CODES AND STANDARDS ENHANCEMENT INITIATIVE (CASE)

Garage Exhaust

2013 California Building Energy Efficiency Standards

California Utilities Statewide Codes and Standards Team September 2011

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1. Introduction

Through Codes and Standards Enhancement (CASE) Studies, the California Investor Owned Utilities (IOUs) provide standards and code-setting bodies with the technical and cost-effectiveness information required to make informed judgments on proposed regulations for promising energy efficiency design practices and technologies.

The IOUs began evaluating potential code change proposals in fall 2009. Throughout 2010 and 2011, the IOU CASE Team (Team) evaluated costs and savings associated with each code change proposal. The Team engaged industry stakeholders to solicit feedback on the code change proposals, energy savings analyses, and cost estimates. This CASE Report presents the IOU code change proposal for garage exhaust. The contents of this report, including cost and savings analyses and proposed code language, were developed taking feedback from the solar and building industries and the California Energy Commission (CEC) into account.

All of the main approaches, assumptions and methods of analysis used in this proposal have been presented for review at three public Stakeholder Meetings hosted by the IOUs. At each meeting, the CASE team asked for feedback on the proposed language and analysis thus far, and sent out a summary of what was discussed at the meeting, along with a summary of outstanding questions and issues.

A record of the Stakeholder Meeting presentations, summaries and other supporting documents can be found at www.calcodesgroup.com. Stakeholder meetings were held on the following dates and locations:

- First Stakeholder Meeting: May , 2010, San Ramon Conference Center, San Ramon, CA
- Second Stakeholder Meeting: November 10, 2010, Webinar
- Working Session: January 20, 2010, Webinar
- Third Stakeholder Meeting: April 5, 2011, Webinar

Specific stakeholder comments addressed in Section 5 of this report.

2. Overview

2.1 Measure Title

Demand controlled ventilation for enclosed parking garages

2.2 Description

The proposed measure would require modulating ventilation airflow in large enclosed parking garages based on pollutant concentrations. By modulating airflow based on need rather than running constant volume, the system will save energy and maintain a safe environment.

2.3 Type of Change

This measure would be a prescriptive requirement.

2.4 Energy Benefits

Energy savings between the basecase and the proposed case were calculated for the prototype garage, which is a 50,000 square foot enclosed parking garage below an office building. The energy savings calculations are discussed at length below in Section 4.1. A summary of the results are shown here in Table 1 for Climate Zone 3.

Table 1. Summary of energy savings from proposed measure

	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (Therms/yr)	TDV Electricity Savings	TDV Gas Savings
Per design cfm	1.23	0.000281	0	$2.19	0
Per Prototype Building	46,250	10.55	0	$82,190	0
Savings per square foot	0.925	0.0002111	0	$1.64	0

The savings from this measures results in the following statewide first year savings.

Table 2. Statewide first year savings

Statewide Power Savings (MW)	Statewide Electricity Savings (GWh)	Statewide Natural Gas Savings (million Therms)	Total TDV Savings ($ million) *
3.17	13.88	0	$24.6

* TDV savings represent the cost savings that accrue over the entire measure life.

2.5 Non-Energy Benefits

Experience from Taylor Engineering and from garage DCV system-manufacturers show that many garage operators in California operate exhaust fans arbitrarily, shutting fans off to conserve energy, and then turning them on as a need is perceived. There is no sensor feedback operating in this manner. Operating garages based on sensor feedback can actually improve the health and safety of occupants in the garage. Other benefits include reduced noise (at low fan speeds) and improved safety due to reduced noise.

2.6 Environmental Impact

The adverse environmental impact of this measure is minimal, and is far out-weighed by the environmental benefit of saving energy. Adverse environmental impacts from this measure come from additional parts of a DCV system versus a constant-volume system. The additional parts are sensors, VFDs, controllers, and wiring. All of these parts have limited impact even when considering their material extraction, manufacture, packaging, shipping, and disposal.

Table 3. Change in material quantities caused by the proposed measure (I – Increase, D – Decrease, NC – No Change). All units are lbs/year

	Mercury	**Lead**	**Copper**	**Steel**	**Plastic**	**Others (Indentify)**
Per square foot	NC	I	I	I	I	NC
Per Prototype Building	NC	I	I	I	I	NC

2.7 Technology Measures

The measure requires the use of carbon monoxide (CO) sensors.

2.7.1 Measure Availability

Commercial CO sensors are readily available on the market from multiple manufacturers including AirTest Technologies, Honeywell, 3M Macurco, MSA Canada, and Brasch Manufacturing Company. Most new enclosed parking garages are already being designed with CO-monitoring systems, so the market is already ready to supply the measure.

2.7.2 Useful Life, Persistence, and Maintenance

All pollutant-sensors require periodic recalibration or replacement ranging from 6 months to 15 years. In order for energy savings to be realized for the life of the building, the sensors must be calibrated or replaced as specified by the manufacturer. Failure to calibrate and/or replace sensors would result in an increase in energy use, as the failsafe position of sensors is to have the fans run at design speeds, as required by the proposed language. If properly maintained, the sensors will continue to provide energy savings for the entire life of the garage.

2.8 Performance Verification of the Proposed Measure

Commissioning of the garage ventilation system is required. Commissioning the system requires:

- Ensuring sensors have been calibrated per the Standard
- Ensuring that sensors are located in the highest expected concentration location in its zone
- Ensuring the control setpoint is at or below the CO concentration setpoint permitted by the Standard
- Simulating a signal for elevated levels of CO and ensuring the sensor detects it and the fans ramp up
- Simulating a signal for low levels of CO and ensuring the fans run at the minimum ventilation rate required by the Standard.

- Simulating a sensor failure and ensuring that the fans ramp up to provide design ventilation and that the system alarms.

See proposed language for acceptance testing in Section 6.3.

2.9 Cost Effectiveness

See Section 4.3 for details on the cost-effectiveness of the measure.

Because DCV in garages is already so common in California, the system costs are not expected to decrease significantly after adoption.

Table 4. Cost effectiveness summary

a	b	c		d		e		f	g	
Measure Name	Measure Life (Years)	Additional Costs Current Measure Costs (Relative to Basecase) ($)		Additional Cost Post-Adoption Measure Costs (Relative to Basecase) ($)		PV of Additional Maintenance Costs (Savings) (Relative to Basecase) (PV$)		PV of Energy Cost Savings – Per Proto Building (PV$)	LCC Per Prototype Building ($)	
		Per Unit	Per Proto Building	Per Unit	Per Proto Building	Per Unit	Per Proto Building		(c+e)-f Based on Current Costs	(d+e)-f Based on Post-Adoption Costs
Garage exhaust	15	$0.97	$36,275	$0.94	$35,300	$0.24	$9,061	$80,688	-$35,352	-$36,327

2.10 Analysis Tools

No special analysis tools are required to quantify energy savings and peak electricity demand reductions. Given the details of the fan and the hours of operation, a simple calculator or spreadsheet can be used to calculate the energy savings.

2.11 Relationship to Other Measures

This measure has no relation to other measures.

3. Methodology

3.1 Energy Savings

Energy savings were calculated based on existing garages with demand-controlled ventilation in which actual fan energy was trended. In the garages analyzed, the CO concentrations, fan speed, and fan kW were trended. The fans were scheduled to run at some minimum setting during all occupied periods, and were to ramp up in the event that the CO concentration went above setpoint. From these garages, average kwh savings/sqft were calculated. See Section 4.1 for details on the case studies.

A conservative average energy savings per square foot was determined based on the case studies. It is assumed that a given garage operates from 7am to 7pm, Monday through Friday. The prototype garage used for the analysis is 50,000 square feet in area.

Taking cost data from manufacturers, the total incremental cost of a demand-controlled ventilation garage versus a constant air volume garage was determined. Combining this with the energy cost calculations, the life-cycle costs of the basecase and the proposed case were calculated in each climate zone. Note that the only differences in the calculations by climate zone are because of the differences in TDV rates.

Table 5. Prototype garage description

	Occupancy Type	Area (Square Feet)	Number of Stories	Other Notes
Prototype 1	Office parking garage	50,000	2	n/a

The statewide energy savings associated with the proposed measures were calculated by multiplying the per unit estimate with the statewide estimate of new construction in 2014. Details on the method and data source of the new construction forecast are presented in Section 8.4.

3.2 Sensor Accuracy and Reliability Field Study

The proposed measure is based on the premise that CO sensors are accurate and reliable. However, no studies are available that prove the accuracy and reliability of CO sensors in parking garages over time. For this reason, a field study was conducted that sought to measure the accuracy and relibility of CO sensors in existing parking garages.

Three parking garages were tested. A random sample of 5 CO sensors in each garage were tested at various gas concentration levels using span gas.

Garages to participate in the field study were identified through contacts of Taylor Engineering and Energy Solutions. Additionally, advertisements were placed with local chapters of ASHRAE and BOMA.

Each sensor was tested at 5 different concentrations of CO (0 ppm, 35 ppm, 50 ppm, 100 ppm, and 200 ppm) using span gas. In each case, the manufacturer or the manufacturer’s representatives were consulted to determine the correct sensor testing procedure. The actual testing was performed by a local firm that specializes in installing CO-monitoring systems in parking garages. The testing was supervised by Taylor Engineering.

4. Analysis and Results

4.1 Energy Savings Case Studies

4.1.1 Cathedral Garage

Description of Project

Cathedral Christ the Light has an enclosed parking garage that is attached to the cathedral itself. The parking garage is two levels, the lower of which is 36,000 ft^2, the upper of which is 47,000 ft^2. The garage has demand controlled ventilation served by several exhaust fans tied to carbon monoxide sensors.

Description of System

There are multiple exhaust fans in the garage to provide the ventilation needed. On the lower level, exhaust fans B2-1, B2-2 and B2-3 draw air from the lower level of the garage into a shaft. Fans B2-1, B2-2, and B2-3 are controlled identically. On the upper level, exhaust fan B1-2 draws air into the same shaft. The shaft extends up to the upper garage level and relieves to the outside above the upper level.

On the upper level, exhaust fan B1-7 is a constant speed fan that transfers fresh air from the adjacent loading dock into the garage. On the upper level, exhaust fan B1-1 draws air from the upper level of the garage into a duct that goes down to serve the lower level.

A shaft with the relief air from the cathedral comes down to the garage and has a damper. Controlled off the building pressure, the damper could be open allowing relatively fresh relief air from the cathedral to flow into the garage. Exhaust fan B2-4 on the lower level draws this cathedral relief air into the lower garage level when the damper is open. When the damper is closed, exhaust fan B2-4 draws air from the upper garage level.

Carbon Monoxide Concentration Levels

The carbon monoxide concentration levels in the garage are measured by seven sensors on the upper level and five sensors on the lower level. The CO concentrations measured by all sensors for one week are plotted in the figures below, as are the fan speeds. The CO concentration generally stayed below a prescribed 50 parts per million (ppm). On the few occasions where the concentration rose above 50 ppm, the fans ramped up in speed, and the CO concentration decreased quickly.

