Carbon Monoxide Measuring in the University Garages

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Abstract Carbon monoxide (CO) is generally regarded as a critical indicator of air pollutants from car exhausts. Carbon monoxide gives human beings variety of health impacts. It causes a sudden death by inhaling high concentration. Its presence can be used to quantify the amount of air pollution, and as an indicator of air quality in the garages. This study investigated carbon monoxide concentrations in the three underground garages at the University of California, Berkeley. In each garage, a portable carbon monoxide monitor was used to record the concentration of carbon monoxide every 5 seconds. At the same time, temperature, numbers of cars leaving/entering, the loading docks and car occupancy, were measured in every 10 minutes. These variables were expected to affect on changing CO concentration. All concentrations collected in this study were below OSHA guidelines. Carbon monoxide concentrations varied greatly depending on the total number of cars, car occupancy and the loading dock. Truck idling was the only statistically significant explanatory variable contributing to increase in carbon monoxide concentration. If more trucks are idling inside a garage, the concentration of carbon monoxide will be higher to have more effect on people's health.

Introduction

One of the solutions for shortage of parking spaces in urban areas is to construct underground garages and multilevel garages. Although these approaches may conserve space, they also create environments where automobile exhaust may accumulate. Unfortunately, very few previous studies have investigated the air pollution from vehicles in micro indoor environment such as enclosed garages and underground garages. In the indoor environments like enclosed garages and underground garages, it is easy to increase the concentration of air pollutants from vehicles because of less air circulation.

The most significant source of air pollution in garage is motor vehicle emissions including CO, NOx, SOx and Particulate Matter. The level of CO in a local car park is the highest among six different indoor environments such as office, mall (Wong et al, 2002). Among air pollutants from vehicles, CO was chosen as a critical indicator of air quality in many previous studies. Because CO is a colorless and odorless element, it is very difficult to detect its existence until seriously injured.

Carbon monoxide is known to be a significant health risk to humans in both the long-term and the short-term in both indoor and outdoor environment (Chang et al 1997, Lee et al 1999). Inhalation of CO causes a variety of symptoms. At low concentrations, it causes headaches, weariness, and an increase in coronary flow and heat rate. It causes reducing Oxygen delivery to the body's organs and tissue. At high concentrations, CO causes a sudden death by anoxia (Chaloulakou et al, 2002, Chan et al, 1997, Morillo et al, 1998).

Enclosed garages are micro-environments which may have higher concentrations of carbon monoxide than outdoors (Chaloulakou et al, 2002). Air pollution in an underground parking may also affect the people who are in the upper floors of the building (Lee et al, 1999). Therefore, investigating CO concentration in underground garages would concern many people's health conditions.

Previous studies measured both short-term and long-term CO exposure in enclosed multi-level parking garages (Chaloulakou et al, 2002 and Morillo et al, 1997, Ho et al 2004). Short-term exposure is the amount which someone like a driver would inhale while in the garages. Long-term exposure is the amount which someone like an employee would be exposed to during a work shift. Human exposure of CO is focused on employees and the garage users. Also previous studies did their experiments in either commercial or residential parking. To identify the effect on human health, most studies compared their results with recommended public health criteria like the OSHA guidelines (Papakonstantinou et al, 2003).

Previous studies suggest that numerous factors can affect CO concentration. For example, some studies have shown that driving behavior, traffic flow in the garage, time inside the garage, vehicle occupancy, engine temperature, and the rate of car entering/exiting garage can affect (Morillo et al 1997, Matsushita et al 1993, Grimaldi et al 1995, Wong et al 2002, Lee et al 1999). Ho et al. (2004) also suggest that age of a car, fuel efficiency, and different varieties of gasoline can also affect on CO concentrations.

Based on these previous studies, I will investigate CO concentration in the University of California, Berkeley underground garages, where no previous CO concentration studies have been conducted. I have two hypotheses for this study. The first is that instantaneous CO concentration will exceed the OSHA guidelines (i.e., be high enough to affect on human health). The OSHA guidelines suggest that CO concentration should not exceed 50 parts per million. Although the OSHA guideline adapts to the working environment, it will be a good indicator to know the level of CO concentration.

