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Emerging Technologies Program

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Demand-Controlled Ventilation
San Francisco, CA

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Demand Controlled Ventilation Evaluation Report
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This evaluation report is a supplement to Report #0609, *Marketable Technologies for the Hospitality Segment*. The full list of supplements follows:

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Preface

The San Francisco office of Architectural Energy Corporation (AEC), an energy and environmental research, development, and design consulting firm headquartered in Boulder, Colorado, prepared this document for PG&E. The report was contributed to by John J. Arent, and reviewed for technical quality and responsiveness by Erik Kolderup and Donald Frey. Wayne Krill of PG&E provided guidance and input as project manager.

Please note that product and manufacturer names used in this report are proprietary and may be trademarked and copyrighted.

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0.0 Executive Summary

Demand control ventilation (DCV) is a well-established technology used to adjust outside ventilation levels to match occupancy levels.

Typically, **carbon dioxide is used as an indicator of the occupancy level in a space**. The objective of the DCV strategy is to provide sufficient ventilation to maintain minimum indoor air quality levels mandated by Title 24 and recommended by ASHRAE Standard 62.1-2004. **This control can achieve substantial energy savings for spaces with high occupant densities and variable occupancy** levels (such as conference rooms and large meeting rooms).

DCV is currently required for new construction of spaces, other than classrooms, that are served by single-zone air handlers and have an occupant density greater than 25 people per 1,000 ft^2.

HVAC units that already have direct digital controls (DDC) are most easily retrofitted to implement DCV. A retrofit of a packaged unitary HVAC unit or air handler to implement DCV involves installing one or more carbon dioxide sensors and programming additional control algorithms.

Costs to implement DCV as a retrofit range from $800 to $1,200 per control unit. Energy savings are highly variable, since they depend on occupant densities, climate conditions, and occupancy patterns. An estimate of energy savings based on reasonable assumptions is shown below.

No product-specific incentives are available for this measure. The Standard Performance Contract program provides incentives of $0.14/kWh for HVAC measures up to 50% of project cost. These incentives will shorten the payback periods as shown in Table 0-1.

Table 0-1: Estimated Simple Payback for DCV (for 5,000 ft^2 space)

Location	Initial Cost	Energy Savings	Simple Payback (without incentive)	Simple Payback (with incentive)
Inland Valleys (San Jose / Contra Costa County)	$800–$1,200	0.5 kWh/ft^2-y	2.3–3.4 years	1.3–2.4 yrs
Coastal (San Francisco)	$800–$1,200	0.15 kWh/ft^2-y	7.6–11.4 years	6.6–10.4 yrs

These estimates assume that the space is unoccupied 50% of the regularly occupied hours when the HVAC system is expected to be running (between 7am and 10pm). During the unoccupied periods, the outside air ventilation can be reduced to the minimum amount required to remove building-related contaminates (0.15 cfm/ft^2 per Title 24). The estimate conservatively assumes that no heating energy savings are achieved, although in practice DCV would save some heating energy due to the reduced volume of outside air passing through the heating coil. Energy savings are greatest for large spaces and the payback periods the shortest, since the **costs to implement DCV do not scale with floor area**. Implementation costs are typically unchanged for spaces up to 5,000 ft^2. Above 5,000 ft^2, an additional CO_2 sensor is recommended, which will increase installed cost by approximately $300. Energy savings are much greater in inland climates such as San Jose and Contra Costa County, because cooling costs are higher due to the larger number of hours where outside conditions do not permit economizer cooling.

A good way of assessing the potential of DCV for a particular retrofit application is through short-term monitoring of indoor CO_2 levels. Title 24 recommends that CO_2 concentrations be maintained no higher than 600 ppm above the outdoor concentration (typically, 400 to 450 ppm). Thus, if monitoring reveals that the indoor CO_2 level is well below 1,000 ppm for a substantial portion of the time, DCV has good potential to produce energy savings.