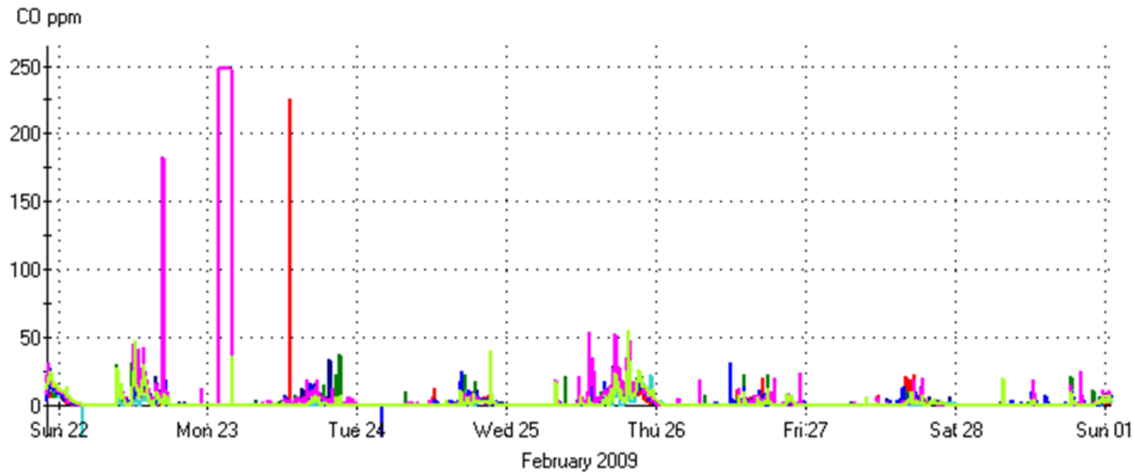


Figure 1. CO concentration in seven zones on the upper level for one week in February 2009

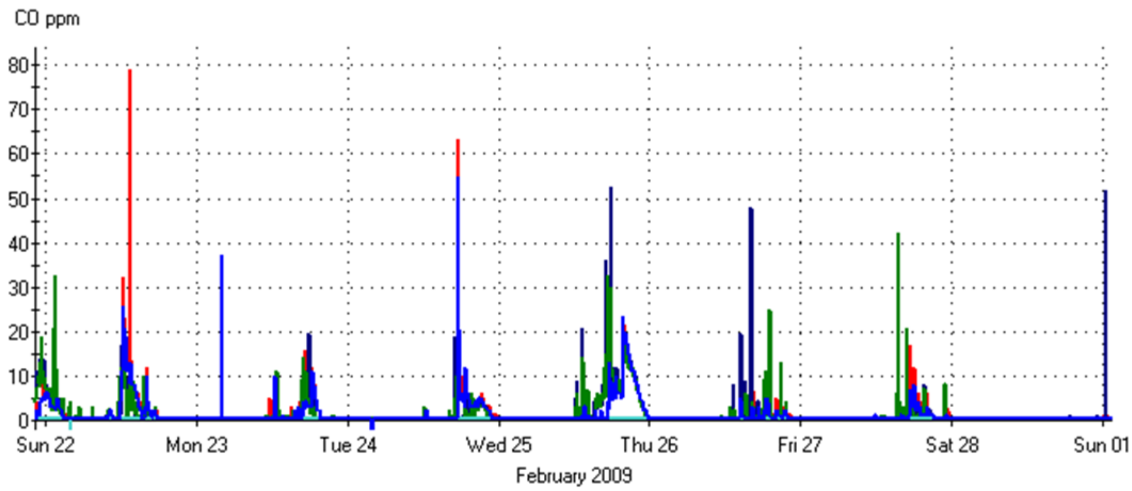


Figure 2. CO concentration in five zones on the lower level for one week in February 2009

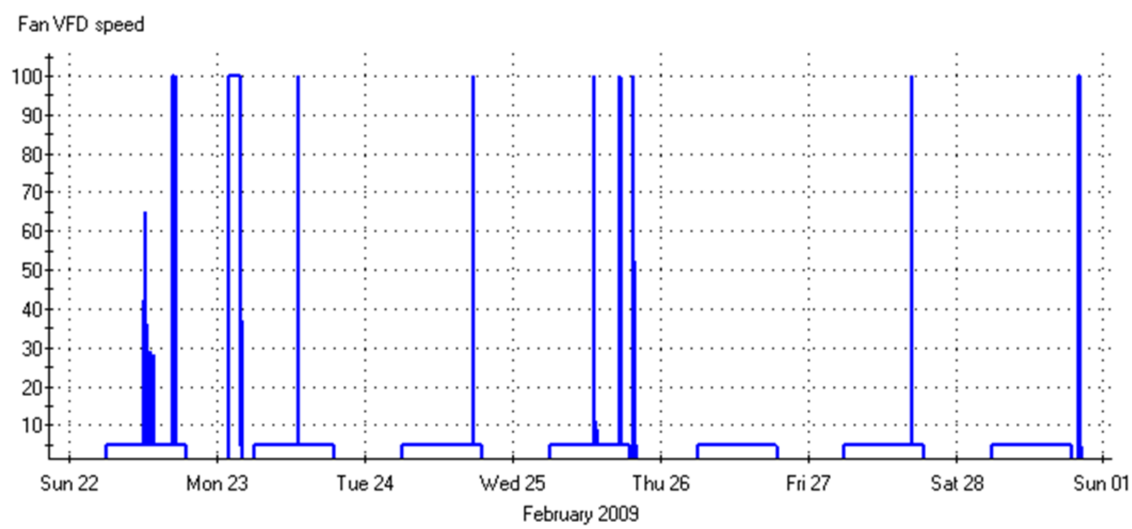


Figure 3. Fan VFD speed of B1-1, B1-2 during one week in February

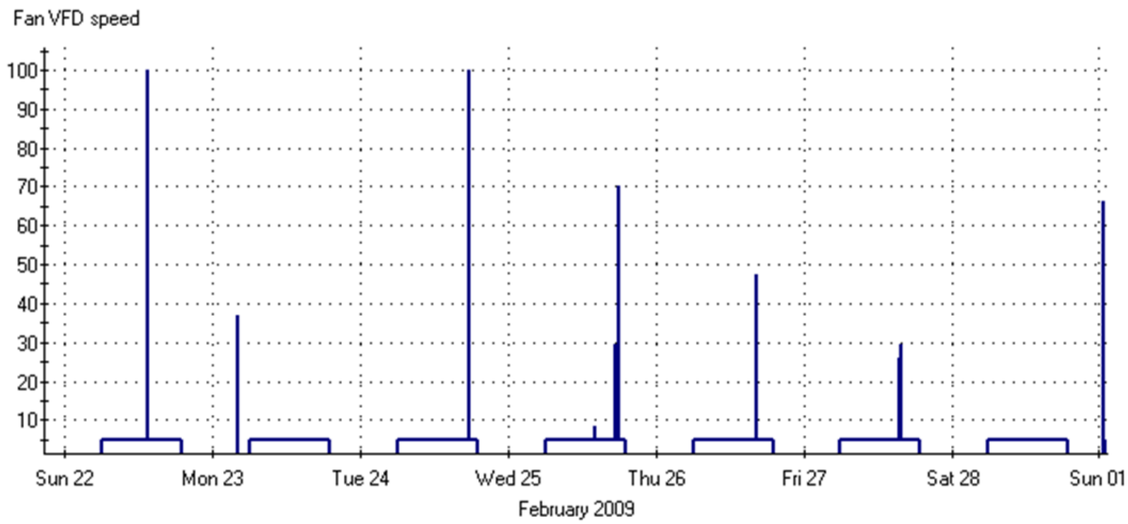


Figure 4. Fan VFD speed of B2-1, B2-2, B2-3 during one week in February

Actual energy use

The figure below shows the actual fan power of exhaust fans B1-1, B1-2, B2-1, B2-2, and B2-3 during one week in February 2009. From the figure it is clear that each of the five fans remain at a minimum power setting for the majority of the time.

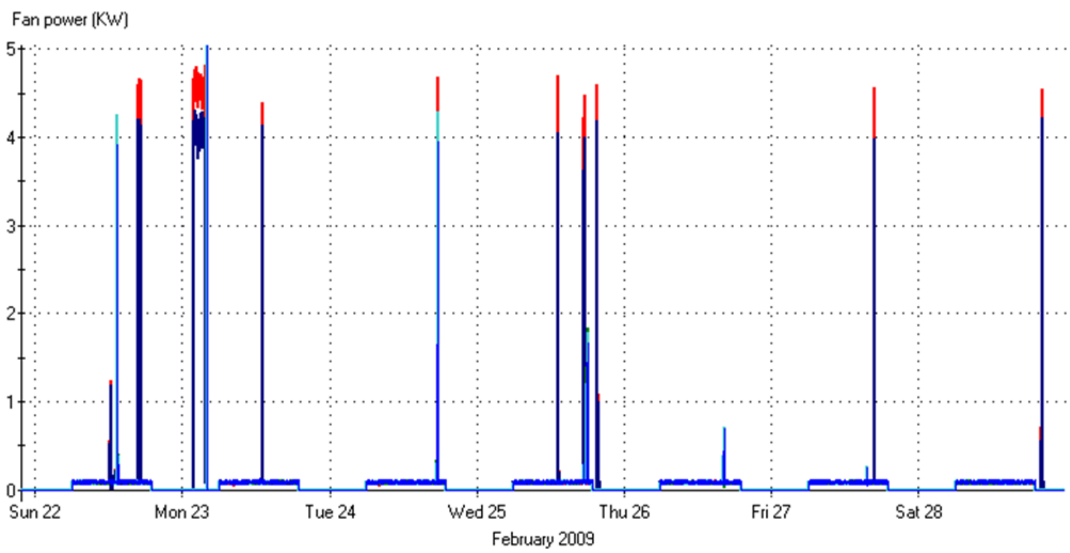


Figure 5. Exhaust fan power

The following figure shows the actual fan power of exhaust fan B2-4 during the same week in February. It is clear that the fan runs all the time, at the same minimum power setting as the other exhaust fans.

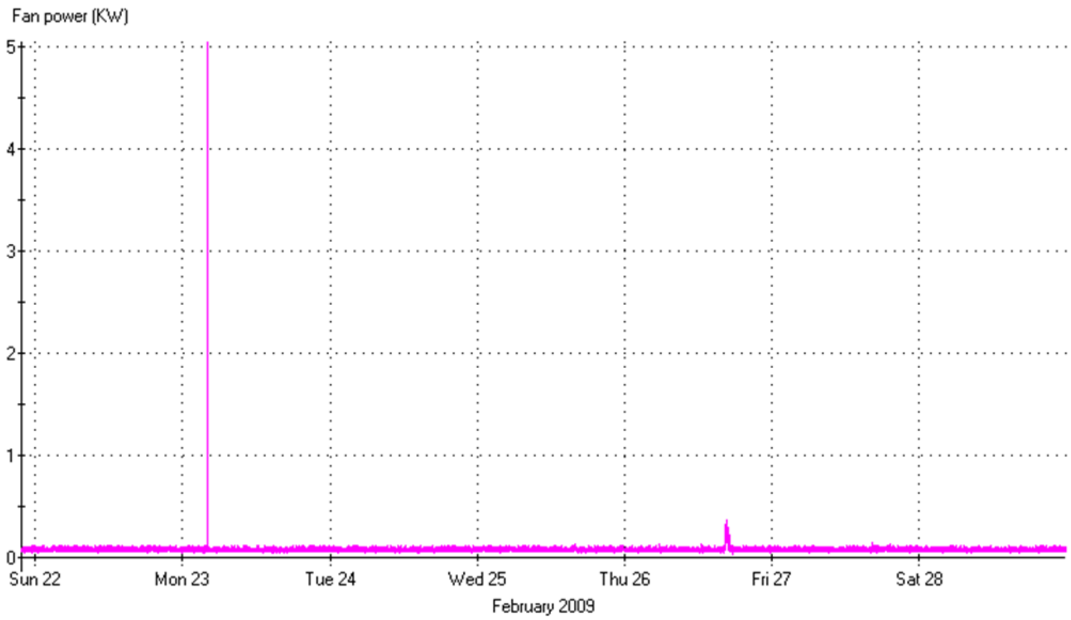


Figure 6. Exhaust fan power

Energy Savings Calculation

If the entire enclosed garage were served by a constant 0.75 cfm/ft^2, that would be 63,000 cfm from the hours of 6am to 7pm. This would have resulted in an energy consumption of 1190 kwh for the 15-day period analyzed. This does not include the energy to exhaust the cathedral 24 hours a day.