My second hypothesis is that CO concentration will linearly correlate with variables such as number of cars which enter and leave, temperature in the garage, monitoring site, parking occupancy, and loading dock idling. The following other possible variables will not be investigated and will be considered confound in this study: engine temperature, age of cars, fuel efficiency, type of cars, varieties of gasoline, location of ventilation, and vehicle engine operating time. Both the degree of enclosure and infiltration rate between garages are control factors in this study. (See Table 1.) I predict the following effects on carbon monoxide from the these proposed variables. Higher concentrations of CO are measured under lower temperature condition. There is a different CO concentration at different measuring times. A larger number of cars which are both entering and exiting during the experiments will result in greater concentrations of CO in the garage. Concentration of CO from the idling truck near the loading dock is higher than other locations. The effect from confounding factors is very small. My intention is to collect data on CO and then consider the simultaneous effects of these variables. The following equation expresses this simultaneous effects with a general linear model.

$$\mathbf{[CO] = B_{temp}\, X_{temp} + B_{\#\ of\ cars}\, X_{\#\ of\ cars} + B_{parking\ occupancy}\, X_{parking\ occupancy} + B_{dock}\, X_{dock} + ?}$$

In this equation, $\mathbf{X}_{\mathbf{temp}}$ represents the ambient temperature, $\mathbf{X}_{\mathbf{\# of cars}}$ is the number of car entering/exiting the garage, $\mathbf{X}_{\mathbf{parking\ occupancy}}$ is the percentage of the garage that is full, and $\mathbf{X}_{\mathbf{dock}}$ is the presence of a truck idling at the loading dock. **?** is the unexpected and hypothesized as small variation in the CO concentration.

Table1: This table shows the variables which may affect on changing CO concentration.

Explanatory variables	Control variables	Pot. Confounds
- temperature - # of cars leaving/entering - Parking capacity - Loading dock idling	- degree of enclosure (semi or fully enclosed)	- engine temperature - age of cars - fuel efficiency - type of cars - varieties of gasoline -location of ventilation -Vehicle engine operating time

Temperature:
Typical temperature in Berkeley in winter is around 5C to 15C.
I will do my experiment in indoor garages. So I assume that temperature in the garage is a little higher than outside temperature.
According to weather records, average high temperature in Berkeley is around 60 F and average low temperature is around 45 F.

Method

In this experiment, I collected CO concentration data and explanatory variable data in the three different university garages: the Martin Luther King Jr. garage, the Recreational Sports Facility garage, and the Genetics garage. All three are semi-enclosed underground garages.[1] I briefly recorded structural information about the type of garage, location, existence of the loading dock, capacity and who parks in a garage. Table 2 summarized these details about each garage. Also, their locations are described in the map in the appendix.

1. A semi- enclosed garage is defined that there were some ventilations between outsides, so the air could be exchangeable.

Table 2: Structural information for the three garages

	MLK garage	Genetics garage	RSF garage
Kinds of garage	Underground	Underground	Underground
Capacity	Approx. 192 cars	Approx. 364cars	Approx. 276 cars

Number of stories	1 story	2 stories	1 story
Purpose of the garage	Cars and motor cycles	Cars, motor cycles and bicycles.	Cars
The Loading Dock	Yes	No	No
User	Mostly students, faculty stuffs and for public use.	Mostly students and faculty stuffs and for public use	Mostly students and faculty stuffs
Number of entrance and exit	1	1	1

I used a HOBO® Carbon Monoxide Loggers (HCML) by Onset Computer Corporation to measure the carbon monoxide concentration in each garage. An HCML was a very small (5.7"H x 2.6"W x 1.6"D) and light (0.13 kilogram) device, and it could detect carbon monoxide concentration between 0.2ppm to 2000ppm. I could choose any time interval when an HCML would measure carbon monoxide concentrations. Also, an HCML could show both maximum and minimum concentration of carbon monoxide during each experiment. An HCML could store data and read it out on a computer. It could set up a delay start too.

I ran my experiment on both weekdays and event days. Event days are the days when either sports events or cultural events were taking place on campus. On event day, I assumed that many cars entered into the garage in the short time period before the events started. Also many cars left from a garage in the short time period after the events ended. So I expected more cars idled in a garage and that the concentration of carbon monoxide would differ from measurements in weekdays.