1.0 Evaluation Summary

Demand controlled ventilation (DCV) is a cost effective strategy to reduce energy use required to heat, cool, and dehumidify buildings. For hotels, DCV is most cost effective when applied to large spaces that have highly variable occupancy patterns and occasionally high occupant densities. The 2005 Title 24 Energy Efficiency Standards require demand controlled ventilation on new construction for single-zone systems with economizers, serving spaces with high occupant densities (greater than 25 people per 1000 ft^2, with exceptions provided for classrooms). DCV is especially effective:

- For meeting rooms and ballrooms that have high peak occupancies and variable occupancies,
- In warm climates that have frequent periods of hot outdoor weather (e.g., areas like Morgan Hill and Walnut Creek),
- With HVAC systems that already have programmable direct digital controls (for less expensive retrofits), and
- For spaces that have low cooling setpoints (this increases the number of hours when DCV provides energy savings). For example, the San Jose ballroom, described later in this report, shows an estimated annual DCV energy savings of 2,472 kWh. The example assumed a space cooling setpoint of 74°F. If the space setpoint was just 2 degrees higher, 76°F, the annual energy savings would drop to 1,761 kWh, which would significantly affect the payback time.

Cost of installation for retrofits is approximately $800 to $900 per zone for systems that have direct digital controls and slightly higher ($1,200) for systems that have other control systems. Energy savings is highly variable, but for a space that is occupied 50% of the time, an annual energy savings of 0.5 kWh/ft^2-yr can be achieved. Simple payback times between 2 and 5 years are typical for facilities in the warmest of the Bay Area climates. With a relatively low first cost, and a good persistence of savings throughout a five-year period, DCV is typically a good retrofit option for conference rooms of hotels in the warmer regions of Santa Clara County and Contra Costa County. For San Francisco and other coastal regions, simple paybacks are considerably longer, typically 5 to 15 years, because the climate in those regions is mild.

DCV has the additional benefit of ensuring that adequate ventilation is provided, when it is set up to achieve acceptable indoor air quality as defined in ASHRAE Standard 62.1-2004. DCV is an energy-saving strategy that will not negatively impact guests or cause them any inconvenience. In fact, they should have no idea that ventilation is controlled on demand.

Table 1-1: Evaluation Summary

Criteria	Score (1=poor, 10=excellent)	Notes
Speed of Implementation	7	Simple installation for HVAC and control systems that support it. Installation on DDC systems is easiest.
Focus on Products	5	This is an add-on to an existing system that requires commissioning for proper operation.
Demand Reduction	5	Some potential for demand reduction (~10-20 kW per hotel), if space has reduced occupancy during peak hours. Otherwise, no demand reduction.
Cost Effectiveness	6	Some studies show payback as low as 1–3 years; payback is likely higher for buildings in moderate climates such as San Francisco and other coastal areas.
Persistence	7	Sensors require re-calibration every 5 years; otherwise, savings should persist.
Customer Satisfaction	8	Will ensure proper ventilation to help maintain indoor air quality (IAQ).
Supply	8	Several manufacturers offer CO_2 sensors for DCV applications. The cost for the sensors is dropping as demand for them increases.
Market Size	3	Applicable mainly to conference / banquet rooms and lobby areas; some limited potential for other areas.
Magnitude of Energy Savings	8	High rate of energy savings (0.2–0.5 kWh/ft2-y); however, limited to high-occupancy spaces.
PG&E Program	6	Good candidate for incentive: established technology and cost effective, but underutilized.
Existing Installations	3	Well-established technology but few installations in the hotel sector.

2.0 Technology Overview

Demand controlled ventilation (DCV) is a technique for automatically regulating the quantity of ventilation air delivered to spaces based on occupant levels. Because occupants exhale carbon dioxide (CO_2) in predictable levels in proportion to their metabolic activity, measurements of indoor CO_2 are a good indicator of occupancy. Outside air typically has low concentrations of CO_2; around 400 to 450 parts per million (ppm). DCV controls use indoor CO_2 measurements as an indication of the number of occupants in a space and regulate the amount of ventilation air admitted to dilute the CO_2 generated by building occupants. The result is that indoor CO_2 can be measured and ventilation rates controlled to a specific cfm/person based on actual occupancy.