The energy consumed by the fans was determined for a 15-day period, and is seen in the table below. This includes the energy to exhaust the cathedral 24 hours a day.

Table 6. Actual energy consumed by each exhaust fan in a 15-day period.

EF	kwh
B1-1	34.8
B1-2	33.5
B2-1	23.3
B2-2	24.0
B2-3	24.6
B2-4	37.0
Total	***177.3***

Therefore, by having demand control ventilation in the garage, 85% less energy was consumed.

The same analysis was done for a 31-day period during the month of December 2009. It was found that the total energy consumption was 255 kwh, and would have been 2,460 kwh had the exhaust been constant volume. The demand-controlled ventilation resulted in a 90% savings in fan energy. See the table below.

Table 7. Actual energy consumed by each exhaust fan in a 31-day period.

EF	kwh
B1-1	42.7
B1-2	40.8
B2-1	30.5
B2-2	29.2
B2-3	32.1
B2-4	79.6
Total	***254.9***

Conclusions

In conclusion, controlling the speed of exhaust fans off of carbon monoxide concentration levels can decrease energy consumption in garages by 85-90%.

4.1.2 San Mateo Garage

Description of Project

The San Mateo Public Library has an underground enclosed parking garage that is three levels. The lowest level is 14,200 ft^2, the middle level is 38,800 ft^2, and the upper level is 8,700 ft^2. The garage has demand controlled ventilation served by several exhaust fans tied to carbon monoxide sensors.

Description of System

There are two exhaust fans that serve the parking garage. Because trend data was only available for one exhaust fan, the trend review was only done on the one fan, and assumed to be the same for the second exhaust fan.

Carbon Monoxide Concentration Levels

The CO concentration measured by one sensor and the fan speed are plotted in the figures below for several days. The CO concentration generally stayed well below a prescribed 50 parts per million (ppm). On the few occasions where the concentration rose above 50 ppm, the fans ramped up in speed, and the CO concentration decreased quickly.

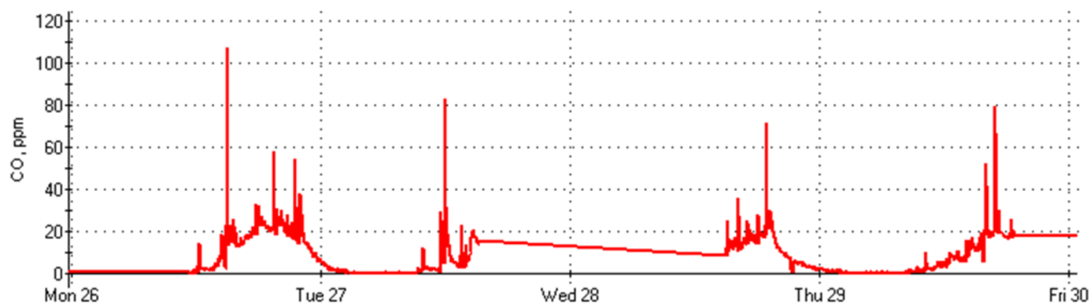


Figure 7. CO concentration for a few days in March 2007

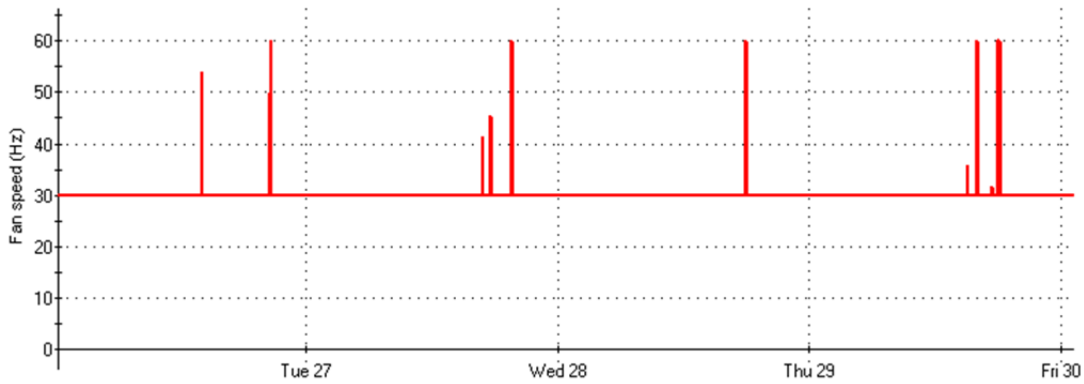


Figure 8. Fan VFD speed during a few days in March 2007

Here is a close up of one day, where it is clearly shown that when the CO concentration rises above 50 ppm, the fan ramps up in speed, and the CO concentration quickly decrease below 50 ppm.

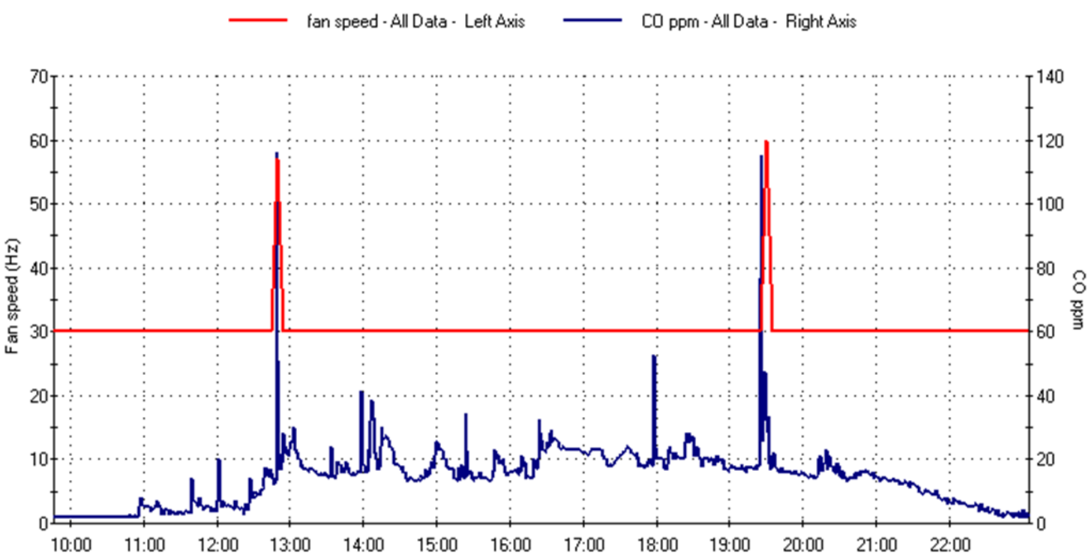


Figure 9. CO concentration and fan speed

Fan Energy

The figure below shows the speed of the exhaust fan during the month of January 2007. From the figure it is clear that the fan operates at its minimum setting of 30 Hz for the majority of the time.

Figure 10. Exhaust fan speed

Energy Savings Calculation

If the entire enclosed garage were served by a constant 0.75 cfm/ft^2, that would be 21,200 cfm per fan for 24 hours per day. This would have resulted in an energy consumption of 8,990 kwh for the four-month period analyzed. Because of the demand-controlled ventilation, the actual energy use for this period was only 2,200 kwh, which is an energy savings of 75%. As previously noted, the CO concentration levels were generally well below the prescribed limit of 50 ppm. This suggests that the minimum fan speed could have been reduced from 30 Hz, for an even higher fan energy saving.

Conclusions

In conclusion, controlling the speed of exhaust fans off of carbon monoxide concentration levels can decrease energy consumption in garages by at least 75%.

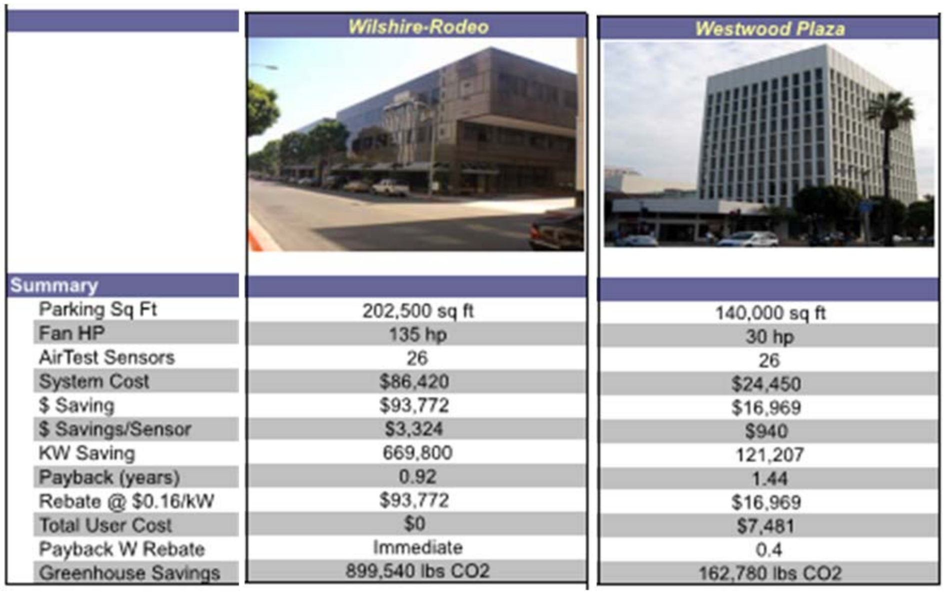
4.1.3 Other Studies Done

One manufacturer compiled energy savings information on 8 different parking garages that they did retrofits on in retrofits on in southern California (AirTest, The Parking Garage Opportunity, 2008). Prior to the retrofit each garage was retrofit each garage was ventilated by constant volume fans. Each garage was retrofitted with a CO-monitoring system monitoring system and fan VFDs. The results of this study are shown in * *Note "KW savings" should read "kWh savings" and that Greenhouse Savings were calculated by manufacturer and do not reflect PG&E data*

Figure 11.

	Lowes Santa Monica Hotel	9601 Wilshire Blvd	8484 Wilshire Blvd
			
Summary			
Parking Sq Ft	159,500 sq ft	284,160 sq ft	192,000 sq ft
Fan HP	120 hp	121 hp	80 hp
AirTest Sensors	23	40	35
System Cost	$64,965	$79,933	$82,924
$ Saving	$76,311	$23,606	$125,578
$ Savings/Sensor	$2,825	$1,998	$2,369
KW Saving	545,079	168,614	896,986
Payback (years)	0.85	3.39	0.66
Rebate @ $0.16/kW	$64,965	$26,978	$82,924
Total User Cost	$0	$52,955	$0
Payback W Rebate	Immediate	2.2	Immediate
Greenhouse Savings	732,040 lbs CO2	226,450 lbs CO2	1,204,650 lbs CO2

	Pacific Plaza	Redondo Beach Library	First Federal Bank
			
Summary			
Parking Sq Ft	77,520 sq ft	88,500 sq ft	218,500 sq ft
Fan HP	40 hp	30 hp	160 hp
AirTest Sensors	12	12	30
System Cost	$28,605	$36,945	$100,498
$ Saving	$25,870	$8,200	$34,000
$ Savings/Sensor	$2,384	$3,079	$3,350
KW Saving	184,786	58,571	242,857
Payback (years)	1.11	4.51	2.96
Rebate @ $0.16/kW	$28,605	$9,371	$50,249
Total User Cost	$0	$27,574	$50,249
Payback W Rebate	Immediate	3.4	1.5
Greenhouse Savings	248.160 lbs CO2	78,661 lbs CO2	326,150 lbs CO2



Summary	Wilshire-Rodeo	Westwood Plaza
Parking Sq Ft	202,500 sq ft	140,000 sq ft
Fan HP	135 hp	30 hp
AirTest Sensors	26	26
System Cost	$86,420	$24,450
$ Saving	$93,772	$16,969
$ Savings/Sensor	$3,324	$940
KW Saving	669,800	121,207
Payback (years)	0.92	1.44
Rebate @ $0.16/kW	$93,772	$16,969
Total User Cost	$0	$7,481
Payback W Rebate	Immediate	0.4
Greenhouse Savings	899,540 lbs CO2	162,780 lbs CO2

** Note “KW savings” should read “kWh savings” and that Greenhouse Savings were calculated by manufacturer and do not reflect PG&E data*

Figure 11. Energy savings study done by one manufacturer (AirTest, The Parking Garage Opportunity, 2008).

