

Carbon Monoxide (CO) Detection and Control Systems for Parking Structures

Guidelines for the Design Engineer

Rev 1.14



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1 General Overview

Carbon Monoxide (CO), one of the most toxic components of vehicle exhaust, is a significant safety concern in parking structures. Gas-powered vehicles make use of these structures on a regular basis and emit CO. When concentrations of CO approach unsafe levels, the ventilation system must be activated to normalize the parking area.

Due to energy and environment concerns, many jurisdictions across Northern America have mandated CO sensing control systems for new parking garages. A wide range of gas detection and control systems is available for handling the sequence of operations for enclosed parking structures. This guide offers detailed support for the Design Engineer in selecting and specifying an optimal solution that will provide a safe environment and minimize energy cost. Ultimately, a parking structure's design will determine which type of gas detection and control system best fits the application.

1.1 Carbon Monoxide and Its Effects

Carbon monoxide (CO) is a colorless, odorless and tasteless gas that is highly toxic to humans and animals; it bonds with hemoglobin and reduces the oxygen-carrying capacity of blood in the body. Its chemistry consists of one carbon atom and one oxygen atom. CO is produced from the partial oxidation of carbon-containing compounds; it forms when there is not enough oxygen to produce carbon dioxide (CO₂), such as when operating a combustion engine in an enclosed space.

The level of CO concentration is measured in parts per million (ppm). For example, 100 ppm CO means that for every 1,000,000 molecules of air, 100 of those molecules are CO. In addition to determining the current level of CO concentration, another method used is the Time Weighted Average (TWA). This measures a person's average exposure (in ppm) to CO over a time span. For example, if a person were exposed to a large dose of CO in the morning but none afterwards into the evening, the TWA for the entire day would be low. However, if a person is continually exposed to 20 ppm CO throughout the day, the TWA will be 20 ppm for that duration.

The table below summarizes some health effects due to prolonged exposure to various concentrations of CO in air. It has been compiled from reputable sources, including the NFPA:

CO Level	Condition & Health Effects	Institute
0 ppm	Normal, fresh air	
9 ppm	Maximum allowable short-term exposure	ASHRAE
10-24 ppm	Possible health effects with long-term exposure	
25 ppm	Max TWA exposure for 8 hour work-day	ACGIH
50 ppm	Maximum permissible exposure in workplace	OSHA
100 ppm	Slight headache after 1-2 hours	
200 ppm	Dizziness, nausea, fatigue, headache after 2-3 hours of exposure	
400 ppm	Headache and nausea after 1-2 hours of exposure / Life threatening in 3 hours	
800 ppm	Headache, nausea, and dizziness after 45 minutes / Collapse and unconsciousness after 1 hour of exposure / Death within 2-3 hours	
1,600 ppm	Headache, nausea, and dizziness after 20 minutes of exposure / Death within 1-2 hours	
3,200 ppm	Headache, nausea, and dizziness after 5-10 minutes / Collapse and unconsciousness after 30 minutes of exposure / Death within 1 hour	
6,400 ppm	Death within 30 minutes	
12,800 ppm	Immediate physiological effects, unconsciousness / Death within 1-3 minutes of exposure	

2 Installation and Application Codes and Standards

Various institutions, societies, organizations and government agencies establish codes and standards to address the limits of CO levels for parking structures. Most building codes allow for demand-based ventilation in enclosed parking garages by monitoring CO levels. This type of design can drastically reduce energy costs (operating of garage fans and heating system), increase fan belt and motor life and reduce noises. Codes and standards vary by city and state. An overview of the most well known is listed below. The design of a garage exhaust system should be based upon the codes and standards of the appropriate local jurisdiction.

2.1 ASHRAE Handbook

To conserve energy, fan systems should be controlled by carbon monoxide meters with multiple fan or variable speed stages for larger systems, if permitted by local codes. In multi-level parking garages or single-level structures of extensive area, independent fan systems, each under individual control, are recommended.

2.2 IMC - International Mechanical Code

Mechanical ventilation systems for public garages are not required to operate continuously where the system is arranged to operate automatically upon detection of a concentration of carbon monoxide of 25 ppm by approved detection devices.