Only the MLK parking has two loading dock. Trucks came to the loadings docks from 8:30 am to 12 pm, and from 12:30 pm to 3:30 pm. Because trucks emit more air pollutants than cars, measuring air quality close to truck idling was presumed to result in higher emission estimates. To capture this effect, I measured CO emission from trucks in the closest place possible. Based on my observation, trucks were idling while they were waiting until one truck left from a loading dock space. It took for about 5 minutes. I measured carbon monoxide emission from idling trucks in the place which was about 5m or 10 m far from loading docks.

From my test run, I found the rear of a garage had higher CO concentrations than exit or entrance at all the times. The location at the rear of a garage was far from the entrance/exit. There was less air exchanging in this location. Most people who used a garage walk inside the garage, so I focused on measuring CO concentration in the rear of a garage. Sampling locations were chosen to be at least five meters from any wall to avoid pooling effects (Morello et al 1998).

Before each experiment, I calibrated the three HCMLs in my room. I set the delay start and set up to measure carbon monoxide concentration every five seconds in this study. Before the HCML started measuring carbon monoxide concentration in a garage, I set up the HCML as the same height as human breathing, which was about 1.0 to 1.5m above the grounds (Chaloulakou et al, 2002, Morillo et al, 1997, Wong et al, 2002, Chan et al, 1997 and Ho et al, 2004). The HCML's location and the date were recorded. When the data collection period was over, I recorded the precise time when I took away the HCML from a garage. The HCML was connected with a PC to transfer the data.

During each experiment, I recorded the value for the following explanatory variables (see the Table 1) every 10 minutes: temperature and car occupancy in a garage, number of cars parked in a garage as a percentage of all parking spots. I counted the number of cars both exiting and entering a garage and I summed up it number in a 10 minutes interval. For the loading dock idling, I recorded the exact time when trucks both entered and left the loading dock.

I used multi regression analysis to investigate the relationship between CO concentration and explanatory variables both each garage and each experiment. I also made single regression analysis for bivariate comparison of individual factors with the dependent variables. Carbon Monoxide concentration made a graph showing the relationship between the numbers of cars and changing of carbon monoxide concentration. Means compared between the garages and among the locations in a garage (Wong et al 2002, Matsushita et al 1993, Morillo et al 1998, Chaloulakau et al 2002, Apte et al 1999). A 10 minutes mean CO concentration was calculated to make it possible to analyze with the explanatory variables. For each explanatory variable, I made a graph with 10 minutes mean CO. concentrations. Also, they were compared with air quality criteria for carbon monoxide like OSHA: U.S. Department of Labor Occupational Safety & Health Administration (Chaloulakou et al 2002 and Apte et al 1999). OSHA guideline suggested that CO concentration should not exceed 50 ppm in a 1 hour working period. I used this as my critical indicator for an exposure risk. From these comparisons, I could investigate both when concentration of CO in a garage was greater than OSHA guideline for carbon monoxide and both which variable and which garage were the highly correlated with changing CO concentration.

Result

In this section, exposure risk was investigated. Each variable was examined and analyzed by a liner regression model to find a liner regression. Finally, all the explanatory variables and a dependent variable were analyzed by a multiple regression in each garage.

In all the garages, experiment had done at least three times; morning, afternoon and event day. In the Genetics garage, maximum carbon monoxide concentrations ranged from 3.2ppm (morning) to 9ppm (afternoon); the average carbon monoxide concentration ranged from 0.54ppm (morning) to 3.04ppm (afternoon). In the RSF garage, maximum carbon monoxide concentrations ranged from 3.2ppm (morning) to 6.6ppm (afternoon); the average carbon monoxide concentrations ranged from 0.77ppm (morning) to 1.25ppm (afternoon). In the MLK garage, the highest carbon monoxide concentration in this experiment was 12ppm; 1 minute's average concentration in the loading dock was 10.3ppm in the loading dock.