Results from this study show that on average, garages saved between 0.6 and 4.7 kwh per square foot per year of garage area after the retrofit, saving the owner between $0.08 and $0.65 per square foot per year.

4.2 Costs

The additional components required for CO control over a constant-volume garage are CO sensors, controllers and fan variable frequency drives (VFDs). In addition to product costs for each of these items, each item requires additional installation time and commissioning time. Also, these items require periodic maintenance and replacement over the life of the garage.

Cost estimates for each item as well as the installation of each item were received from manufacturers. Larger garages tend to have lower cost per item than smaller garages, both for product and installation. Installation costs vary with local labor rates and the market. The table below shows the range of the end cost of each item. In addition to this, each garage requires controls and commissioning work, which is another $1,000 added to each system at installation.

Table 8. Product and installation costs

Product	Cost	Installation cost	Frequency
CO sensor	$250 - $400	$800 - $2500	One sensor per 5,000 sqft
Controller	$3,000 - $4,000	Included in sensor installation cost	One per 16 or 32 sensors
VFD	$2,600	$500	One per 10,000 cfm

Additionally, over a 15-year life of a garage, the sensors will likely need to be calibrated once per year and replaced once in five years (can vary depending upon manufacturer’s recommendations). Calibration procedures vary by manufacturer, but typically take 15 to 30 minutes per sensor, and are typically required once per year or once per two years. Some sensors require no calibration at all.

Some manufacturers offer replacement sensor options where just the sensing element itself needs to be replaced, and the casing of the original sensor can be reused. Replacing just the sensing element itself can save as much as 85% off the original sensor price. Controllers and VFDs do not require maintenance.

4.3 Life-cycle Cost Calculation

The life cycle cost for the basecase (constant ventilation rate garage) and the proposed measure (variable ventilation rate garage) were calculated based on the energy savings calculations and cost estimates given in Sections 4.1 and 4.2. The garage is assumed to be occupied from 7am to 7pm for five days a week. Based on a review of several actual garage ventilation systems, it is assumed that in the basecase the fan supplies 0.75 cfm/sqft and 1" of static pressure with 60% efficiency. Based on the energy case studies, it is assumed that the proposed case uses 85% less energy than the basecase. Note that in the case studies presented, the CO concentration limit is set at 50 ppm, whereas the proposed code limits the CO concentration to 25 ppm. The difference in CO concentration limits makes a negligible difference in energy savings because the majority of the energy savingsare from when the fan is at the minimum speed setting which is about the same with setpoints of 25 and 50 ppm.

The total system cost is largely a function of garage size, with smaller garages having a higher cost per area than larger garages, but the same energy cost per square foot of energy savings. Therefore the threshold above which the proposed measure is effective was determined. Combining the energy cost and all of the incremental costs of the proposed case together, the 15-year life-cycle cost of both the baseline and proposed cases were calculated for a range of garage sizes, as shown in Figure 12.

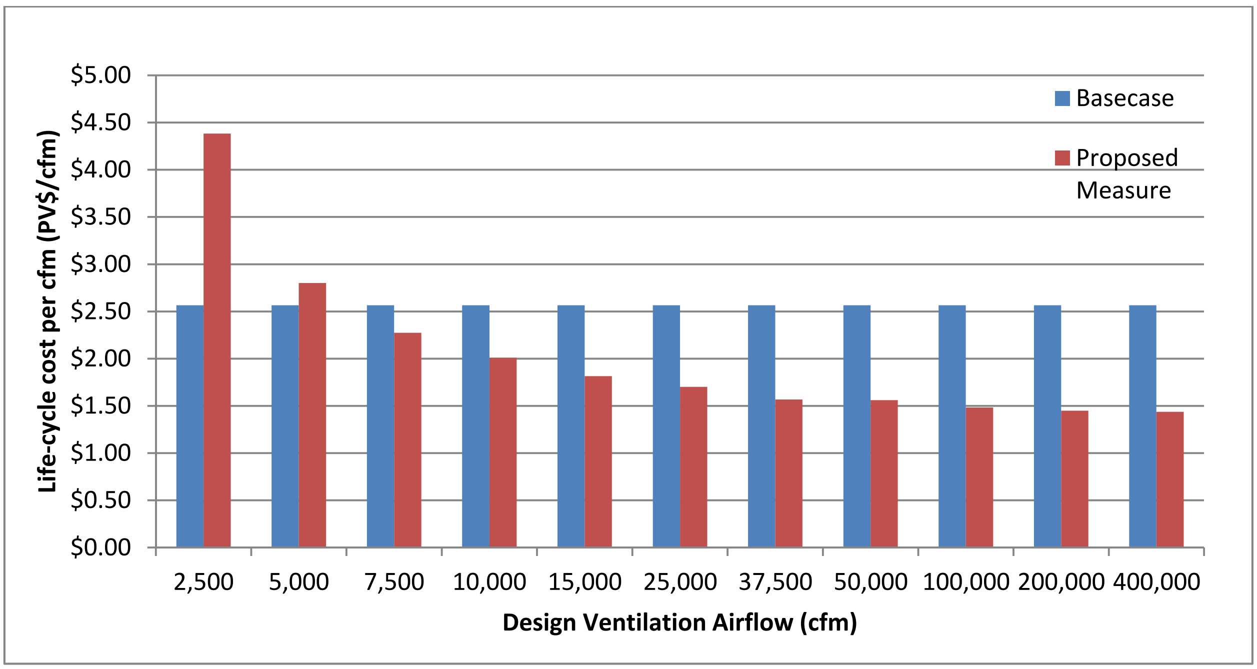


Figure 12. 15-year life-cycle cost for basecase (blue) and proposed measure (red) in Climate Zone 12

For these calculations, it is assumed that the average sensor cost is $325 initially, and then gets down to $250 as the proposed measure influences the market. Because different sensors require different calibration and replacement frequencies, the annual sensor maintenance cost was assumed to be the average of the annualized sensor replacement costs and sensor calibration costs. The sensor calibration procedure and materials required vary by manufacturer, but generally requires 15 to 30 minutes of labor per sensor. The calibration generally requires cans of span gas at 2 or three different CO-concentrations as well as a flow regulator. The cost of these items vary by manufacturer and by garage size, but average about $40 per sensor.

Based on the life-cycle costs calculated, it was decided that the proposed measure would apply to only garages where the design ventilation rate was 10,000 cfm and greater.

The baseline and proposed life-cycle costs for a 50,000 square foot garage (a medium-sized parking garage) were calculated for each climate zone and are tabulated below in

Climate Zone	15-year LCC, $/design cfm	
	Baseline	**Proposed**
CZ01	$2.56	$1.57
CZ02	$2.57	$1.57
CZ03	$2.58	$1.57
CZ04	$2.57	$1.57
CZ05	$2.60	$1.57
CZ06	$2.58	$1.57
CZ07	$2.59	$1.57
CZ08	$2.57	$1.57
CZ09	$2.56	$1.57
CZ10	$2.58	$1.57
CZ11	$2.54	$1.56
CZ12	$2.53	$1.56
CZ13	$2.55	$1.57
CZ14	$2.56	$1.57
CZ15	$2.55	$1.56
CZ16	$2.57	$1.57

. These costs include the incremental first cost, the net present value of the incremental maintenance and the energy cost savings. As shown in this table the proposed case lifecycle cost is always less than the baseline lifecycle cost and this measure is cost effective.

Table 9. 15-year life-cycle cost for 50,000 sqft garage, $/design cfm

Climate Zone	15-year LCC, $/design cfm	
	Baseline	Proposed
CZ01	$2.56	$1.57
CZ02	$2.57	$1.57
CZ03	$2.58	$1.57
CZ04	$2.57	$1.57
CZ05	$2.60	$1.57
CZ06	$2.58	$1.57
CZ07	$2.59	$1.57
CZ08	$2.57	$1.57
CZ09	$2.56	$1.57
CZ10	$2.58	$1.57
CZ11	$2.54	$1.56
CZ12	$2.53	$1.56
CZ13	$2.55	$1.57
CZ14	$2.56	$1.57
CZ15	$2.55	$1.56
CZ16	$2.57	$1.57

4.4 Accuracy and reliability of CO sensors

Reliability of carbon monoxide sensors is a concern from health and safety regulatory bodies. CO sensors use electrochemical and solid state sensors that have been used in health and safety and industrial applications for over 60 years. These sensors for garages are using the same technologies that are used for critical life safety applications in mines and confined space entry, and therefore are adequate for use in parking garages. However CO sensors drift over time and thus must have some self-calibration or user calibration every couple of years to assure they are providing the needed level of protection.

4.4.1 Pollutant Regulations

The California Division of Occupational Safety and Health (Cal OSHA) Permissible Exposure Limit for carbon monoxide is 25 ppm (Department of Industrial Relations), which means that over an 8-hour period, a worker cannot be exposed to more than a time-weighted average of 25 ppm of CO. There is also a ceiling on CO of 200 ppm (Department of Industrial Relations), which means that a worker cannot be exposed to more than 200 ppm at any time. Limits for CO concentrations in confined spaces into which people enter are the same. Before entering a confined space, workers are required to check the concentrations of various pollutants (OSHA C. , 1998), and are not permitted to enter if the CO concentration is greater than 25 ppm.

The table below highlights the inconsistencies in CO exposure limits and required ventilation between various regulatory bodies, both international and domestic (Krarti & Ayari, 2011). Note: According to the table below, the OSHA 8-hour exposure limit is 35 ppm. According to OSHA Carbon Monoxide Fact Sheet (OSHA Fact Sheet, 2002), the limit is 50 ppm .

	Time (hrs)	PPM	Ventilation
ASHRAE	8 1	9 35	7.6 L/s · m² (1.5 cfm/ft²)
ICBO	8 1	50 200	7.6 L/s · m² (1.5 cfm/ft²)
NIOSH/ OSHA	8 Ceiling	35 200	—
BOCA	—	—	6 ACH
SBCCI	—	—	6–7 ACH
NFPA	—	—	6 ACH
ACGIH	8	25	—
Canada	8 1	11/13 25/30	—
Finland	8 15 minutes	30 75	2.7 L/s · m² (0.53 cfm/ft²)
France	Ceiling 20 minutes	200 100	165 L/s · car (350 cfm/car)
Germany	—	—	3.3 L/s · m² (0.66 cfm/ft²)
Japan/South Korea	—	—	6.35–7.62 L/s · m² (1.25–1.5 cfm/ft²)
Netherlands	0.5	200	—
Sweden	—	—	0.91 L/s · m² (0.18 cfm/ft²)
U.K.	8 15 minutes	50 300	6–10 ACH

Figure 13. Summary of U.S. and international standards for ventilation requirements of enclosed parking garages (Krarti & Ayari, 2011)

4.4.2 CO Sensor Background

The two types of sensors used in garage ventilation applications are solid state and electrochemical. These two types have been commonly used in garage ventilation applications for the past 40 to 50 years. A third type of sensor, infrared, was previously prohibitively expensive, but is becoming less expensive, and more common in garage ventilation applications. Characteristics of all three sensor types are listed below.