2.3 UMC - Uniform Mechanical Code

Automatic carbon monoxide-sensing devices may be employed to modulate the ventilation system to maintain a maximum average concentration of carbon monoxide of 50 ppm during any eight-hour period, with a maximum concentration not greater than 200 ppm for a period not exceeding one hour.

2.4 UBC - Uniform Building Code

Automatic CO sensing devices may be employed to modulate the ventilation system to maintain a maximum average of 50 ppm CO during any eight-hour period, with a maximum average concentration not greater 200 ppm for a period not exceeding one hour.

Standard for Installation of Carbon Monoxide Detection & Warning Equipment – Requires carbon monoxide monitoring equipment (i.e. sensors/transmitters) to be performance tested and certified to standard UL 2075.

3 Carbon Monoxide Exposure Limits

Each organization has its own vocabulary to describe the type of limit or level. Here is a summary of some common terms:

TWA - Time Weighted Average. This is the level of CO (in ppm) that a person has been exposed to on average over some period of time (usually 8 hours).

PEL - Permissible Exposure Limit. This is the term OSHA uses for the limits it publishes. For CO, it happens that all of OSHA's PELs are actually TWA limits.

Ceiling - An upper limit on the permissible concentration of CO at any moment. For example, a ceiling value of 200 ppm means that the level of CO should never rise above 200 ppm.

STEL - Short Term Exposure Limit. This is a TWA defined over a short time period of 15 minutes. According to ACGIH, it should not be exceeded during any part of a workday, even if the 8-Hour TWA is within its limit.

Excursion Limit - An ACGIH term that refers to the ceiling limit within a short duration (typically 15 - 30 minutes). This limit is used when no STEL is published, and is defined as 5 times the 8-Hour TWA limit (Source: ACGIH Handbook of TLVs and BEIs, 2004).

The table below summarizes the alarm levels and national standards for garage CO exposure levels:

Organization	Type	CO Level in Air	Alarm Level
ACGIH – American Conference of Governmental Industrial Hygienists	TWA (8 Hours)	25 ppm	Smallest CO ppm amount for Low Alarm Level Trip/Setpoint
IMC – International Mechanical Code		25 ppm	
NIOSH – National Institute for Occupational Safety and Health	TWA (1 Hour)	35 ppm	Acceptable CO ppm amount for Low Alarm Level Trip/Setpoint
EPA – Environmental Protection Agency	TWA (1 Hour)	35 ppm	
OSHA – Occupational Safety and Health Administration	OSHA PEL as TWA (8 Hours)	50 ppm	Acceptable CO ppm amount for Low Alarm Level Trip/Setpoint. Maximum concentration for low alarm!
Manufacturer's recommendation		75 ppm	CO ppm amount for Medium Alarm Level Trip/Setpoint
Manufacturer's recommendation		100 ppm	Smallest CO ppm amount for High Alarm Level Trip/Setpoint
ACGIH – American Conference of Governmental Industrial Hygienists	Excursion Limit (EL)	125 ppm	Acceptable CO ppm amount for High Alarm Level Trip/Setpoint
NIOSH – National Institute for Occupational Safety and Health	Ceiling	200 ppm	Acceptable CO ppm amount for High Alarm Level Trip/Setpoint Maximum concentration for high alarm!

4 Detection and Control System

4.1 Ventilation Requirements

A controller monitoring multiple CO sensors should be capable of zoning. The controller should have multiple relay outputs and thresholds in order to control exhaust fans, make-up fans and supply fans. Analog outputs from the controller can be used to ramp up variable-frequency drives (VFD) based on the serviced area of the exhaust fan.

When the exhaust fans are stopped or operating at low speed the garage will have minimal ventilation. On hot and humid days the controller should be able to increase the speed of the exhaust fans to compensate for high temperature or high humidity conditions.

4.2 Sensing Technology

The International Mechanical code states that ventilation systems for enclosed parking garages are not required to operate continuously if the system is arranged to react automatically upon detection of a concentration of carbon monoxide of 25 ppm by approved automatic detection devices.

The accurate detection of CO at low levels is critical in garage applications. There are currently two types of CO sensing technology available: electro-chemical and solid state. The most accurate devices utilize an electro-chemical element. These sensors are gas specific and have an accuracy reading of +/- 0.5 to 1 ppm. By contrast, solid state sensors approximate the CO levels and are susceptible to temperature or humidity. Solid state sensors are also cross sensitive to other gases and heavy solvents in the environment, and thus, prone to false alarms.