ASHRAE Standard 62.1-2004 defines acceptable indoor ventilation levels for buildings. This standard has become the basis of many state building codes, including California's Title 24. According to ASHRAE Standard 62, for a typical metabolic activity level, a ventilation rate of 15 cfm/person will result in an indoor CO_2 concentration level that is 700 ppm above the outdoor concentration. Increasing the ventilation rate to 20 cfm/person will reduce the concentration level to 530 ppm above the outdoor level. The goal with demand controlled ventilation is to adjust the outside air ventilation rate to maintain the desired indoor CO_2 level. An indoor CO_2 concentration level that is no more than 700 ppm above the outdoor concentration level is deemed acceptable by this standard.

For California, the 2005 Title 24 Energy Efficiency Standard governs requirements for DCV systems. It states that the control should maintain CO_2 levels at or below 600 ppm above the outdoor CO_2 concentration. If the outdoor concentration is not measured, it should be assumed to be 400 ppm. The CO_2 sensor is to be installed in the space, between 1–6 feet above the floor. When the space is unoccupied, the ventilation control must ensure that a minimum outside air rate of no less than 0.15 cfm per ft^2 of floor area is delivered to the space.

2.1 Technology Description

DCV is a control option that is available as a standard feature on many HVAC systems, and may also be introduced as a retrofit on some systems. It consists of one or more carbon dioxide sensors and a system controller that can vary outside air ventilation rates. DCV is implemented on systems that have adjustable outside air dampers and is normally available on systems that have economizers. It is most easily retrofitted on systems that use direct digital controls (DDC), but can also be fitted into systems with electronic or pneumatic controls. Carbon dioxide sensors from two manufacturers that can be used for DCV are shown in Figure 2-1.

Figure 2-1: Examples of CO_2 Wall-Mount Sensors: Vaisala GM-25 (left) and Telaire Ventostat 8102 (right)

2.2 Where Demand Controlled Ventilation is Applicable

Demand controlled ventilation is most applicable in areas with variable occupancy, and areas that have high occupant densities when fully occupied. By reducing the outside air ventilation rate during times of partial occupancy, DCV allows for savings of both cooling and heating energy costs. Examples of ideal applications are conference rooms and ballrooms, lobbies, meeting rooms, and gymnasiums. DCV may also be suitable for cafeterias and dining rooms, but only when air handling systems are properly balanced.

Situations where DCV is desirable include:

- Buildings or areas that have significant heating and cooling loads not met by economizer cooling. DCV provides energy savings when outside air conditions are either very warm to hot, or cold. Buildings located in temperate regions such as San Francisco will have lower energy savings levels than buildings located in the inland valleys. In San Francisco and other coastal regions, the cooling load can often be met by providing outside air to the space.

- Areas with highly variable occupancy and high occupant densities at peak capacity. Spaces with very low occupancy levels at off-hours (for example, a conference room that is only occupied on average for 2–4 hours a day) will provide the greatest opportunity to reduce outside air intake. When these unoccupied periods coincide with warm or cold outdoor conditions, energy will be saved.

- HVAC systems with DDC controls that allow for an easy retrofit. Systems with DDC controls will have significantly lower installation costs, reducing payback time.

- Areas where building furnishings are not a significant source of pollutants. Even when unoccupied, a minimum outside air rate must be maintained to offset building-generated pollutants (such as volatile organic compounds, or VOCs). For conference rooms, lobbies and offices, the required minimum ventilation rate to address building-related contaminants is very low (0.06 cfm/ft^2 per ASHRAE 62.1-2004). For spaces such as science classrooms and laboratories, minimum ventilation requirements are much higher.

DCV is less desirable with HVAC systems that incorporate energy recovery devices to exchange heat between the supply and exhaust air streams. These systems will not benefit greatly from the addition of DCV. Single-zone systems are more easily retrofitted than variable air volume (VAV) systems. With variable air volume systems serving multiple spaces, additional sensors are required, increasing installation cost. Moreover, the space with the greatest outside air demand will dictate ventilation requirements. If the spaces have variable occupancies, energy savings may be lower than in spaces with a single-zone system.

2.3 Market Readiness (Current Status)

Demand controlled ventilation is an established technology that is readily available for new large air handling units, or as an addition to existing air handling units. It is not normally an option for packaged terminal air conditioners used for guestrooms.