Solid State Sensors

- Less gas specific, but can be biased towards measuring certain gases like CO (but not NO_2)
- Sensitive to changes in temperature and humidity
- Inexpensive
- Commonly used in residential applications
- Less accurate at low CO concentration levels (but still suitable for use in garages)
- Life: 5-7 years

- Require calibration every 1-2 years

Electrochemical

- More gas specific than solid state sensors
- Less sensitive to changes in temperature and humidity
- Drift ~5% per year
- Accuracy: +/-1 ppm for CO, +/- 0.1 ppm for NO_2
- Depletion of electrolyte with use causes drift and eventually sensor failure
- Life: 18 months - 5 years
- Have been used in a variety of industrial applications
- Are of excellent quality and actual performance closely matches manufacturers claims

Infrared

- Highly gas specific
- Life: 10-15 years
- Minimal drift
- Require calibration every ~2 years. CO_2 sensors use infrared measurement technology that has only been around for the past 15 years [Schell email, 1/20/2020].

4.4.3 Existing Studies on CO Sensors

Very limited studies were available on the accuracy and reliability of CO sensors in parking garages over time. However, one study found was on residential CO sensors and their performance over time. Another study found was on CO sensors (among other gas sensors) used in aircrafts. Though neither of these studies have the application that is of interest, both studies are about sensors that utilize the same technology of many sensors used in garage ventilation applications. The third study presented was an informal study conducted by a manufacturer, which involved testing the CO sensors in a garage 2 years after they were installed. The conclusion from all three studies regarding CO sensors is positive.

UL conducted a study on residential carbon monoxide sensors (Carbon Monoxide Alarm Field Study, 2004), which use the same technology as commercial-grade CO sensors. They tested many CO sensors over a period of four years to determine possible drift and the effectiveness of alarms. They tested sensors at CO concentration levels of 70 ppm, 150 ppm, and 400 ppm. UL2034, which is a standard for residential CO sensors, specifies the time period in which a sensor must alarm at each of these three concentrations. Overall they found the sensors to be very reliable. A few sensors gave early or delayed signals during the testing, but all of the sensors provided sufficient signaling to protect against exposure to fatal CO concentrations.

A study conducted by AirTest on a large parking garage in the Los Angeles area tested CO sensors 26 months after they had been installed. These sensors have a specified drift of <5% per year. 26 CO sensors were tested for drift at three different concentration levels. It was found that the average sensor drifts over 2+ years at 0 ppm, 35, ppm, and 100 ppm were 3.7 ppm, 3.9 ppm (11%), and 11.1 ppm (11%), respectively. These results align with the manufacturer's claims and are very promising.

4.4.4 Nongasoline Vehicles

One concern over CO control was that CO concentrations alone may not be representative of all potentially harmful pollutants in a parking garage. Other combustion products of concern include CO_2, NO, NO_2 and Hexane. CO is a good indicator of the other products for gasoline engines. Diesel engines, however, do not typically give off CO but do produce NO_2. For diesel garages in the US, NO_2 sensors are commonly used to control ventilation because it is sometimes required by existing codes (for example, in the Wisconsin Mechanical Code) and customer requests, even though NO_2 sensors are significantly more expensive than CO and CO_2 sensors, and have a shorter life [Schell's emails, 12/30/2009, 1/6/2010]. This is likely because there is little understanding about using CO_2 to sense combustion fumes and there is some controversy over measuring a surrogate for combustion fumes instead of the major toxic components of combustion fumes.

In Asia CO_2 has also been used as a surrogate for diesel engine emissions instead of N_{O2} because CO_2 sensors are cheaper and have longer lives than NO_2 sensors. The introduction of infrared NO_2 sensors could change this. [Schell's email, 1/6/2010]

The US Bureau of Mines conducted a study in which they looked at using CO_2 concentration levels as a surrogate for the concentration levels of other pollutants in the exhaust emissions of diesel engines (Staff, 1992). For mine equipment, the relative concentrations of the byproducts of combustion vary with the mode of operation, the condition of the equipment, the environment, and the operator. It was found that though the concentrations of the pollutants varied significantly with these factors, CO_2 was stable and did not vary much. Out of the potentially harmful products of combustion, CO_2 is present in much greater quantity than any of the other products, as seen in the table below. The accuracy of pollutant sensors is generally less reliable at very low concentrations, and is more susceptible to variations in environmental conditions. For this reason, measuring CO_2 as a surrogate for other pollutant concentrations can actually be more accurate than measuring the concentrations of pollutants individually.

Table 1.—Products of combustion of diesel fuel, volumetric basis, percent

Complete combustion products:	
Nitrogen (N_2)	73
Carbon dioxide (CO_2) plus oxygen	13
Water (H_2O)	13
Incomplete combustion products (pollutants):	
Hydrocarbons (HC)	<1
Carbon monoxide (CO)	<1
Nitric oxide (NO)	<1
Nitrogen dioxide (NO_2)	<1
Carbon (C) or smoke	<1
Sulfur dioxide (SO_2)	<1
Total	100

Figure 14. Products of combustion (Staff, 1992)

CO_2 is the most plentiful byproduct of combustion in automobiles, both gasoline and nongasoline, with quantities of 100 times or greater than any other harmful gas produced (carbon monoxide, hexane, nitric oxide, nitrogen dioxide) (AirTest, CO2 and Combustion Sensing). The Threshold Limit Value (TLV) concentrations of the harmful byproducts of combustion are given in the chart below, as well as are the equivalent CO_2 levels for combustion. From this it is clear that maintaining CO_2 concentration at a reasonable level will maintain all other byproducts at reasonable levels as well.

Combustion By-Product	TLV Concentration	CO_2 Proportional Level Equivalent
Carbon Dioxide	5,000 ppm	5,000 ppm
Hexane	500 ppm	91,700 ppm
Carbon Monoxide	50 ppm	4,580 ppm
Nitric Oxide	25 ppm	4,580 ppm
Nitrogen Dioxide	5 ppm	7,860 ppm

Figure 15. TLV concentration and equivalent CO_2 concentration levels for the byproducts of combustion (AirTest, CO_2 and Combustion Sensing)

Due to concerns expressed by state regulatory agencies, it was decided to not require NO_2 sensors, and instead make an exception to the code for all garages where more than 20% of the vehicles expected are nongasoline. See Section 5.5 below.

4.4.5 Field Study Results

CO sensors in three different garages were tested. Each garage had sensors that were of a different age and a different manufacturer. Refer to the Appendix in Section 8.3 for details on each garage tested.

The system in Garage A is about 5 years old, and likely has not been serviced since it was installed. This garage contains electrochemical sensors and require calibration once per year. In this garage, 5 out of the 5 sensors tested failed completely, meaning that the sensors did not respond to even very high concentrations of CO. See the results in Table 10 below.

Table 10. Results from electrochemical CO sensor (5 years old) testing, Garage A

Actual CO level	0 ppm		35 ppm		50 ppm		100 ppm		200 ppm		
Sensor CO measurement	**volts**	**ppm**	**volts**	**ppm**	**volts**	**ppm**	**volts**	**ppm**	**volts**	**ppm**	**Conclusion**
Sensor 1	0.45	9.0	2.29	45.8	1.2 - 0	-	0.99 - 0	-	0.6 - 0	-	failed
Sensor 2	0.39	7.8	0.24	4.8	0.24	4.8	0.23	4.6	0.23	4.6	failed
Sensor 3	0.44	8.8	0.24	4.8	0.24	4.8	0.24	4.8	0.25	5	failed
Sensor 4	0.49	9.8	2.28	45.6	2.29	45.8	2.29	45.8	2.29	45.8	failed
Sensor 5	0.42	8.4	0.23	4.6	0.23	4.6	0.23	4.6	0.23	4.6	failed

The manufacturer was contacted again after the testing was complete to check if the results were what the manufacturer would have expected, and to see if they had any insight on probable causes for the failures. The manufacturer was not surprised that all of the sensors had failed given that they had not been calibrated in likely 5 years. Though all 5 sensors tested had failed, the garage appeared to have sensors that were still functioning, because while the garage was being tested (which occurred during an occupied period), the garage exhaust fans started up and stopped periodically, apparently in response to CO concentration levels detected by other sensors.

The system in Garage B is about 12 years old, and likely has not been serviced since it was installed. This garage contains solid state sensors and require calibration two times per year. In this garage, 4 out of the 5 sensors tested failed completely, meaning that the sensors did not respond to even very high concentrations of CO. The fifth sensor did not detect CO concentration accurately, but it did detect elevated levels of CO, and provided warnings and alarms appropriately. See the results inTable 11 below.

Table 11. Results from solid state sensor (12 years old) testing, Garage B

Actual CO level	0 ppm		35 ppm		50 ppm		100 ppm		200 ppm		
Sensor CO measurement	**volts**	**ppm**	**volts**	**ppm**	**volts**	**ppm**	**volts**	**ppm**	**volts**	**ppm**	**Conclusion**
Sensor 1	0.98	0.63	0.98	1	0.98	1	0.98	1	0.98	1	failed
Sensor 2	0.98	0.62	2.33	85	2.67	106	3.02	128	3.28	144	operating but out of calibration
Sensor 3	0.98	0.00	0.98	0	0.98	0	0.98	0	0.98	0	failed
Sensor 4	0.99	0.00	0.99	0	0.99	0	0.99	0	0.99	0	failed
Sensor 5	0.98	0.00	0.98	0	0.98	0	0.98	0	0.98	0	failed

As was done with Garage A, the manufacturer was contacted again after the testing was complete to see if the results were what the manufacturer would have expected. The manufacturer was not surprised given the age and lack of maintenance of the sensors.

The system in Garage C is about 2 years old, and is maintained well. According to the garage operator, on two previous occasions the system had alarmed to indicate that a sensor had failed. The garage operator then had these sensors replaced. These sensors are electrochemical sensors, and do not require calibration. Upon a sensor failure, the sensor requires replacement. In this garage, 5 out of the 5 sensors responded well. 80% of the time the response was within 5% of the full scale reading. 76% of the time the sensors gave readings within the accuracy stated by the manufacturer. The remaining times, the sensors always read CO concentration levels that were higher than the actual concentration level. See the results in Table 12 below.

Table 12. Results from electrochemical CO sensory (2 years old) testing, Garage C

Actual CO level	**0 ppm**	**35 ppm**		**50 ppm**		**100 ppm**		**200 ppm**	
Sensor CO measurement	**ppm**	**ppm**	**% Diff of Full Scale**	**ppm**	**% Diff of Full Scale**	**ppm**	**% Diff of Full Scale**	**ppm**	**% Diff of Full Scale**
Sensor 1	0	31	-2%	49	0%	104	2%	200	0%
Sensor 2	0	30	-2%	46	-2%	102	1%	210	4%
Sensor 3	0	33	-1%	47	-1%	250	60%	248	19%
Sensor 4	0	35	0%	53	1%	114	6%	206	2%
Sensor 5	0	40	2%	62	5%	139	16%	241	16%

The response time of the sensors in Garage C was variable. It took anywhere from 10 seconds to 8 minutes for the sensors to respond. It was not known what drove the response time, and why it was so variable. Inquiries about this were made to the manufacturer, but the manufacturer did not provide a response.

From this abbreviated field study, the conclusion drawn was that with older CO-monitoring systems, if the system is not maintained, then sensor failure is likely. However, with newer systems that are maintained, CO sensors do a great job of accurately and reliably notifying of elevated concentrations of CO.

Refer to Section 8.3 for details on each garage tested.