All the data points were compared with the OSHA standards to determine any exposure risks in the garages. The OSHA guideline is a CO exposure regulation in work place. The OSHA PEL is 50ppm. The OSHA standards prohibit worker exposure to more than 50ppm of air average during 8hour time period (Occupational Safety and Health Administration, Department of labor). Compared with these regulations, all the CO concentration data points in all the three garages did no exceed the regulations. There were no health risks in these semi-enclosed garages.

Temperature in this experiment did not affect on changing CO concentration. During each experiment, temperature was mostly stable and changed within 2 F° rages. In addition, temperature differences among the experiments were within 20 F°. In these ranges, significant effects on CO concentration can not found. In most days when the experiments were done, it rained and was cold days. The varieties of temperature could not be got in my experiment. In my experiments, temperature was not an independent variable which changed CO concentration.

Total number of cars which means adding entering and exiting had an effect on CO concentration. With reference to figure 1, as the larger total numbers of cars were in the garage in both morning and afternoon experiments, the higher average concentrations of carbon monoxide were recorded. The Second bump of total number of cars in the figure 1 was matched the highest bar of CO concentration. The first bump of total number of cars may be disturbed by some errors. As increasing the number of cars operating in the garage, the more CO was emitted in the air.

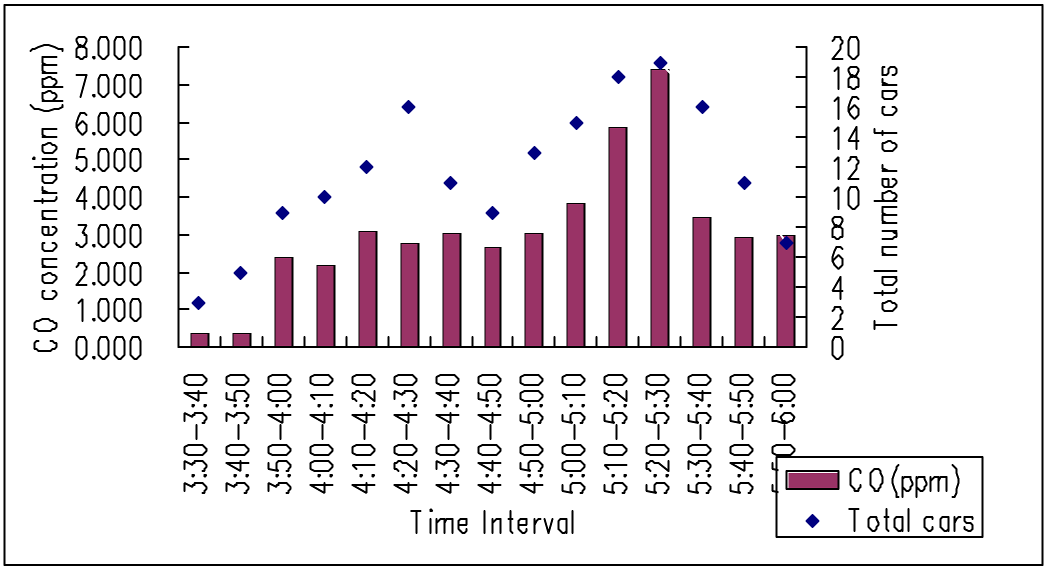


Figure 1: Average concentration of carbon monoxide and total number of cars in the afternoon experiment at the Genetics Garage