3.0 Market Opportunity, Benefits, and Cost Effectiveness

3.1 Average System Energy and Demand Savings

Energy savings produced by demand controlled ventilation are highly variable and depend upon occupancy patterns, peak occupant densities, climate, among other factors. In general, demand controlled ventilation will be cost effective for large spaces (> 2,000 ft^2) that are served by a single air handling unit and have high peak occupant densities (> 25 people per 1,000 ft^2). It is an excellent option for conference centers and ballrooms. It can also be very cost effective for smaller spaces with high occupant densities; however, installation costs per ft^2 will be higher for small spaces. Energy savings estimates for convention centers in Oregon (Jeannette, 2006) were estimated at $0.10/$ft^2$ annually. For other types of spaces in other climates, the author estimated savings as high as $0.20–0.30/$ft^2$ annually.

Demand controlled ventilation ensures that acceptable indoor air quality is maintained. It can provide improvement in indoor air quality for areas that experience poor indoor air quality. It should be noted, however, that a DCV system installed on a space with poor air quality due to inadequate ventilation could end up increasing energy use because the ventilation use will increase.

One way to assess potential benefits of DCV is by conducting short-term monitoring of CO_2 levels in a space being considered for DCV. A portable CO_2 sensor with data logging capability can be used to record CO_2 levels over a three or four day period. Graphs of the data will show peaks and valleys of the CO_2 concentration. The peaks indicate times when the space is occupied and valleys indicate that it is unoccupied. The more the space is unoccupied, the greater the potential for savings. Also examine the CO_2 levels during occupied periods when the system is not in economizer mode, such as warm afternoons when the outside temperature is above the economizer setpoint. When not in economizer mode, the system will be bringing in the minimum volume of outside air needed for fully occupied space. If measured CO_2 levels during these periods are at or below acceptable code minimum levels (1100 – 1150 ppm indoors), the ventilation in the space is adequate. If CO_2 levels are at or above 1100 ppm, additional ventilation is needed and should be increased. Once the ventilation is adequate to maintain acceptable indoor air quality, the savings from DCV system are actually increased (do you mean decreased, or energy use is increased??). Heating and cooling energy use during occupied periods will be increased, because the proper volume of outside air will be coming into the building. Such an increase should be viewed as necessary to maintain a healthy indoor environment.

3.1.1 Factors Affecting Energy Savings

When evaluating DCV for a particular facility, consider the following factors and their impact on energy savings. Where possible, it is helpful to obtain some basic information about operating schedules, HVAC system size, and peak occupancy levels. This information can be used to make an approximate estimate of energy savings.

1. *Operating hours and peak occupancy.* Demand controlled ventilation saves energy by reducing the energy required to cool, heat, and dehumidify the outside air during times of

partial occupancy. To obtain an estimate of energy savings, it is important to know the operating hours and occupant schedules of the space under consideration. A technique for doing this is suggested above. In general, buildings with variable and unpredictable loads that peak at a high value are good candidates.

2. *Peak occupant density (people per ft² of floor space).* The higher the occupant density, the greater the energy savings possible when DCV is implemented. Peak occupant densities for a space should be available from the hotel or facility manager. Different uses may have different peak occupancies for a space (a reception area vs. a dining area, for example). A study that was conducted for the 2005 update of the Title 24 Standards showed that demand controlled ventilation is cost effective for spaces that have peak occupant densities of 25 people per 1,000 ft^2 or greater (or in other words, 40 ft^2 of space per person or less). Many conference centers and meeting rooms have peak densities of 50 people per 1,000 ft^2 or greater.

3. Climate. Energy savings is achieved by reducing the amount of outside air that is introduced to the space when it is not needed for ventilation purposes. Cooling energy savings occurs only when the space is partially occupied and when the outside air temperature is warmer than the space temperature. Therefore, DCV will be more cost effective in locations that experience hot weather more frequently (parts of Santa Clara County and Contra Costa County as well as the Central Valley, in PG&E's territory). In general, DCV is most cost effective in locations that require hearing and/or cooling for most of the year.