4.4.6 Sensor Spacing

The required spacing of CO sensors was determined based on the conservative end of manufacturer's recommendations. Recommendations from several different manufacturers is listed below.

Table 13. Sensor density requirements prescribed by various manufacturers

Manufacturer	Model	Sensor density prescribed
Brasch Manufacturing company	1-687 GSE	Place sensors every 7000 to 9000 sqft (Brasch Manufacturing Company)
Honeywell	Vulcain 301	The radius of coverage is 50 feet per carbon monoxide monitor or 10,000 sq.ft. (Vulcain, Inc.)
Airtest	TR2000	Area spacing: 5000 – 10,100 square feet. Depends on area configuration, air flow, etc. Closer spacing results in faster response. (AirTest, 2008)
3M Macurco	CM-21A	One sensor per 5000 square feet (approximately) (3M Macurco)
MSA Canada	ZGuard	Radius of surveillance: 50 ft. Guarded area: 7,854 sqft (MSA Canada, 2005)

4.5 Summary of Relevant Codes

The current version of the California Mechanical Code (CMC) is the 2010 version, which is based on the 2009 Uniform Mechanical Code (UMC). The 2009 UMC does not address CO control in enclosed parking garages. The 2010 CMC amends the UMC to explicitly allow modulating the ventilation airflow based on CO concentration. The CO concentration must be maintained at a maximum average concentration of CO of 50 ppm during any 8-hour period, with a maximum concentration not greater than 200 ppm for a period not exceeding one hour. See Section 8.1: Appendix A for the actual code language. Previous versions of the CMC and UMC either explicitly allowed CO control or were ambiguous.

The proposed language for the Standard is more stringent than the CMC, and requires maintaining lower concentrations of CO. Under the performance path, buildings can still comply with the Standard by modulating ventilation rates and maintaining higher CO concentrations as allowed by the CMC.

Some jurisdictions such as the State of Oregon require CO control in large garages. The State of Washington requires CO control for enclosed garages and loading docks serving gasoline powered vehicles and fuel-appropriate sensors where more than 20 percent of the vehicles are powered by nongasoline fuels.

See

Table 14 for a summary of relevant codes and Section 8.2: Appendix B for the full language of each of the relevant codes.

Table 14. Summary of relevant codes in other jurisdictions

Jurisdiction	Model Code	Sensors allowed/ required	Gas sensed	Concentration limit
California Mechanical Code 2010	UMC	Allowed	CO	50 ppm during any 8-hour period, max concentration of 200 ppm for a period not exceeding one hour
Current Oregon Energy Code (since 2004)	-	Required for >30,000 cfm	CO	50 ppm during any 8-hour period, max concentration of 200 ppm for a period not exceeding one hour
Proposed Oregon Energy Code (will go into effect July 2011)	-	Required for >30,000 cfm. System must be capable of ventilating >1.5 cfm/sqft	CO	50 ppm during any 8-hour period, max concentration of 200 ppm for a period not exceeding one hour
Oregon Mechanical Code	IMC 2009	Allowed	Approved automatic detection devices	Not specified
2009 Washington State Energy Code	-	Required for >8,000 cfm	CO, for predominately gasoline-powered vehicles	35 ppm
			Fuel-appropriate sensor, for >20% non-gasoline vehicles	No less than the standard used by OSHA for 8-hour exposure
Washington State Building Code	IBC 2003	Not specified	-	-
Washington State Mechanical Code	IMC 2003, chapter on ventilation, use http://sbcc.wa.gov/page.aspx?nid=4	Not specified	-	-
Minnesota State Building Code 2007	IMC	Optional	CO	25 ppm
New York City Mechanical Code	-	Optional	CO	25 ppm
-	Old UBC	Optional	CO	50 ppm during any 8-hour period, max concentration of 200 ppm for a period not exceeding one hour
-	Proposed UMC (language proposed by staff)	Allowed	CO	Not specified
Wisconsin Mechanical Code	IMC	Optional, but system must not reduce ventilation rate below 0.05 cfm/sqft and must run at 0.5 cfm/sqft for at least 5 hours in each 24-hour period.	CO, all garages	35 ppm
			NO_2 (in addition to CO), where diesel-fueled vehicles are stored	1 ppm

4.6 Statewide Energy Savings

The total energy and energy cost savings potential for this measure are 0.21W/SF, 0.925 kWh/SF, and $1.24/SF. Applying these unit estimates to the statewide estimate of new construction of 15 million square feet per year results in first year statewide energy savings of 3.17MW, 13.88 GWh, and $24.6 million.

5. Stakeholder Input

5.1 Concerns Over CO Sensor Accuracy and Reliability

Mike Apte from Lawrence Berkelely Lab (LBL) expressed concerns about the accuracy and reliability of CO sensors based on a study done on CO sensors used for aircrafts. In his experience, commercial electrochemical sensors drift, require frequent recalibration, and have fairly short lifetimes. Because of this, sensors require a lot of maintenance, which is not often seen in the field. Even expensive IR sensors require maintenance. Aside from the accuracy and reliability of CO sensors, he is also concerned that CO is no longer a good indicator of toxic exhaust emissions. Vehicles using alternative fuels, which are becoming more popular, may not emit any CO, but may emit other toxic emissions (like NO_2). He is in favor of field testing actual garages.

Leon Alevantis from the California Department of Public Health (CDPH) commented that Cal OSHA has objected to any devices that control ventilation based on pollutant sensors because they can compromise health and safety. He commented that lab testing of CO sensors would be necessary, and also a study to see if CO is even the appropriate gas to be measuring for pollutant control. Leon is working on ASHRAE Std 62.1 in addressing comments related to these issues. 62.1 will also be asked to provide input to changes on the UMC or the IMC on this issue. He is working on getting some ASHRAE publications on this topic.

To address concerns over the accuracy and reliability of CO sensors, a field study was conducted on CO sensors already installed in parking garages. See Section 0 for a description of the study and the results. Additionally, fail-safe requirements are proposed for the standard that would expose bad sensors and result in them being improved or not being specified. See Section 6.1 for the proposed language. Additionally, garages where large numbers of non-gasoline vehicles are expected are proposed to be exempt from the standard.

5.2 Definition of Enclosed Parking Garage

During a stakeholder meeting with Cal OSHA a question came up about the definition of an enclosed parking garage. Members of Cal OSHA were interested in having the definition of an enclosed parking garage either in Title 24 or having a reference to where it is defined. Enclosed parking garages are defined in the California Building Code. However, for the purpose of Title 24, the definition of an enclosed parking garage is irrelevant. If a garage is enclosed then it has fans in it and there is energy to be saved. If a garage does not have fans in it, then there is no energy to be saved. Whether or not the garage is enclosed and requires mechanical ventilation is not in the scope of Title 24. Refer to the Meeting Minutes from the February 3, 2011 meeting with Cal OSHA.

5.3 Sensor Density

During a stakeholder meeting with Cal OSHA, some concern was expressed over the spacing of CO sensors. Based on recommendations from manufacturers (see Section 4.4.6), the proposed sensor density was at least one sensor per 7,000 square feet of garage area. Members of Cal OSHA felt that this minimum sensor density requirement did not provide sufficient coverage of the entire garage. Based on this feedback, the minimum sensor density requirement was increased to at least one sensor per 5,000 square feet of garage area, and the location of the sensor is required to be the highest expected concentration location. Refer to the Meeting Minutes from the February 3, 2011 meeting with Cal OSHA.

5.4 Obstructions

During a stakeholder meeting with Cal OSHA, Cal OSHA was concerned that obstructions that block the air path could interfere with sensors accurately detecting pollutant concentrations in the entire garage. Prior to this meeting, there was nothing in the proposed language about obstructions. Based on the feedback from Cal OSHA, a definition for proximity zones was added, which addresses obstructions, and a requirement for at least two CO sensors per proximity zone was added. Refer to the Meeting Minutes from the February 3, 2011 meeting with Cal OSHA.

5.5 Nongasoline Vehicles

During a stakeholder meeting with Cal OSHA, Cal OSHA expressed concern that NO_2 was not a good indicator of diesel vehicle emissions. Prior to this meeting, the proposed code language required garages where more than 20% of the expected vehicles were nongasoline-fueled to have NO_2 control as well as CO control. See Section 4.4.4 above for background on NO_2 control. Due to the concerns expressed by Cal OSHA, the requirement for NO_2 control was dropped, and instead an exception was made in the proposed language for garages where more than 20% of the expected vehicles are nongasoline-fueled. Refer to the Meeting Minutes from the February 3, 2011 meeting with Cal OSHA.

6. Recommended Language for the Standards Document, ACM Manuals, and the Reference Appendices

6.1 Recommended language for the Standard

Enclosed Parking Garages. Mechanical ventilation systems for enclosed parking garages where the total design exhaust rate for the garage is greater than or equal to 10,000 cfm shall conform to all of the following:

1. Automatically detect contaminant levels and stage fans or modulate fan airflow rates to 50% or less of design capacity provided acceptable contaminant levels are maintained
2. Have controls and/or devices that will result in fan motor demand of no more than 30 percent of design wattage at 50% of design airflow
3. CO shall be monitored with at least one sensor per 5,000 ft2, with the sensor located in the highest expected concentration locations, with at least two sensors per proximity zone. A proximity zone is defined as an area that is isolated from other areas either by floor or other impenetrable obstruction.
4. CO concentration at all sensors is maintained ≤ 25 ppm at all times.
5. The ventilation rate shall be at least 0.15 cfm/ft2 when the garage is scheduled to be occupied.
6. The system shall maintain the garage at negative or neutral pressure relative to other occupiable spaces when the garage is scheduled to be occupied.
7. CO sensors shall be:
    1. Certified by the manufacturer to be accurate within plus or minus 5% of measurement.
    2. Factory calibrated.
    3. Certified by the manufacturer to drift no more than 5% per year.
    4. Certified by the manufacturer to require calibration no more frequently than once a year.
    5. Monitored by a control system. The system shall have logic that automatically checks for sensor failure by the following means. Upon detection of a failure, the system shall reset to design ventilation rates and transmit an alarm to the facility operators.
        a. If any sensor has not been calibrated according to the manufacturer's recommendations within the specified calibration period, the sensor has failed.
        b. During unoccupied periods the systems compares the readings of all sensors. If any sensor is more than 30% above or below the average reading for a period of longer than 4 hours, the sensor has failed.
        c. During occupied periods the system compares the readings of sensors in the same proximity zone. If any sensor in a proximity zone is more than 30% above or below the average reading for a period of longer than 4 hours, the sensor has failed.

Exception: Any garage, or portion of a garage, where more than 20% of the vehicles expected to be stored have nongasoline combustion engines.

6.2 Alternative Calculation Method

Where enclosed parking garages are included in a building they shall be included in the performance approach. The garage hours of occupancy shall follow the building hours of occupancy and shall be the same in the basecase and proposed case. The design flow rates shall also be the same.

If the proposed garage airflow rate is below 10,000 cfm or if the garage is expected to serve more than 20% diesel vehicles then the basecase garage fan power shall be 0.35 W/cfm (This is a reasonably conservative estimate based on 1.5" total static and 50% fan efficiency). Fan power shall be constant during occupied hours.

If the proposed garage airflow rate exceeds 10,000 cfm and the garage is not expected to serve more than 20% diesel vehicles then the basecase garage fan power shall be 0.044 W/cfm (This is a reasonably conservative estimate based on 1.5" total static, 50% fan efficiency and an average fan speed of 50%). Fan power shall be constant during occupied hours.

6.3 Acceptance Testing

NA X.X.X. CO-monitoring system for Garage Ventilation

NA X.X.X.X. Construction Inspection

Prior to Functional Testing, verify and document the following:

- Carbon monoxide control sensor is factory-calibrated per §X of the Standard.
- The sensor is located in the highest expected concentration location in its zone per §X of the Standard..
- Control setpoint is at or below the CO concentration permitted by §X of the Standard.