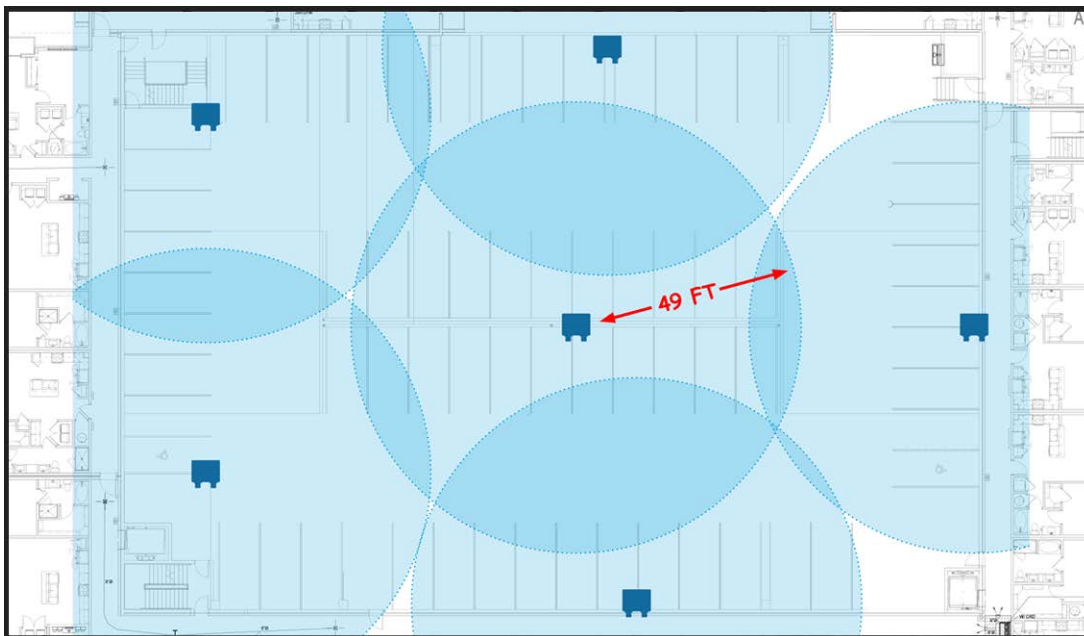
The market offers mainly two types of CO gas sensing element technologies for commercial garage applications – electrochemical and solid state			
Technology	Accuracy PPM CO	Life Span	Features
<u>Electrochemical</u> – Type High Accuracy	< +/- 1	5+ years	<ul style="list-style-type: none"> ▪ Detects the true level of CO in ppm ▪ Reduced drift <p><i>“High accuracy & reduced drift means fewer calibration intervals”</i></p>
<u>Electrochemical</u> – Type Standard	+/- 3	< 5 years	
Solid State / <u>Semiconductors (MOS)</u> – Type 1	+/- 7 to 15	7+ years	Solid state sensors: <ul style="list-style-type: none"> ▪ Are cross sensitive and prone to false alarm ▪ Subject to drifts of readings at sizeable space temperature and/or humidity changes ▪ Shorter calibration intervals
Solid State / <u>Semiconductors (MOS)</u> – Type 2	Unknown	2.5 years	

4.3 Location of Sensors and Controllers

Sensors shall be located in the garage area and mounted on columns at approximately 5 ft above the floor. Each CO sensor can cover approximately 5,000 to 10,000 sq ft of open space. CO gas will disperse and flow with natural air current and car movement.

Using the average of 7,500 sq ft per sensor and a circular radius of 49 feet, the sensors area coverage could be scaled and placed on the garage floor plan layout to cover the open floor area.