4. HVAC system type. Greatest savings are available for single-zone air handlers, where the outdoor ventilation rate can be controlled based on the CO_2 levels in a single space. For variable air volume (VAV) systems that serve multiple spaces, savings may be lower because the system needs to bring in enough outside air to satisfy the individual space/zone with the greatest need for ventilation.

3.2 Demand Response Capability

DCV reduces HVAC energy use during periods of partial occupancy but does not directly address peak demand. However, the control can reduce the peak load on the cooling system if the space is partially occupied during periods of peak utility demand, which occur during periods of hot weather when DCV can provide its biggest savings. DCV is not a demand response strategy.

3.3 Cost Effectiveness

Several manufacturers produce carbon dioxide sensors for demand controlled ventilation applications. Manufacturers include Johnson Controls, Vaisala, Telaire Systems, AirTest Technologies, Digital Control Systems, Honeywell Control Products, Texas Instruments and Veris Industries. Sensors cost approximately $250 each. One sensor is required for each 5,000 ft^2 of floor space, and at least one sensor is required for each air handling unit. Some common spaces that are served by multiple units may require several CO_2 sensors. Carbon dioxide sensors are usually wired to a 24V power supply.

Costs to upgrade existing rooftop units with DCV are estimated at $300 to $900 per unit, depending upon what is required. Retrofits of systems that already contain direct digital controls

(DDC) will carry installation costs of $700 to $900 per unit. Retrofits of systems that use pneumatic or non-programmable controls will be somewhat higher, around $900 to $1,200 per unit.

It is not possible to generalize the cost effectiveness because there is significant variation in both installation cost and energy savings. However for single-zone systems, the simple payback period typically falls in the range of 2 to 8 years. For an infrequently used space with high peak occupancy levels, a simple payback much shorter than 2 years is possible. The following example shows a 3.3 year simple payback period.

3.4 Savings Estimation Tools

The example below shows how an energy savings estimate can be made by applying weather data and basic information about operating schedules, occupancy levels, and cooling equipment efficiencies. Several controls manufacturers, such as Carrier and Honeywell, have developed free software tools that can be used to evaluate DCV. Hourly simulation programs can also be used to predict savings, as long as information about expected variations in occupancy levels is available to use as an input.

As previously mentioned, monitored data on occupancy levels can greatly improve the estimate of energy savings and verify that DCV will be cost effective for a particular facility.

3.5 Case Studies

There are few case studies documenting measured savings resulting from DCV. Because the energy savings are highly variable, it is helpful to show an example of a savings calculation. This example is representative of the savings possible with DCV in the Bay Area. Consider a large ballroom (5,400 ft^2) that has a peak occupancy level of 900 (for reception). (This estimate is based on the Hyatt San Francisco grand ballroom, but the San Jose climate data is used in the calculation.) The occupancy will be less when the space is used for other types of events; and much less when it is not being used at all. The space occupancy is assumed to be 500 for a banquet and 450 when used as a lecture hall. When the space is unoccupied, a minimum outside air ventilation rate, per Title 24, of only 810 cfm (0.15 cfm/ft^2) is required. This example assumes that 50% of the time the space is unoccupied.

A load calculation for the space results in a design cooling load of approximately 45 tons. The peak supply airflow rate is 18,200 cfm. At peak occupancy, the outside air ventilation rate is 9,810 cfm, equal to 54% of the peak supply airflow.

Table 3-1: Assumptions for Hypothetical Example

Parameter	Value	Assumption
Floor space (ft^2)	5400 ft^2	Based in Hyatt San Francisco Grand Ballroom.
Peak occupancy (people)	900	Peak occupancy, such as for a reception.
Occupancy - theater (people)	700	Occupancy when used as a theater.
Occupancy - banquet (people)	500	Occupancy when used for a banquet.
Occupancy - lecture (people)	450	Occupancy when used for a lecture.
Minimum ventilation rate (cfm)	810 cfm	Based on 0.15 cfm/ft^2
Maximum ventilation rate (cfm)	9810 cfm	Peak OA ventilation rate.
Sensible cooling load (Btu/h)	380,000 Btu/h	Estimated cooling load. (Sensible)
Latent load (Btu/h)	112,500 Btu/h	Approximate latent load.
Total load (Btu/h)	492,500 Btu/h	Total load.
Supply airflow rate (cfm)	18,200 cfm	Total supply airflow rate based on sensible load calculation.
Space Cooling Setpoint (°F)	74°F	DCV provides energy savings whenever the outside air temperature exceeds this value.