NA X.X.X.X. Functional Testing

Conduct the following tests with garage ventilation system operating in occupied mode and with actual garage CO concentration well below setpoint.

1. With all sensors active and all sensors reading below 25 ppm, observe that fans are at minimum speed and fan motor demand is no more than 30 percent of design wattage
2. Apply CO span gas with a concentration of 30 ppm, and a concentration accuracy of +/- 2%, one by one to 50% of the sensors but no more than 10 sensors per garage and to at least one sensor per proximity zone. For each sensor tested observe:
    a. CO reading is between 25 and 35 ppm
    b. Ventilation system ramps to full speed when span gas is applied
    c. Ventilation system ramps to minimum speed when span gas is removed.
3. Temporarily override the programmed sensor calibration/replacement period to 5 minutes. Wait 5 minutes and observe that fans ramp to full speed and an alarm is received by the facility operators. Restore calibration/replacement period.
4. Temporarily place the system in unoccupied mode and override the programmed unoccupied sensor alarm differential from 30% for 4 hours to 1% for 5 minutes. Wait 5 minutes and observe that fans ramp to full speed and an alarm is received by the facility operators. Restore programming.
5. Temporarily override the programmed occupied sensor proximity zone alarm differential from 30% for 4 hours to 1% for 5 minutes. Wait 5 minutes and observe that fans ramp to full speed and an alarm is received by the facility operators. Restore programming.

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8. Appendices

8.1 Appendix A: 2010 California Mechanical Code

403.7 Exhaust Ventilation. Exhaust airflow shall be provided in accordance with the requirements in Table 4-4. Exhaust makeup air shall be permitted to be any combination of outdoor air, recirculated air, and transfer air.

403.8 Exhaust Ventilation for Enclosed Parking Garages. Exhaust airflow for enclosed parking garages shall be provided in accordance with the requirements in Table 4-4 and this Section. Exhaust makeup air shall be permitted to be any combination of outdoor air or transfer air.

403.8.1 Exhaust Inlet Distribution. To ensure proper exhaust of contaminated air and fumes from parking garages, exhaust systems utilizing multiple exhaust inlets shall be designed so that exhaust inlets are distributed in such a manner that no portion of the parking garage is more than 50 feet (15 240 mm) from an exhaust inlet. Such exhaust inlets shall be installed so that the highest elevation of the exhaust inlet is no greater than 12 inches (305mm) below the lowest ceiling level.

Exception: Garage exhaust systems designed without distributed exhaust inlets shall have their exhaust inlets designed based on the principles of engineering and mechanics and shall provide the minimum required exhaust rate in Table 4-4.

403.8.2 Alternative Exhaust Ventilation for Enclosed Parking Garages. Mechanical ventilation systems used for enclosed parking garages shall be permitted to operate intermittently where the system is arranged to operate automatically upon detection of vehicle operation or the presence of occupants by approved automatic detection devices.

403.8.2.1 Minimum Exhaust Rate. Ventilation systems shall be capable of providing 14,000 cfm (6608 L/s) of exhaust air for each operating vehicle. Number of operating vehicles shall be determined based on 2.5 percent of all parking spaces (and not less than one vehicle).

403.8.2.2 Automatic Carbon Monoxide Sensing Devices. Automatic carbon monoxide sensing devices may be employed to modulate the ventilation system to maintain a maximum average concentration of carbon monoxide of 50 parts per million during any eight-hour period, with a maximum concentration not greater than 200 parts per million for a period not exceeding one hour. Automatic carbon monoxide sensing devices employed to modulate parking garage ventilation systems shall be approved pursuant to the requirements in Section 302.1.

8.2 Appendix B: Relevant Codes from Other Jurisdictions

8.2.1 IMC 2009

SECTION 404 ENCLOSED PARKING GARAGES

404.1 Enclosed parking garages. Mechanical ventilation systems for enclosed parking garages shall be permitted to operate intermittently where the system is arranged to operate automatically upon detection of vehicle operation or the presence of occupants by approved automatic detection devices.

404.2 Minimum ventilation. Automatic operation of the system shall not reduce the ventilation airflow rate below 0.05 cfm per square foot (0.00025 m3/s · m2) of the floor area and the system shall be capable of producing a ventilation airflow rate of 0.75 cfm per square foot (0.0038 m3/s · m2) of floor area.

404.3 Occupied spaces accessory to public garages. Connecting offices, waiting rooms, ticket booths and similar uses that are accessory to a public garage shall be maintained at a positive pressure and shall be provided with ventilation in accordance with Section 403.3.

TABLE 403.3—continued MINIMUM VENTILATION RATES

OCCUPANCY CLASSIFICATION	PEOPLE OUTDOOR AIRFLOW RATE IN BREATHING ZONE, R_p CFM/PERSON	AREA OUTDOOR AIRFLOW RATE IN BREATHING ZONE, R_a CFM/FT[2] [a]	DEFAULT OCCUPANT DENSITY #/1000 FT[2] [a]	EXHAUST AIRFLOW RATE CFM/FT[2] [a]
Storage				
Repair garages, enclosed parking garages[b,d]	—	—	—	0.75
Warehouses	—	0.06	—	—

b. Mechanical exhaust required and the recirculation of air from such spaces is prohibited (see Section 403.2.1, Item 3).

d. Ventilation systems in enclosed parking garages shall comply with Section 404.

http://publicecodes.citation.com/icod/imc/2009/icod_imc_2009_4_sec004.htm

8.2.2 Current Oregon Energy Code

1317.2.3 Enclosed parking garage ventilation controls. In Group S-2 parking garages, other than open parking garages, used for storing or handling automobiles operating under their own power having ventilation exhaust rates 30,000 cfm and greater shall employ automatic carbon monoxide sensing devices. These devices shall modulate the ventilation system to maintain a maximum average concentration of carbon monoxide of 50 parts per million during any eight-hour period, with a maximum concentration not greater than 200 parts per million for a period not exceeding one hour. Such system shall be designed to exhaust a minimum of 14,000 cfm (6,608 L/s) for each operating vehicle, but not less than 2.5 percent (or one vehicle) of the garage capacity. Failure of such devices shall cause the exhaust fans to operate in the on position.

8.2.3 Proposed Oregon Energy Code (goes into effect July 2011)

503.2.5.3 Enclosed parking garage ventilation controls. In Group S-2, enclosed parking garages used for storing or handling automobiles operating under their own power having ventilation exhaust rates 30,000 cfm and greater shall employ automatic carbon monoxide sensing devices. These devices shall modulate the ventilation system to maintain a maximum average concentration of carbon monoxide of

50 parts per million during any 8-hour period, with a maximum concentration not greater than 200 parts per million for a period not exceeding 1 hour. The system shall be capable of producing a ventilation rate of 1.5 cfm per square foot (0.0076m3/s • m2) of floor area. Failure of such devices shall cause the exhaust fans to operate in the ON position.

8.2.4 2009 Washington State Energy Code

1412.9 Enclosed Loading Dock and Parking Garage Exhaust Ventilation System Control. Mechanical ventilation systems for enclosed loading docks and parking garages shall be designed to exhaust the airflow rates (maximum and minimum) determined in accordance with the State Mechanical Code (chapter 51-52 WAC).

Ventilation systems shall be equipped with a control device that operates the system automatically upon detection of vehicle operation or the presence of occupants by approved automatic detection devices. Each of the following types of controllers shall be capable of shutting off fans or modulating fan speed.

1. Gas sensor controllers used to activate the exhaust ventilation system shall stage or modulate fan speed upon detection of specified gas levels. All equipment used in sensor controlled systems shall be designed for the specific use and installed in accordance with the manufacturer's recommendations. The following are minimum gas sensor system requirements:

a. Garages and loading docks used predominantly by gasoline-powered vehicles shall be equipped with a controller and a full array of carbon monoxide (CO) sensors set to maintain levels of carbon monoxide below 35 parts per million (ppm). Spacing and location of the sensors shall be installed in accordance with manufacturer recommendations.

b. Where more than 20 percent of the vehicles using the garage or loading dock are powered by nongasoline fuels, the area exposed to nongasoline fueled vehicle exhaust shall be equipped with a controller and fuel-appropriate sensors. The set-point for the nongasoline sensors shall be no less than the standard used by OSHA for eight hour exposure. The controller shall activate the ventilation system when sensor set-point is reached. Spacing and location of the sensors shall be installed in accordance with manufacturer recommendations.

2. Automatic time clocks used to activate the system shall activate the system during occupied periods. The time clock shall be capable of scheduling multiple start and stop times for each day of the week, varying the daily schedule, and retaining programming for a 10-hour period during loss of power.

3. Occupant detection sensors used to activate the system shall detect entry into the parking garage along both the vehicle and pedestrian pathways.

1412.9.1 System Activation Devices for Enclosed Loading Docks. Ventilation systems for enclosed loading docks shall be activated by one of the following:

1. Gas sensors; or

2. Time clock and a manual over-ride switch located in the dock area that is accessible to persons in the loading dock area.

1412.9.2 System Activation Devices for Enclosed Parking Garages. Ventilation systems for enclosed parking garages shall be activated by gas sensors.

EXCEPTION: A parking garage ventilation system having a total design capacity under 8,000 cfm may use a time clock or occupant sensors."

8.2.5 2007 Minnesota State Building Code

1346.0404 SECTION 404 GARAGES.

Subpart 1. **Section 404.1.** IMC Section 404.1 is amended to read as follows:

404.1 Enclosed parking garages. Mechanical ventilation systems for enclosed parking garages shall provide a minimum exhaust rate of 0.75 cfm per square foot (0.0038 m^3/s) of floor area. Mechanical ventilation systems are not required to operate continuously where the system is arranged to operate automatically upon detection of a concentration of carbon monoxide of 25 parts per million (ppm) by approved automatic detection devices.

8.2.6 New York City Mechanical Code

SECTION MC 404

ENCLOSED PARKING GARAGES

404.1 Enclosed parking garages. Mechanical ventilation systems for enclosed parking 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 parts per million (ppm) by approved automatic detection devices.

8.2.7 Wisconsin Mechanical Code (based on IMC)

Comm 64.0404 Minimum enclosed garage ventilation.

(1) Substitute the following wording for the requirements in IMC section 404.2: Automatic operation of the system shall not reduce the ventilation rate below 0.05 cfm per square foot of the floor area and the system shall be capable of producing a ventilation rate of 0.5 cfm per square foot of floor area.

(2) This is a department alternative to the requirements in IMC sections 404.1 and 404.2: Mechanical ventilation systems for enclosed parking garages are not required to operate continuously where the system conforms to all of the following:

(a) The system is arranged to operate automatically upon detection of carbon monoxide at a level of 35 parts per million (ppm) by automatic detection devices.

(b) If diesel−fueled vehicles are stored, the system is arranged to operate automatically upon detection of nitrogen dioxide at a level of one part per million (ppm) by automatic detection devices.

(c) The system includes automatic controls for providing exhaust ventilation at a rate of 0.5 cfm per square foot for at least 5 hours in each 24−hour period.

(d) The system maintains the garage at negative or neutral pressure relative to other spaces.

History: CR 00−179: cr. Register December 2001 No. 552, eff. 7−1−02; CR 01−139: r. and recr. (1) Register June 2002 No. 558, eff. 7−1−02; CR 06−120: r. and recr. Register February 2008 No. 626, eff 3−1−08.

8.2.8 Title 24 2008 section on DCV devices

Demand Control Ventilation Devices.