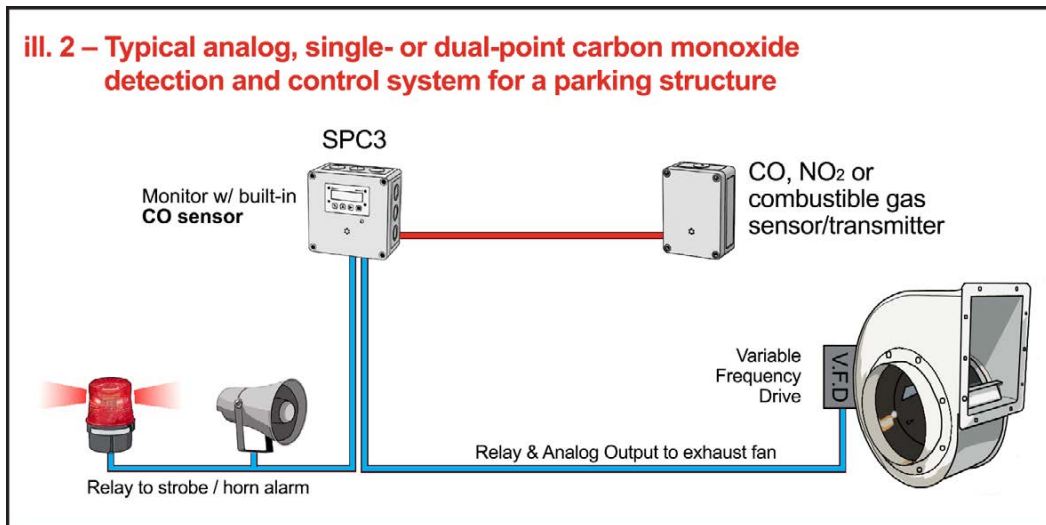
Based on the number of CO sensors and the location of the exhaust fans and make-up air handlers, one can determine the most cost effective CO detection equipment to minimize the total cost of sensors, controllers, conduit, wiring, termination, startup and final commissioning.



ill. 1 Sample CO sensor placement

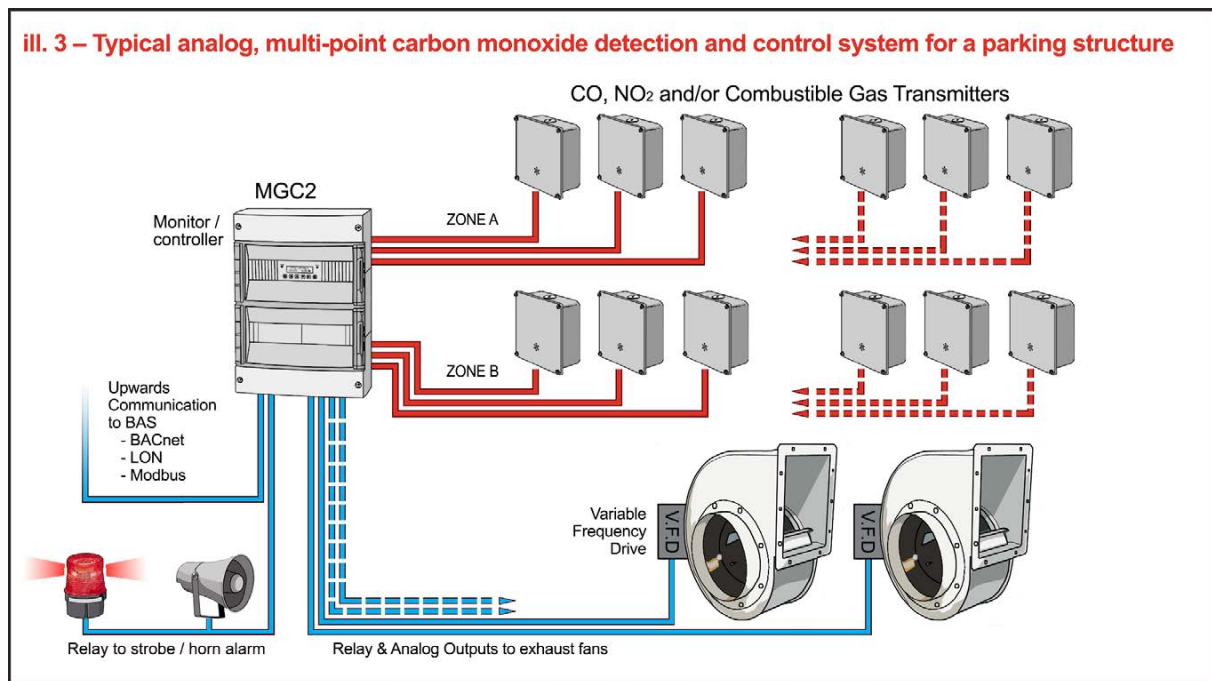
4.4 Selection of Detection and Control System Type

Single & Dual Sensor Systems are best for smaller size areas (7,500 to 15,000 sq ft). The system monitors one or two gas types and has relay outputs for fan control. The single or dual sensor system will also have an analog output to control one VFD.