This example assumes that the space is served by a chiller with a coefficient of performance (COP) of 4.6. The air handler includes an economizer with differential dry-bulb control. This example assumes that the minimum outside air setting is set to 5% of supply airflow (910 cfm).

The table below shows the energy savings for this space. Energy savings is achieved when the outside air temperature is warmer than the air entering the air handler (MAT, for mixed air temperature in the table below). In this example, the chiller load is reduced by as much as 16 kW during peak conditions. It is assumed that the space is unoccupied for 50% of operating hours (7am to 10pm daily). For these conditions, an annual energy savings of 2,472 kWh is achieved.

Table 3-2: Calculated Energy Savings For Hypothetical Example, San Jose, California

OAT	Hours 7am-10pm	Base MAT (°F)	Base AHU Cooling Load (Btu-hr)	Base Chiller Load (kW)	DCV MAT (°F)	DCV AHU Cooling Load (Btu-hr)	DCV Chiller Load (kW)	Chiller Load Savings (kW)	% Time Unocc-upied	Chiller Energy Savings (kWh)
40	78	55	-	-	55	-	-	-	50%	0
45	148	55	-	-	55	-	-	-	50%	0
50	368	55	-	-	55	-	-	-	50%	0
55	735	55	-	-	55	-	-	-	50%	0
60	1013	60	100,100	6.3	60	100,100	6.3	-	50%	0
65	885	65	200,200	12.7	65	200,200	12.7	-	50%	0
70	737	70	300,300	19.0	70	300,300	19.0	-	50%	0
75	668	74.5	391,182	24.7	74.1	381,381	24.1	0.6	50%	207
80	468	77.2	445,191	28.1	74.3	386,386	24.4	3.7	50%	870
85	241	79.9	499,200	31.6	74.6	391,391	24.7	6.8	50%	821
90	77	82.6	553,209	35.0	74.8	396,396	25.1	9.9	50%	382
95	21	85.3	607,218	38.4	75.1	401,401	25.4	13.0	50%	137
100	7	88.0	661,227	41.8	75.3	406,406	25.7	16.1	50%	56
									Total	2,472

If an average electricity rate of $0.14/kWh is assumed, the energy savings is $346 annually. Since this space exceeds 5,000 ft^2, at least two CO_2 sensors are recommended. The cost of the DCV retrofit will be approximately $1,150 per zone installed, if the HVAC system already has a DDC programmable control. A simple payback for this example is 3.3 years.

If the ballroom is used much more frequently than 50% of the time, the energy savings will be much lower. The payback period would also be shorter in a location warmer than San Jose. This example does not calculate the potential natural gas savings due to reduced need for heating of outdoor air during cold weather. If heating savings are considered, then the payback period would also be somewhat shorter.

Table 3-3: Calculated Energy Savings For Hypothetical Example, San Francisco, California

OAT	Hours 7am-10pm	Base MAT	Base AHU Cooling Load (Btu-hr)	Base Chiller Load (kW)	DCV MAT	DCV AHU Cooling Load (Btu-hr)	DCV CH Load (kW)	Chiller Load Sa-vings (kW)	% Time Unocc-upied	Chiller Energy Savings (kWh)
40	28	55	-	-	55	-	-	-	50%	0
45	120	55	-	-	55	-	-	-	50%	0
50	383	55	-	-	55	-	-	-	50%	0
55	918	55	-	-	55	-	-	-	50%	0
60	1505	60	100,100	6.3	60	100,100	6.3	-	50%	0
65	1176	65	200,200	12.7	65	200,200	12.7	-	50%	0
70	716	70	300,300	19.0	70	300,300	19.0	-	50%	0
75	392	74.5	391,182	24.7	74.1	381,381	24.1	0.6	50%	121
80	158	77.2	445,191	28.1	74.3	386,386	24.4	3.7	50%	294
85	54	79.9	499,200	31.6	74.6	391,391	24.7	6.8	50%	184
90	23	82.6	553,209	35.0	74.8	396,396	25.1	9.9	50%	114
95	1	85.3	607,218	38.4	75.1	401,401	25.4	13.0	50%	7
									Total	720

Comparing Table 3-3 illustrates how dependent the energy savings of DCV is on climate. For the same 5,400 ft^2 ballroom in San Francisco, assuming the same occupancy and cooling equipment, the energy savings is only 720 kWh, about 1/3 the savings for the same hotel located in San Jose. In the San Francisco example, the payback would be in excess of 10 years.