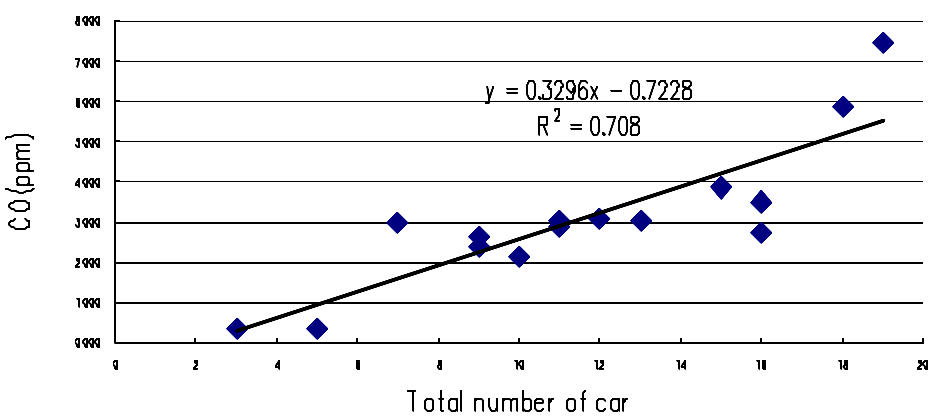
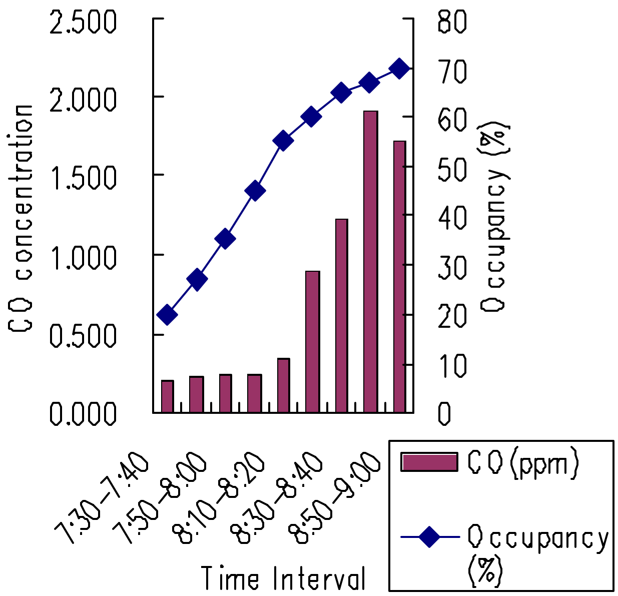


Figure 2: Linear regression between CO concentration and total number of car in the Genetics garage

The linear regression analysis was applied in this graph and the result was shown in figure 2. As the figure was shown, CO concentration and total number of cars was highly correlated with each other.

Occupancy had several tendencies which depended on experiment time. As occupancy changed in both dramatically increasing and decreasing, concentrations of CO increased. In the lower occupancy, CO concentrations remained lower. After the occupancy exceeded 50%, carbon monoxide concentrations became gradually higher (Fig. 3). In the event day, it is a significant relationship between CO concentration and occupancy in all the garages. Before the event started, many cars entered into the garage. So as occupancy increased, CO concentration increased like figure 3. On the other hand, after the event finished, a lot of cars left the garage at once causing an increased total number of cars inside the garage. In the garage, a small amount of traffic resulted in more carbon monoxide emissions into the air in the garage. In front of the entrance and exit, people often pass through constantly and there is a lot of traffic on weekends (Fig. 4).



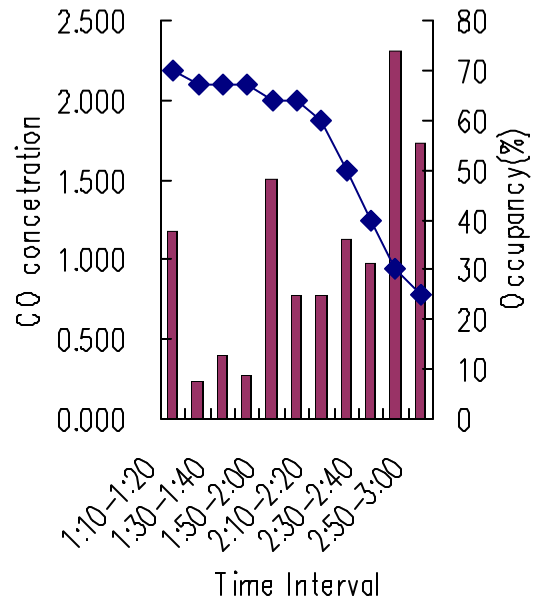
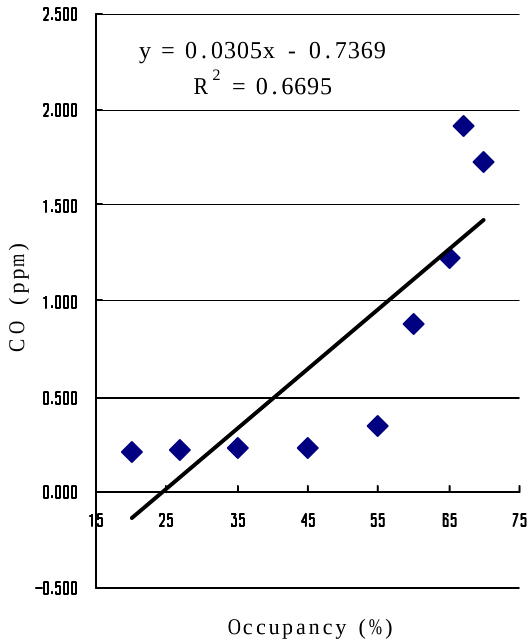