A. For each system with demand control ventilation, CO_2 sensors shall be installed in each room that meets the criteria of Section 121(c)3B with no less than one sensor per 10,000 ft² of floor space. When a zone or a space is served by more than one sensor, signal from any sensor indicating that CO_2 is near or at the setpoint within a space, shall trigger an increase in ventilation to the space;

CO_2 sensors shall be located in the room between 3 ft and 6 ft above the floor or at the anticipated height of the occupants heads;

Demand ventilation controls shall maintain CO_2 concentrations less than or equal to 600 ppm plus the outdoor air CO_2 concentration in all rooms with CO_2 sensors;

EXCEPTION to Section 121(c)4C: The outdoor air ventilation rate is not required to be larger than the design outdoor air ventilation rate required by Section 121(b)2 regardless of CO_2 concentration.

Outdoor air CO_2 concentration shall be determined by one of the following:

i. CO_2 concentration shall be assumed to be 400 ppm without any direct measurement; or

ii. CO_2 concentration shall be dynamically measured using a CO_2 sensor located within 4 ft of the outdoor air intake.

When the system is operating during hours of expected occupancy, the controls shall maintain system outdoor air ventilation rates no less than the rate listed in TABLE 121-A times the conditioned floor area for spaces with CO_2 sensors, plus the rate required by Section 121(b)2 for other spaces served by the system, or the exhaust air rate whichever is greater;

CO_2 sensors shall be certified by the manufacturer to be accurate within plus or minus 75 ppm at a 600 and 1000 ppm concentration when measured at sea level and 25°C, factory calibrated or calibrated at start-up, and certified by the manufacturer to require calibration no more frequently than once every 5 years. Upon detection of sensor failure, the system shall provide a signal which resets to supply the minimum quantity of outside air to levels required by Section 121(b)2 to the zone serviced by the sensor at all times that the zone is occupied.

The CO_2 sensor(s) reading for each zone shall be displayed continuously, and shall be recorded on systems with DDC to the zone level.

8.2.9 UMC approved change

403.6 Exhaust Ventilation. Exhaust airflow shall be provided in accordance with the requirements in Table 4-4. Exhaust makeup air shall be permitted to be any combination of outdoor air, recirculated air, and transfer air.

403.7 Dynamic Reset. The system shall be permitted to be designed to vary the design outdoor air intake flow (Vot), or the space or zone airflow, and the exhaust airflow as operating conditions change.

8.3 Appendix C: Details on CO sensor field study

8.3.1 Garage A

System and garage background

The sensor manufacturer is Critical Environment Technologies. The sensor unit model is AST-MCO (W), which is an electrochemical sensor with a range of 0 to 200 ppm. The sensor requires calibration 1 to 4 times per year, depending upon application. The garage has 4 zones, multiple fans per zone. According to one of the garage operators, the system was installed about 5 years ago, and has likely not been serviced since then. According to one of the garage operators, the fans only run when the garage is busy. They do not run every day, they just run when the garage is busy.

There is a sticker on each sensor that states the date of calibration. It looks like a sticker from when it was factory calibrated, so it is possible that it has been calibrated since then. The dates of the initial calibration range from June 2004 to May 2005.

Testing details

The testing was conducted on October 21, 2010. The sensor with its cover on is shown in Figure 16 and is typical of all sensors in the garage.

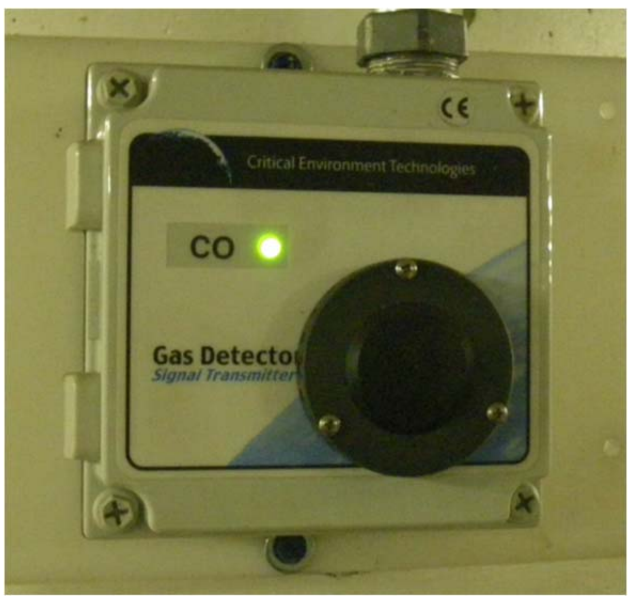

Figure 16. Typical CO sensor in Garage A

Table 15. Notes on sensor testing in Garage A

Sensor 1	At 50 ppm the sensor reading is not stable. The reading was initially 1.2 volts, and continually decreased until we removed the meter at 0.5 volts. At 100 ppm the sensor reading is not stable. The reading was initially 0.99 volts, and continually decreased until we removed the meter. We thought maybe there was a leak in the connection somewhere between the gas can and the sensor. Frank taped a plug on the sensor fitting so that it was more secure. This made no difference, because the 200 ppm reading had the same trouble. The fan closest to the sensor activated at all tests except the 0 ppm test. The fan shut off shortly after we stopped flowing the gas.
Sensor 2	The fan closest to the sensor started and stopped a few times, but ran almost continuously throughout the test. The fan was probably activated by other sensors tripping due to cars (the starting and stopping was not consistent with our testing).
Sensor 3	Fan closest to the sensor was not on intially. The fan came on when we were testing with 200 ppm gas, though that was also when a car in the garage started up, so it is unclear as to what tripped it. The fan continued to run throughout the testing of Sensor 4 (and possibly longer).
Sensor 4	At 0 ppm the reading was initially 0.89 volts, and then decreased until it settled out at about 0.49 volts. All other readings were very stable.
Sensor 5	No comments.

8.3.2 Garage B

System and Garage Background

This system contains 40 sensors, divided up into 4 zones, which are served by 7 exhaust fans. The sensor manufacturer is MSA Canada. The panel model is TGMX 40 40PT 250 PPM CO and the sensor unit model is UNTGS-$CO_2$50-FIG-SS (solid state sensor). The sensor range is 0 to 250 ppm. This is a discontinued model that the manufacturer no longer supports, but according to the manufacturer, the sensors should be calibrated two times per year.

The sensor control panel (shown in Figure 17) has three lights for each sensor to indicate whether or not the sensor has power (green), is in warning (amber), or is in alarm (red). The tag next to the sensor indicates the zone and exhaust fan it corresponds to. The display on the right scrolls through the sensors and displays the readings in ppm of each sensor, one at a time.

Figure 17. Sensor control panel in Garage B

The system was installed in 1998. The garage operators don't have any documentation on the system at the garage and they've never seen any documentation. One of the operators who has been with the garage for about 4 years has never seen the sensors calibrated. According to the operators, the exhaust fans only operate very rarely. Also very rarely, the lights on the sensor control panel indicate a warning, but then shut off after a time.

Testing Details

The testing was conducted on October 29, 2010. These sensors require some humidity in order to operate because they are solid state sensors. Therefore a humidifier was used during the testing of these sensors. The jumper on board was used to test voltage output at 100% and at 50% of the full scale. Otherwise the testing procedure was identical to the procedure used in the other garages. The sensor with its cover on is shown in Figure 18 and is typical of all sensors in the garage.

Figure 18. Typical CO sensor in Garage B

Table 16. Notes on sensor testing in Garage B

		Using jumper on board			
	Ambient voltage reading	**100% Full Scale voltage**	**50% Full Scale voltage**	**Calculated 0 reading**	**Notes**
Sensor 1	0.98	4.95	2.96	0.97	
Sensor 2	0.98	4.97	2.97	0.97	Sensor responded with a change in voltage about 30 seconds after applying the gas. About 30 seconds after its initial response, the voltage reading jumped up again. After that, the reading was stable. This was typical at all gas concentrations (except 0 ppm). The Warning light came on 35, 50, 100, and 200 ppm. The Alarm light came on at 50, 100, and 200 ppm.
Sensor 3	0.98	4.96	2.97	0.98	
Sensor 4	0.99	4.97	2.98	0.99	
Sensor 5	0.98	4.96	2.97	0.98	

8.3.3 Garage C

System and Garage Background

The sensor manufacturer is Honeywell Vulcain. The sensor unit model is Vulcain 301(W) which is an electrochemical sensor. The system was installed 2 years ago. According to the garage operator, two sensors failed last year and were replaced. Two more sensors have failed recently, and will be replaced shortly. The system indicates when a sensor has failed. According to the manufacturer, the sensors are accurate to +/- 10ppm at 25^0C and are maintenance-free, requiring no regular calibration.

Testing Details

The testing was conducted on November 1, 2010. All sensors were functioning. Sensors gave a reading outside of Honeywell's stated accuracy 24% of the time, as seen in Table 12 in Section 4.4.5 above. There was generally a long lag time (anywhere from 10 seconds up to 8 minutes) between the time that span gas was applied to the sensor and the elevated gas concentration was detected by the system. There is a continuous reading on the display showing the ppm at each sensor. The sensor with its cover on is shown in Figure 19 and is typical of all sensors in the garage.

Figure 19. Typical CO sensor in Garage C

8.4 Appendix D: Non-Residential Construction Forecast Details

8.4.1 Summary

The Non-Residential construction forecast dataset is data that is published by the California Energy Commission's (CEC) demand forecast office. This demand forecast office is charged with calculating the required electricity and natural gas supply centers that need to be built in order to meet the new construction utility loads. Data is sourced from Dodge construction database, the demand forecast office future generation facility planning data, and building permit office data.

All CASE reports used the statewide construction forecast for 2014. The TDV savings analysis is calculated on a 15 or 30 year net present value, so it is correct to use the 2014 construction forecast as the basis for CASE savings.

8.4.2 Additional Details

The demand generation office publishes this dataset and categorizes the data by demand forecast climate zones (FCZ) as well as building type (based on NAICS codes). The 16 climate zones are organized by the generation facility locations throughout California, and differ from the Title 24 building climate zones (BCZ). The Heschong Mahone Group (HMG) has reorganized the demand forecast office data using 2000 Census data (population weighted by zip code) and mapped FCZ and BCZ to a given zip code. The construction forecast data is provided to CASE authors in BCZ in order to calculate Title 24 statewide energy savings impacts. Though the individual climate zone categories differ between the demand forecast published by the CEC and the construction forecast, the total construction estimates are consistent; in other words, HMG has not added to or subtracted from total construction area.

The demand forecast office provides two (2) independent data sets: total construction and additional construction. Total construction is the sum of all existing floor space in a given category (Small office, large office, restaurant, etc.). Additional construction is floor space area constructed in a given year (new construction); this data is derived from the sources mentioned above (Dodge, Demand forecast office, building permits).

Additional construction is an independent dataset from total construction. The difference between two consecutive years of total construction is not necessarily the additional construction for the year because this difference does not take into consideration floor space that was renovated, or repurposed.

In order to further specify the construction forecast for the purpose of statewide energy savings calculation for Title 24 compliance, HMG has provided CASE authors with the ability to aggregate across multiple building types. This tool is useful for measures that apply to a portion of various building types' floor space (e.g. skylight requirements might apply to 20% of offices, 50% of warehouses and 25% of college floor space).

The main purpose of the CEC demand forecast is to estimate electricity and natural gas needs in 2022 (or 10-12 years in the future), and this dataset is much less concerned about the inaccuracy at 12 or 24 month timeframe.

It is appropriate to use the CEC demand forecast construction data as an estimate of future years construction (over the life of the measure). The CEC non-residential construction forecast is the best publicly available data to estimate statewide energy savings.

8.4.3 Citation

"NonRes Construction Forecast by BCZ v7"; Developed by Heschong Mahone Group with data sourced August, 2010 from Abrishami, Moshen at the California Energy Commission (CEC)