4.0 Design Considerations

This section provides some useful information to consider when designing a demand controlled ventilation system.

4.1 Design Fundamentals

4.1.1 Determining the CO_2 Threshold

A first step in designing a demand controlled ventilation system is to determine the maximum permissible CO_2 level in the space. This can be either an absolute value, based on measurement, or a differential between the indoor CO_2 level and the outdoor CO_2 level. If the outdoor concentration is not measured, a value of 400 ppm is typically assumed. The plot in Figure 4-1 illustrates the typical relationship between ventilation rate and indoor CO_2 concentration. The y-axis is the differential between the indoor and outdoor CO_2 levels. As expected, the indoor CO_2 level increases as the ventilation rate decreases.

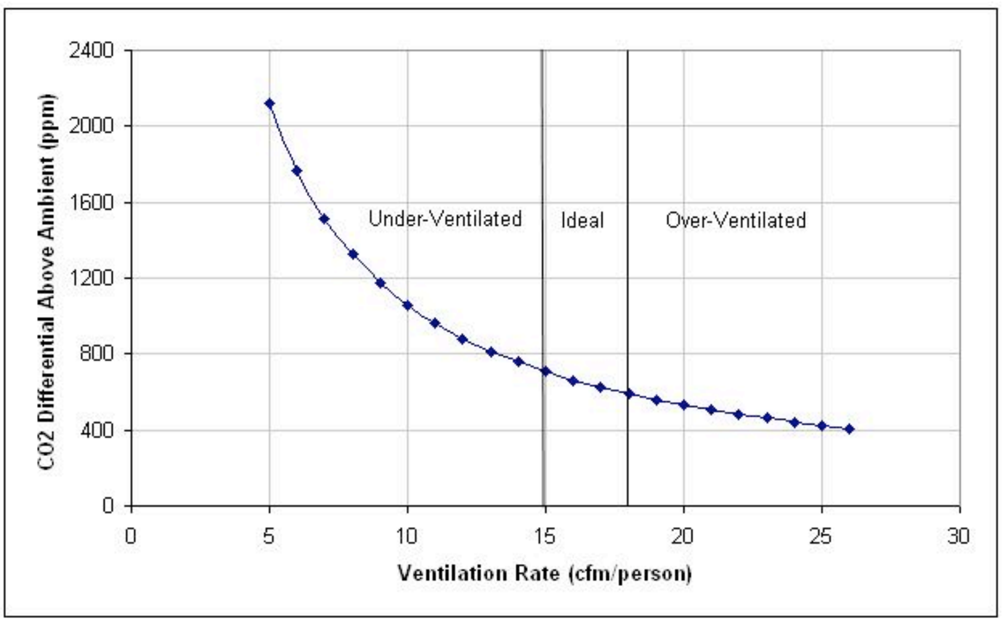

Figure 4-1: Effect of Ventilation Rate on CO_2 Level

Source: adapted from Carrier (2001)

Ventilation rate is normally controlled to maintain the indoor concentration of CO_2 at 600-700 ppm above the ambient concentration. (Title 24 2005 requires that this differential be controlled to 600 ppm.) This target corresponds to a ventilation rate of 15-18 cfm/person. If the CO_2 concentration is lower, the space is over-ventilated, and there is an energy savings opportunity that can be realized by reducing the outside air ventilation rate. If the indoor-outdoor differential is higher than 700 ppm, the space is under-ventilated, and an indoor air quality improvement can be achieved by increasing the outside air ventilation rate.