Figure 3: Average CO concentration (ppm) and occupancy (%) in the morning experiment in the RSF garage

Figure 4: Average CO concentration (ppm) and occupancy (%) after finishing the event in the RSF garage

For both figure 3 and 4, the linear regression analysis were used to know the correlation. The results were showed the graphs below in figure 5 and 6. Compared with the analysis of total number of cars, both analyses were not as good as the total numbers of cars. From these two analyses, as occupancy changed rapidly, CO concentration would be changed. Usually, when occupancy was increasing in both morning and time before the event started. On the other hand, when occupancy was decreasing in both afternoon and time after the event ended.

Near the loading dock, carbon monoxide concentration highly correlated with truck idling. As soon as trucks started their engine, concentration of carbon monoxide instantly got higher. The highest carbon monoxide concentration in this experiment was 12ppm; 1 minute's average concentration in the loading dock was 10.3ppm. Compared to the average carbon monoxide concentration, the higher concentration continued for about 2 minutes. When a truck started its engine, carbon monoxide concentration grew higher very quickly, and gradually concentration was decreased becoming average carbon monoxide level in the garage (Fig. 7).



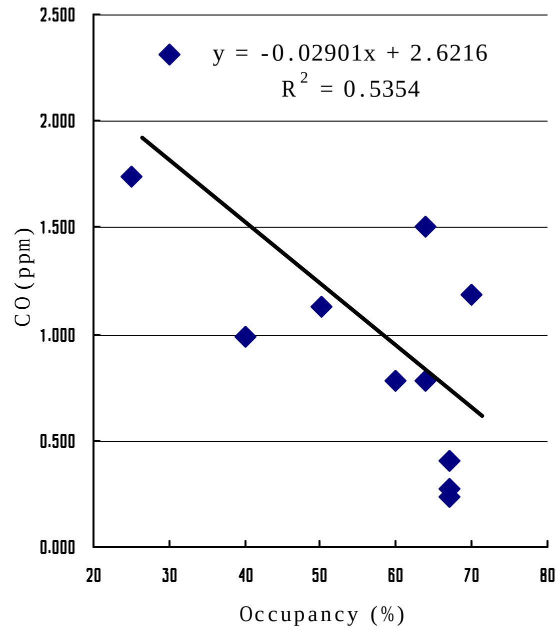


Figure 5: A single linear regression analysis for CO (ppm) and occupancy (%) for figure 3

Figure 6: A single linear regression analysis for CO (ppm) and occupancy (%) for figure 4

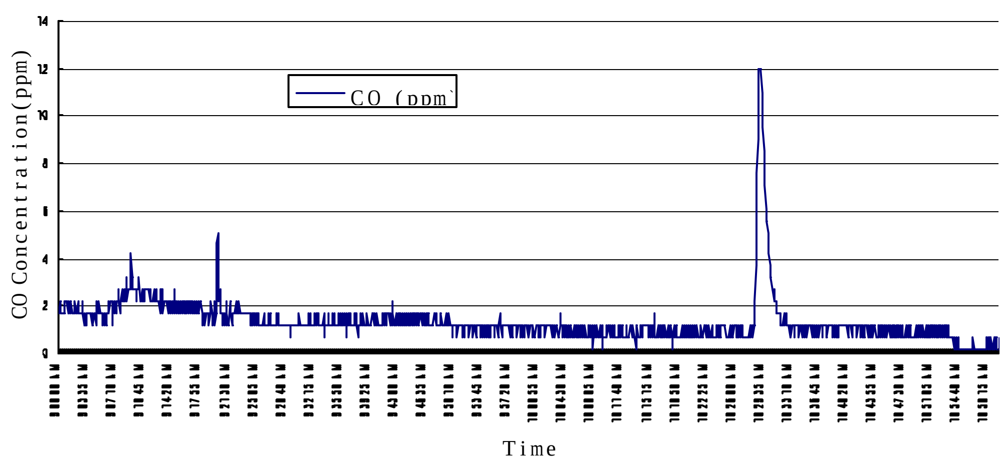


Figure 7: Changing Carbon monoxide concentration near the loading dock by time in the MLK garage: trucks were idling around 9:09am, 9:21am and 10:29am