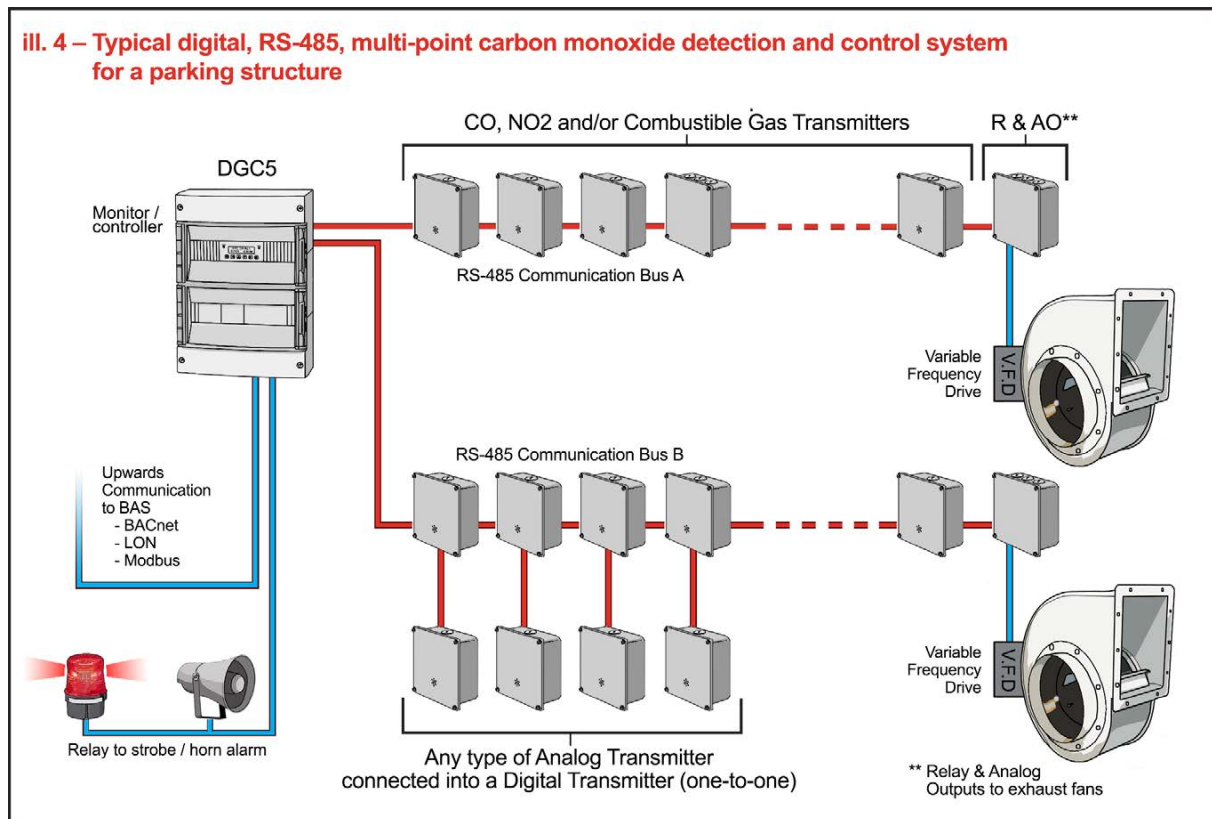
ill. 2 Typical single- or dual-point system

Multi-Point Analog Systems are best for small to medium size areas (15,000 to 90,000 sq ft). The system can monitor multiple gas sensors and control multiple relays for fan control. All sensor wiring is home run to the multi-point controller using two-wire (three-wire for combustible gas transmitters) shielded cable. The controller should be capable of providing multiple relay outputs for fan control and have multiple analog outputs to control VFD's.