4.1.2 Sensor Location and Number

A CO_2 sensor is required for each system, and for every 5,000 ft^2 of floor space. The sensor should be installed in the space at a height between 1–6 feet above the floor. Care should be taken not to install the sensor close to open windows or doors, in abnormally high traffic areas, or where people will breathe directly on it.

4.1.3 Outside Air Minimum Setpoint

A minimum amount of outside air should be provided at all times during normal occupied hours, even when the space is unoccupied. The ventilation air helps to dilute contaminants generated by building materials. This minimum level is a function of the floor area and space type, and is normally a small fraction of the airflow at design occupancy. Title 24 sets a minimum ventilation rate limit of 0.15 cfm/ft^2 for most spaces.

4.1.4 Control Strategies

A variety of control strategies are available for DCV, including set point control, modulated proportional control and proportional-integral (PI) control. Proportional-integral control can provide the best comfort, since the control responds not only to the CO_2 level but to how quickly it is changing. Proportional control approaches work well for most spaces.

4.1.5 DCV in Variable Air Volume Systems

DCV controls for multiple-zone variable air volume (VAV) air handlers are somewhat more complicated that for single-zone air handlers. In a VAV system, the controls must monitor the CO_2 concentrations in each space and ensure that they all get adequate ventilation. A good reference for more detail about DCV in VAV systems is the *Advanced VAV System Design Guide*, available at www.newbuildings.org/downloads/FinalAttachments/A-11_LG_VAV_Guide_3.6.2.pdf.

4.2 System Persistence Risks

DCV helps to ensure that indoor air quality meets or exceeds recommended standards. Feedback from occupants is normally positive from such a system. A minor risk is the possibility of higher concentrations of volatile organic compounds (VOCs) building up when airflow is reduced during unoccupied periods. This can occur in situations where the building has significant sources of contaminants. However, in most situations VOC levels will be maintained at acceptable levels.

DCV systems, through their capability to monitor space CO_2 concentrations, have the potential to reduce risk of indoor air quality problems. These systems can provide the building operator with data that helps to identify problems of under-ventilation so they can be fixed. They can also be used to maintain a record showing that code-required levels of ventilation have been maintained.

4.3 Codes and Standards

The 2005 Title 24 Energy Efficiency Standards require demand controlled ventilation on new construction for single-zone systems with economizers serving spaces with high occupant densities (greater than 25 people per 1000 ft^2, with exceptions provided for classrooms). A CO_2 level that is no greater than 600 ppm above the ambient concentration must be maintained by the system.

There is a proposed change to the current Title 24 Standards that, if accepted, would take effect in 2008. The change would modify required ventilation levels to be consistent with ASHRAE 62.1-2004 and the Uniform Mechanical Code requirements on ventilation. The ASHRAE procedure specifies two components of ventilation requirements – occupancy-based and floor area-based – to address two components of the contamination. The proposed change would effectively reduce required ventilation rates for offices and other areas but would increase minimum ventilation requirements for schools.

5.0 Energy Savings Opportunity in PG&E's Territory

The opportunity for energy savings from demand controlled ventilation is estimated by starting with an estimate of the number of large hotels in PG&E's service territory that would be candidates for being retrofit with DCV. This measure is considered most cost effective for large ballrooms and conference spaces.

Table 5-1: Potential Market Impact

Full-service hotels in PG&E territory	250	Hotels	PG&E Estimates
Qualifying candidates	100	Hotels	Assumption
Ballroom floor space per hotel	10,000	ft^2	Assumption, compared with information from local hotels
Applicable floor space	1,000,000	ft^2	Calculation
Market penetration	10	%	Assumption
Incentive program length	2	years	
Annual savings	0.46	kWh /ft^2-yr	Calculation (from example savings estimate in this report)
Energy savings per hotel	4,578	kWh /yr	Calculation
Demand savings per hotel	32	kW	Calculation (from example savings estimate in this report)
Annual PG&E energy savings	91.6	MWh/yr	4,578 kWh x 100 hotels x 10% x 2 yrs
Annual PG&E demand savings	640	kW	32 kW x 100 hotels x 10% x 2 yrs

6.0 References

ASHRAE 62.1-2004, Ventilation Requirements for Acceptable Indoor Air quality, ASHRAE 2004.

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