The CO level was hypothesized to be dependent on total number of cars in the garage, occupancy, and the loading dock. Multiple linear regression equations relating carbon monoxide level to three of them were derived using the method of least square fitting in each garage. The equation was written blow.

$$[CO] = B_{temp} X_{temp} + B_{\#\ of\ cars} X_{\#\ of\ cars} + B_{parking\ occupancy} X_{parking\ occupancy} + B_{dock} X_{dock} + ?$$

In both the Genetics garage and the Recreational Sports Facility garage, there is no loading dock.

For this multiple linear regression analysis, explanatory variables were less linearly correlated with CO concentration. No significant results were found in the entire garages. Confounding factors in this study affected changing CO concentration more than I expected.

Discussion

Overall this experiment found that occupancy and total number of cars in the garage affect the increase carbon monoxide concentration in the three garages. In the loading dock, truck idling was highly correlated with CO concentration. CO level was lower than OSHA guideline. These concentrations did not have bad effect on human health in both short-term and long-term.

From my experiments, there were different tendencies of CO concentration among the three garages in statistical analysis. The higher carbon monoxide concentrations were measured in both event days in all the three garages and the loading dock in the MLK garage. Both total numbers of cars inside the garage and occupancy affected on changing carbon monoxide concentration in this experiment. The Genetics garage and the MLK garage had a similar tendency in the multiple regressions. Both were higher correlation in the afternoon experiment. In the MLK garage, there were less correlation between explanatory variables and CO concentration. When the experiment was done, the garage was occupied more quickly than I expected. In addition, the MLK garage was the reserved garage for disabled people in that event. So I could not find the expected result. As a result, the correlation was smaller. Compared with the other garages, the RSF garage had the higher correlation in the morning. One of the reasons is that not only students, but also people who use the gym parked in the RSF garage. Overall, I could not find the higher correlation in my experiments because the number of experiments was very small to investigate the relationship.

In commercial and residential garages in urban areas like other studies did, CO concentration may be more affected by my explanatory variables. Specially, commercial garages in urban city are quickly filled with cars and people wait with idling inside a garage until parking their cars. Under this environment, both total number of car and occupancy will be more correlated with CO concentration. In addition, the higher CO concentration may be measured in these environments.

There are no existing building regulations to govern air quality in car parks except for employees (OSHA). Legislative control of air quality in underground garages is currently under consideration, but many people who use them are exposed daily to carbon monoxide. In my experiment, carbon monoxide did not exceed the regulations. Those garages maintained better air quality than similar experiments' results. In these garages, the ventilation systems work effectively and the air circulates frequently. Carbon monoxide was quickly purged to the outdoors by the ventilation systems in those garages which could effectively control the pollutant to an acceptable level (Ho et al 1997). This is not always the same condition at other sites and the effectiveness of a ventilation system may vary. To estimate the exposure risk inside underground garages which affect the users and an average exposure time is defined. Apart from activities, drivers would spend at least 1 minute in the contaminated environment and probably less then 5 minutes. So 1 minute maximum concentration of carbon monoxide is suitable for a reference level.

Truck drivers may go to many underground garages to both load and unload and they will be exposed higher concentration of pollutants during their working time. The higher carbon monoxide concentration was recorded near the loading docks in most cases. So truck drivers and workers in the loading dock have a higher possibility to be exposed to the higher carbon monoxide. There is no evidence that this group of workers is more or less healthy than the general people. Also, these workers and truck drivers who are smokers and under these working conditions is a matter of concern (Ho et al 1997). In addition, they may load or unload in the worse environments than my experiment. That condition will affect truck drivers' health because they have longer hours of exposure compared to users and are at higher risk from exhaust from vehicles.

