a continuum. At the end of each 8 hour sampling period, raw data is divided by the amount of hours of sampling, resulting in a mean ppm concentration. NCSS 2020, v20.0.1 was used to analyze the raw data.

A one sample t-test compares the mean numerical data to a standard value (Heacock, 2018b). A one sample t-test was performed because there are 3 different sets of data, one for each floor, which is being compared to a single standard of CO (25 ppm). A one-way ANOVA is performed when there is 3 or more means of numerical data. The purpose of the ANOVA is to determine if there is a significant difference (variance) between all 3 data sets or if they all remain consistent with each other.

H0(s) and HA(s)

Each one sample t-test, is a right-tailed t-test with a null hypothesis(Ho) that states that the mean CO levels in this floor of the underground parking lot is less than or equal to the standard 25 ppm TLV-TWA (represented by figures 6, 7, and 8). The alternate hypothesis (Ha) states that the mean CO levels in this floor of the underground parking lot is more than the standard 25 ppm TLV-TWA.

The one-way analysis of variance (ANOVA) test involves two-tailed tests. The null hypothesis states that there is no difference in CO levels between P1, P2, and P3. The alternate hypothesis states that there is a difference in CO levels between P1, P2, and P3.

Results of Descriptive Statistics

After gathering the raw data and dividing each sample by the number of hours of the sampling period, the TLV-TWA of 25 ppm is not exceeded at any time. The Following charts demonstrate the raw data collected each day, within an 8 hour period.

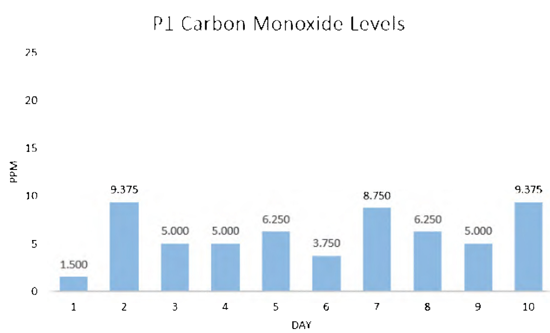

Figure 6: P1 Carbon monoxide Levels.

The average CO concentration in the upper lot is 6.025 ppm for the entirety of the sampling program.

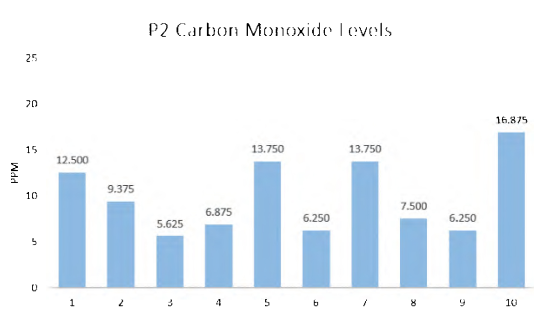

Figure 7: P2 Carbon monoxide Levels.

The average CO concentration in the middle lot is 9.875 ppm for the entirety of the sampling program.

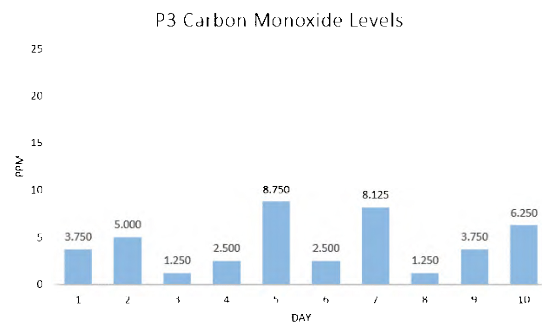

Figure 8: P3 Carbon monoxide Levels.

The average CO concentration in the middle lot is 4.313 ppm for the entirety of the sampling program. The resulting data is a right sided one-tailed t-test. Table 1 shows overall data in a compiled format.