ill. 3 Typical analog, multi-point system

Digital Multi-Point Bus Systems are best for medium to large areas (90,000+ sq ft). It reduces the total overall installation cost when using a digital “daisy chain” setup, where four wires are connected to each sensor or remote relay. The conduit is minimized to ½” since only two wires are used for power and two twisted shielded wires for the communication. The system can monitor up to 98 digital gas sensors. The fans can be turned on and ramped up via relays and analog outputs located in the controller or remote relay/AO modules located anywhere along the bus.



ill. 4 Typical digital, RS-485, multi-point system

4.5 Basic Central Controller Recommendations

- The controller should not be located where water, oil etc. may influence proper operation or where mechanical damage might be possible.
- Mount where service technicians can gain access.
- The controller shall allow five programmable stage alarm levels per sensor (four stages for standalone) with each stage assignable to a control relay output. The controller shall also provide analog outputs (4-20mA) corresponding to the real-time value of the highest gas sensor within a sensor zone.
- Analog transmitters (AT-series) shall output a 4-20mA signal corresponding to the real-time gas value readings and connect to the controller (or digital transmitter) via two-wire (loop powered) or three-wire connection.
- Digital transmitter (DT5-series) shall output a digital signal that shows the real-time gas value readings and connect to the controller via 4-wire connection (two wires for power and two wires for RS-485 communication).

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- The controller shall be capable of zoning the highest real-time value reading of a sensor.
- The controller shall have a digital display with keypad that is password protected and allows for programming or changing of all system parameters and for viewing of all sensor readings.

4.6 Controller Output Signals

- The quantity of relay outputs varies depending on the system configuration. Some relay contacts are SPDT 8A, 250VAC max. Some relay contacts are (1) SPDT 0.5A and (1) SPNO/SPNC 0.5A, 30VAC max. Systems can have up to 30 relay outputs depending on the system configuration. The relays can be used to control fans, horns, and strobes, or provide status to the building automation system (BAS).
- Analog Output: A sensor (or sensors) can be assigned to a particular analog output (4-20mA signal) to show the highest sensor reading value of a zone group in real-time. The system should be capable of 12 analog outputs. The analog outputs normally connect to variable-frequency drives to increase or decrease fan speed as the gas ppm concentration increases or decreases.
- The controller can be provided with a BACnet or Modbus coupler that provides upwards communication to the BAS.

4.7 System Self-Test Diagnostic with Malfunction Warning

- The controller shall notify appropriate personnel when a fault has occurred.
- The controller, with the correct level password, allows manual override of the relays outputs. The controller can be programmed to assign any of the four digital inputs to override the assigned relay to off or on condition automatically.
- Controller can be programmed to alarm the operator of system maintenance whenever a set date has been reached by displaying the phone number to contact for further instructions.
- The controller's integrated fault management shall keep records of the last 15 faults with date and time stamps that can be viewed by authorized personnel with the appropriate password.

4.8 Sample Sequence of Operations

In this example, a small enclosed parking garage with a low setpoint of 25 ppm and a high of 100 ppm. When any CO sensor exceeds a threshold (ppm level in air) the following shall happened:

- Threshold # 1 (low alarm level trip/setpoint) at 25 ppm:
 - Start the exhaust fan at minimum speed with relay #1 to bring in fresh air and reduce the CO level.
- Threshold # 2 (medium alarm level trip/setpoint) at 75 ppm:
 - Step up the exhaust fan to high speed with relay # 2 to bring more fresh air and reduce the CO level.
 - If the exhaust fans have VFDs preferably use the analog output associated with this exhaust fan to ramp up the VFD between 25 ppm and 75 ppm proportionally to highest speed.
- Threshold # 3 (high alarm level trip/setpoint) at 100 ppm:
 - Turn on with relay # 3 remote horns/strobes located in garage area or areas where security or maintenance personnel can be warned of high ppm CO concentrations.
- Threshold # 4 (high alarm level trip/setpoint) at 100 ppm:
 - Notify with relay high alarm level condition to the BAS.
- Threshold # 5 (high alarm level trip/setpoint) at 100 ppm:
 - Activate controller's horn/buzzer and alarm LED.