Although other papers mentioned that temperature can act to increase the toxic concentration, it could not be seen as a significant factor in changing CO concentration in my experiment. During each experiment, temperature was stable, and temperature differences between experiments are within 20F°. If this experiment is done in summer and compared my results, temperature will be a factor of changing concentration.

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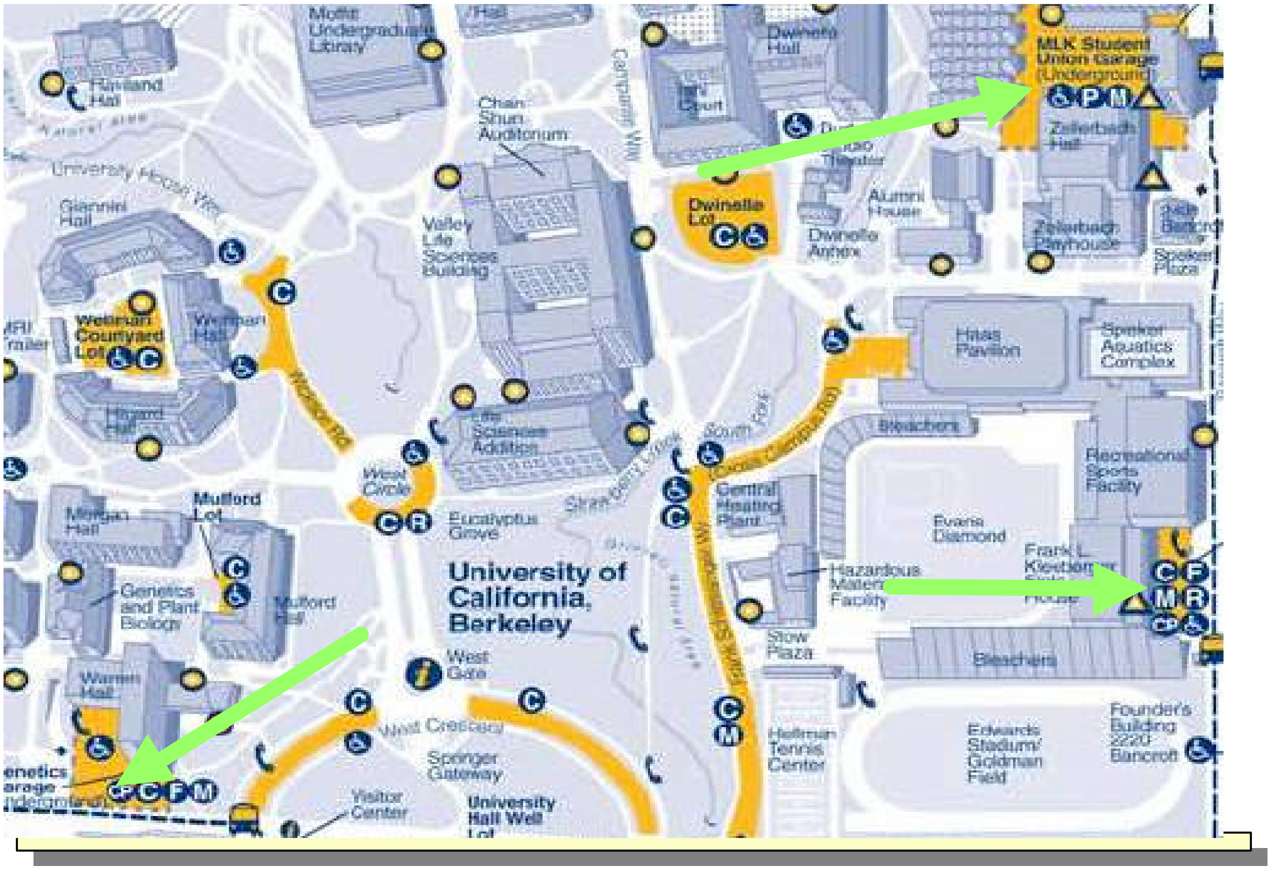
Appendix



Map for Study sites. The green arrows show the study sites.