Day	P1 (ppm)	P2 (ppm)	P3 (ppm)
1 (Jan 14)	1.500	12.500	3.750
2 (Jan 15)	9.375	9.375	5.000
3 (Jan 17)	5.000	5.625	1.250
4 (Jan 20)	5.000	6.875	2.500
5 (Jan 21)	6.250	13.750	8.750
6 (Jan 22)	3.750	6.250	2.500
7 (Jan 23)	8.750	13.750	8.125
8 (Jan 24)	6.250	7.500	1.250
9 (Jan 27)	5.000	6.250	3.750
10 (Jan 28)	9.375	16.875	6.250

Table 1: Compiled Data of all 3 levels

Inferential Statistics

All one sample t-tests performed on the P1, P2, and P3 raw data, yielded the same results. All three t-tests obtained a p-value of 1.000 is. The results are statistically significant at the 5% level, due to p-value being greater than 0.05, thus we cannot reject H_0. For all three lots, we can accept that the carbon monoxide level is less than or equal to the standard of 25 ppm TLV-TWA.

The one way analysis of variance (ANOVA) performed on the raw data yielded a p-value of 0.008. The data is normally distributed with unequal variance. Following Welch's test, we reject equal means. Since p-value is less than 0.05, we reject H0 and accept Ha, which states that there is a difference in CO levels between P1, P2, and P3.

Discussion

As mentioned in the results section of the study, it is found that the levels of carbon monoxide (CO) within the enclosed space of the underground parking lot of Langara, adheres to the provincial regulatory limits that are considered safe for an 8 hour, TLV-TWA (Threshold limit value – Time weighted average), daily exposure to carbon monoxide. The average CO levels found in each level is distinguishable by the amount of traffic that each level receives. As mentioned in the literature review, CO is found to equalize within enclosed spaces and does not accumulate at corners, on the floor, or the ceiling of an enclosure (Hampson et al, 2012). CO can freely disperse out into the exterior of buildings and into the outside atmosphere. After 10 business days of air sampling, the middle level accumulated the highest CO average of 9.875 ppm due to receiving the most automobile movement in an enclosed space, combined with the lack of immediate opening to outside air. The upper level of the parking lot has a wide opening to the outside of the building which serves as the parking lot entrance, significantly affecting the amount of fresh air that enters and the amount of CO escaping the building, resulting in an average CO of 6.025 ppm. The lower level received the least amount of traffic, due to most people locating a parking spot in the upper and middle levels, resulting in the lowest average CO concentration of 4.313 ppm. None of the lots exceeded the 25 ppm CO limit, therefore it is concluded that the standard is observed within the Langara underground parking lot, and that there is no immediate threat to public health. This is statistically supported by the one sample t-test conducted on each level, as discussed in the inferential statistics section. We accept the null hypothesis which states that the mean CO levels in a specific floor of the underground parking lot is less than or equal to the standard 25 ppm TLV-TWA.

Most healthy individuals will not experience any symptoms of CO exposure from 1 to 70 ppm (CPSC, 2019). Due to the majority of the underground lot being used by students who can have varying lengths of stay as dictated by their classes, most individuals do not stay within the underground lot long enough to experience any serious symptoms, nor are the CO levels high enough to cause any discomfort and severe effects (The Short term exposure limit, STEL, is 400 ppm within 15 minutes of constant exposure). The 25 ppm TLV-TWA is enforced in order to protect those that are immunocompromised (such as the elderly) or those that have any pre-existing and underlying cardiovascular diseases (CCOHS, 2019). Exposure to 25 ppm of CO is equivalent to 4 percent of Carboxyhemoglobin in blood. However, as little as 3 percent blood saturation is enough to impair cardiovascular function (Center for Disease Control, 2011), therefore, these groups are more susceptible to serious cardiovascular injury even below the 25 ppm threshold.

It is also important to note that the specific day of the week and time of day and have significant effects on CO levels. Each dosi-tube was set up to take advantage of the most movement of traffic, usually starting before the first classes of each day (7 am to 3pm) to accurately portray the most CO emissions as traffic moves into the lots until the end of the day when most students leave. Looking at figures 4, 5, and 6, the highest concentrations of CO would occur during days that had the most students attending class, such as Tuesdays and Thursdays(Jan 14, 21, 23, and 28). The rest of each week, had the lowest levels of CO during the sampling period. During the first few days of sampling (Jan 14 to 17), a snowstorm descended upon the lower mainland which disrupted many of the transit services (The Canadian Press, 2020), resulting in the reliance on car transportation. However, this did not add significant carbon monoxide emissions for to each lot. This may be due to less engine idling to warm up cars or simply due to the fact that people idle the same amount during severe weather conditions as they do at times of regular weather.