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5 System Commissioning and Project Sign-off

5.1 Commissioning and Start-up

- A qualified gas control system service technician should perform the following:
- Thoroughly check that onsite assembled equipment, specified cables, control unit station(s), remote sensors/transmitters & other field control modules are properly placed and installed.
- Verify that electrical connections follow electrical and building codes. The wiring end must terminate correctly.
- Apply calibration gases on the sensors in order to test the correct functions of the alarm setpoints and verify the operations sequence of the carbon monoxide detection and control system.
- Issue a written report of the test results and corrective actions to be completed if required.
- The report should include the verification of all devices, i.e. remote strobe, horn, sign, other alarm units and protective equipment, etc.
- Malfunctioning products are repaired or replaced.

5.2 Performance Demonstration and Training

The building owner's maintenance personnel should be trained by a qualified gas system service technician. This individual will be responsible for changing setpoints & operations sequence, troubleshooting, performing scheduled maintenance, and calibrating the CO detection and control system using the appropriate tools and test gases.

6 Calibration and Services

6.1 Calibration

- Calibration intervals must comply with the manufacturer's recommendations.
- Calibration tool kit shall be provided at the time of the installed system's completion.
- Building owners may consider maintaining and calibrating the CO, as well as NO₂ and combustible, gas detection and control system periodically by a qualified gas detection service company.

7 Other Concerns

7.1 Energy Cost & Greenhouse Savings and Return of Investment Potential

The table below is an example of the potential savings by using an appropriate gas detection demand control system.

Underground Garage/Parking Structure of an Office Building - 100,000 sq ft for about 350 parking spaces for automobiles - Approximately total 75 HP (Horsepower), combined of all fans - 12 hours/day and 7 days/week garage operation		
HP (Horsepower) to Watts (Electrical Power) Conversion (In this example the fan motor efficiency and load factor canceling out each other) $75 \text{ HP} \times 746 \text{ Watts/HP} = 55,950 \text{ Watts divided by } 1,000 = 55.95 \text{ kWatts}$		
Annual Fan Power Consumption (kWh)	Without Gas Detection Demand Control 12 hours/day x 365 days x 55.95 kWatts = 245,061 kWh	
	With Gas Detection Demand Control 2 hours/day x 365 days x 55.95 kWatts = 40,844 kWh	
Annual Savings	kWh Savings per Year: No Demand Control 245,061 kWh Demand Control - 40,844 kWh Savings = 204,217 kWh	Electricity Cost Savings per Year: 204,217 kWh x \$ 0.175 per 1 kWh Savings = \$ 35,738
- Installation Cost - Return of Investment	With Utility Rebate	Immediate to 0.5 Year
	(No Rebate)	0.8 to 1.5 Year
Greenhouse Savings	273,651 lbs CO	

7.2 Time of Day Fan Scheduling

Some products offer a time clock in their CO detection and controls system package for actuating a ventilation system based on the time of the day. This is unnecessary! The CO detection and control system detects the presence of CO and actuates the fans ONLY when needed.

Overriding the ventilation system with a time switch diminished the benefits of a CO system. Instead of using a time of day override function, integrate high temperature and/or relative humidity limit ventilation control to facilitate and secure adequate space comfort when no CO is present.

7.3 Diesel Fume Detection and Control

Diesel-powered vehicles emit exhaust containing nitrogen dioxide (NO₂), a major contaminant and carcinogen (cancer causing agent). The monitoring of NO₂ must be addressed in the design of a ventilation system.

- Nitrogen dioxide detection and control is applied wherever numerous diesel engines are used, i.e. train stations, bus and truck maintenance garages, rapid transit authorities, car dealerships, ambulance bays, loading docks and diesel-powered vehicle parking structures.

7.4 Combustible Fume Detection and Control

When vehicles using fuel types such as methane, propane, or where gasoline spillage is of concern then consider combustible gas detection sensors in the design of the ventilation system.

7.5 Rough Environmental Conditions

Depending on the parking structure design, type of usage, and installation location, special product packaging requirements may apply; i.e. sensors and/or controllers exposed to:

- Dust, dirt, light water splashing
 - Provide optional NEMA 4X enclosure (X = Designates resistance to corrosive agents).
- Washing cars and/or hosing down walls
 - Provide optional NEMA 4X enclosure with splash guard protection.
- Low temperature environment, sensor/transmitter ambient temperature below -10°C (14°F)
 - Provide optional heater, built-in sensor/transmitter enclosure, allows ambient temperature down to -40°C (-40°F).