Limitations

The study was limited by location, time, and money. The initial location that was chosen for gathering data was Metrotown mall in Burnaby, BC, due to the large amount of visitors (Dobie, 2018) and subsequent automobile traffic within its underground parking spaces. Unfortunately, upon contacting management, the request to gather data was denied due to security concerns by the managerial department. Hence, data collection was conducted within the Langara underground parking lots, which provided a similar environment but in a smaller scale. Timing was crucial for gathering data that is representative of activity within the parking lot, which should be during peak operating hours. Metrotown was considered initially due to close proximity with BCIT. As classes were still occurring at the time of sampling, it would be the most efficient location in terms of travel time and convenience. Due to sampling restrictions, Langara was chosen as it was the second most viable option in terms of time and location. Langara was close enough to be able to set up dosi-tubes to record samples at the most representative time (7 am to 3 pm) before heading to BCIT and simultaneously attend class.

Internal validity may have been affected by the fluctuation of traffic near the tube's orifice and the manner with which a parked car's tail pipe is facing, whether towards or away from the tube. This would have been resolved by increasing the amount of samples taken in each level and increasing the amount of sampling days, however due to budget and time constraints, only 30 dosi-tubes were available for use. In terms of external validity, the findings in this study cannot be generalized to all parking lots as they vary in size, ventilation, and traffic. We can only compare our findings to medium-sized parking lots. For example, the Metrotown underground parking lot is much larger than Langara's, which could result in lower average concentration of CO due to a larger area for the gas to disperse and equalize. Other malls with medium-sized underground parking lots such as the Marine gateway shopping mall, could possibly have higher levels of CO due to higher traffic within the lots and would have been a better candidate for air sampling.

Knowledge Translation

The resulting levels of CO that were monitored are within the required limits set by the Canadian Center for Occupational Health and Safety (CCOHS). Since the limits were observed, there is no need to modify or add onto the legislation. However, it is important to note that aside from regular movement of traffic, idling within the parking lot will still produce CO, which can easily accumulate. There is a lack of education towards idling and carbon monoxide accumulation in enclosed spaces, therefore, signs should be placed within each level to advise drivers not to idle cars within the enclosed spaces or set a time limit for how long they can idle (such as in the event that the car is idled to be warmed up). Informational posters can be placed near the entrances or other visible locations within the lots to notify users of detrimental health effects caused by CO, as well as identify which population is most vulnerable (the elderly, pregnant women, and immunocompromised), due to the effects of CO possibly being felt even below the standard 25 ppm TLV-TWA limit. It can also advise to avoid staying within the underground parking any longer than is necessary. In the case that CO levels are found to be higher than the regulatory limits, it may be attributed to higher levels of traffic each day. Therefore, the strength of ventilation systems should be increased to compete with higher levels of emissions or limit the number of cars that are allowed to park and congregate within each lot.

Future Research

There are a few possible future student research projects that can be done to expand knowledge about air quality in confined spaces:

- Measurement of carbon monoxide levels in other busy underground mall parking lots (provided that they are able to obtain permission from the establishment)
- Measurement of the carbon monoxide in terms of the short-term exposure limit: student will measure for 15 minutes to see how much CO is emitted in short periods of time using electronic measuring equipment such as the ToxiRAE Pro Single Gas Monitor or the QRAE Plus Multi Gas Monitor (Herle, 2018).
- Measure TLV-TWA for underground parking lots but with multiple dosi-tubes per level, instead of just 1 each to get a better representative air sample.

Conclusion

Underground parking makes effective use of building space by combining usable building space above, with parking space below. However, the enclosed space underneath can accumulate carbon monoxide emissions from vehicles, due to increased traffic which can potentially overwhelm ventilation systems. Langara College's underground parking was sampled for air quality in regards to carbon monoxide concentration, which resulted in levels that meet the 8 hour TLV-TWA standard. Thus, Langara is following building code regulations and is maintaining safe levels of carbon monoxide through proper ventilation. This does not mean that every underground parking lot will meet this standard of air quality, especially commercial shopping centers that receive heavy traffic. These places are more likely to be visited by vulnerable populations such as the elderly, pregnant women, and immunocompromised. Therefore, it is important to maintain carbon monoxide levels within regulatory limits for the sake of public health and safety of all.

This does not mean that every underground parking lot will meet this standard of air quality, especially commercial shopping centers that receive heavy traffic. These places are more likely to be visited by vulnerable populations such as the elderly, pregnant women, and immunocompromised. Therefore, it is important to maintain carbon monoxide levels within regulatory limits for the sake of public health and safety of all.

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Competing Interest

The authors declare that they have no competing interests

References:

American Heart Association. (2016). *Older Americans and Cardiovascular Disease*. Retrieved from https://www.heart.org/idc/groups/heart-public/@wcm/@sop/@smd/documents/downloadable/ucm_483970.pdf

BC government. (2018a). *BC Building Code 2018*. Retrieved from http://free.bcpublications.ca/civix/document/id/public/bcbc2018/bcbc_2018dbp6s63

BC government. (2018b). *BC Building Code 2018*. Retrieved from http://free.bcpublications.ca/civix/document/id/public/bcbc2018/bcbc_2018dbp3s33

Canadian Center for Occupational Health and Safety. (2017b). *Carbon monoxide*. Retrieved from https://www.ccohs.ca/oshanswers/chemicals/chem_profiles/carbon_monoxide.html

Center for Disease Control. (2011). *Carbon monoxide*. Retrieved from https://www.cdc.gov/niosh/pel88/630-08.html
The Canadian Press. (2020). *Commuter mayhem as powerful storm dumps snow across southern BC*. Retrieved from https://www.theglobeandmail.com/canada/british-columbia/article-rare-blizzard-warning-issued-for-area-of-southern-bc-as-snow-frigid/

The Canadian Press. (2019). *A list of other carbon monoxide injuries or deaths in Canada*. Retrieved from https://toronto.citynews.ca/2019/07/09/a-list-of-other-carbon-monoxide-injuries-or-deaths-in-canada/

Cohen, I., Garis, L., Rajabali, F., and Pike, I. (2017). *Carbon Monoxide Poisoning Hospitalizations and Deaths in Canada*. Retrieved from https://cjr.ufv.ca/wp-content/uploads/2017/10/Carbon-Monoxide-2017-Final-.pdf

Dobie, C. (2018, January 14). Metropolis ranked eighth most profitable mall in Canada. Retrieved from https://www.burnabynow.com/business/metropolis-ranked-eighth-most-profitable-mall-in-canada-1.23142160

Gastec. (2019). *Lab manual*. Retrieved from https://www.gastec.co.jp/en/instructionmanual/

Government of Canada. (2019). *Carbon Monoxide Poisoning*. Retrieved from https://www.canada.ca/en/health-canada/services/air-quality/indoor-air-contaminants/keep-carbon-monoxide-out-your-home.html

Hampson, NB., Courtney, TG., Holm, JR. (2012). *Should the placement of carbon monoxide (CO) detectors be influenced by CO's* *weight relative to air?* Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/21536403

Heacock, H. (2019b). Module 4- Introduction to Inferential Statistics. Retrieved from https://learn.bcit.ca/d2l/le/content/569884/viewContent/4069828/View

Herle, K. (2018). *ENVH 3600 Lab Manual*. Burnaby, BC: BCIT.

Langara College. (2020). *Langara at a Glance*. Retrieved from https://langara.ca/about-langara/langara-at-a-glance/index.html

National Academies Press. (2002). *The Ongoing Challenge of Managing Carbon Monoxide Pollution in Fairbanks, Alaska: Interim Report (2002).* Retrieved from https://www.nap.edu/read/10378/chapter/3

Penney, D., Benignus, V., Kephalopoulos, S., Kotzias, D., Kleinman, M., Verrier, A. (2010). *Carbon monoxide*. Retrieved from https://www.ncbi.nlm.nih.gov/books/NBK138710/

Sircar, K., Clower, J., Shin, M., Bailey, C., King, M., and Yip, F. (2015). *Carbon monoxide poisoning deaths in the United States, 1999 to 2012*. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4573527/

United States Environmental Protection Agency. (2016). *Ambient Concentrations of Carbon Monoxide*. Retrieved from https://cfpub.epa.gov/roe/indicator.cfm?i=4#1

U. S. consumer product safety commission (2019). *Carbon-Monoxide-Questions-and-Answers*. Retrieved from https://www.cpsc.gov/Safety-Education/Safety-Education-Centers/Carbon-Monoxide-Information-Center/Carbon-Monoxide-Questions-and-Answers

Reference to Complete Paper

Villanueva, J. (2020). Measurement of Carbon Monoxide concentration levels within an underground parking lot throughout the day. BCIT Environmental Health Journal