# 9 Office Building Application Primer

## 9.1 Executive Summary

This primer discusses how OptiNet® can be applied to deliver reliable $CO_2$-based demand control ventilation (DCV) for a variety of common recirculating ventilation system topologies, pertaining to most office and general commercial buildings. The discussion includes a review of the ventilation requirements specified within ASHRAE Standard 62.1-2010, along with an in-depth explanation of how to meet these requirements using OptiNet's unique $CO_2$ measurement and signaling capabilities. This includes details on a broad range of applications, from coarse control approaches based only on $CO_2$ rise in the supply plenum to more efficient applications involving a combination of that and $CO_2$ levels throughout multiple zone systems.

Required OptiNet Equipment:

- Sensors: Any one of the several available $CO_2$ sensor models can be used which include: CO2-2A, CO2-2B, CO2-3, and C2D-3. The choice of sensor will be based on accuracy and speed of response requirements, unless economizer control is also desired, in which case, the C2D-3 should be specified, as it incorporates both $CO_2$ and moisture measurement performance required for economizer applications.
- Outside Air Measurement: One of the important advantages OptiNet has in DCV applications is its ability to provide a precise measurement of $CO_2$ rise at locations throughout a building. In order to accomplish this in an effective manner each SST must have a dedicated outside air sampling locations as a reference. This should be a sampling location in proximity to the air handler's outside air intake. Here, either a duct mounted or wall mounted outside air probe should be specified (DPB202 or DPB203).
- DCV signals may be conveyed to the BAS or ventilations controls either via the OptiNet BACnet option or via the EXP2 analog output options.

## 9.2 Demand-Controlled Ventilation with Recirculating Air Handler Systems

OptiNet can support a variety of $CO_2$-based demand-controlled ventilation (DCV) approaches that vary based on the complexity of the ventilation system and performance expectations. In general the objective in these applications is to optimize the amount of outside air that is introduced to the ventilation system (the ventilation rate) as building occupancy, and therefore the need for fresh air, varies; thereby reducing the added energy costs associated with conditioning outside air. If fresh air quantities are not varied with building occupancy (static rate ventilation), based on ASHRAE 62.1, the outside air minimum flow must be set based on the building design occupancy which can lead to spaces within the building being over-ventilated thus leading to higher than necessary energy costs.

## 9.3 Design Ventilation Rate

A review of how design ventilation rates are established as well as related operating assumptions is important, as these will influence DCV requirements. ASHRAE 62.1-2007 recognizes that both the materials that a building is constructed of and its furnishings, as well as its occupants present contaminants that contribute to potential IAQ problems. In Figure 6-1 of the standard, for a given zone, ventilation requirements are, therefore, based on human occupancy and floor space as described as follows:

$$V_{bz} = (R_p \cdot P_2) + (R_a \cdot A_z) \qquad \textbf{(Equation 1)}$$

Where:

$V_{bz}$ = breathing zone outdoor air flow

$R_p$ = cfm/person ventilation rate described in Table 6-1 of Standard 62.1

$P_z$ = zone population

$R_a$ = outdoor airflow rate (cfm/ft$^2$) per unit area described in Table 6-1 of Standard 62.1

$A_z$ = floor area of the zone (ft$^2$)

In order to determine what the ventilation system needs to deliver, after determining $V_{bz}$ it must be adjusted by applying the zone air distribution effectiveness in order to determine the zone outdoor air flow, which is used for design.

$$V_{oz} = V_{bz} / E_z \qquad \textbf{(Equation 2)}$$

Where:

$V_{OZ}$ = Zone Outdoor Airflow

$E_z$ = Zone Air Distribution Effectiveness (Table 6-2 from ASHRAE 62.1)

As an example, assuming an office space that is 1350 ft$^2$, with design occupancy of 20 people, the following is determined:

From ASHRAE 62.1- 2007, Table 6-1:

$R_p$ = 5 cfm/person

$R_a$ = .06 cfm/ ft$^2$

$V_{bz}$= (5 cfm/person)(20 people) + (.06 cfm / ft$^2$)(1350ft$^2$) = 181 cfm

**Note:** Alternatively, Table 6-1 (ASHRAE 62.1) provides a default value for cfm/person that may be used if the occupant density is not known at the time of the design.

Assuming the value for $E_z$ is 1, then 181 cfm is the design minimum ventilation rate for this space while occupied by 20 people.

The values in this column are conservative and usually lead to much higher design ventilation. For example, a 17 cfm/person would not have been used, which would have led to $V_{bz}$ = 340 cfm, therefore, using the default values can lead to extremely over-ventilated spaces.

## 9.4 Implications of Present Standards on $CO_2$-Based Control

As explained previously, Standard 62.1-2007 describes ventilation requirements that involve both a fresh air component to address human contaminants (bioeffluents) and a component used to dilute building pollutants. These requirements were originally introduced as Addendum N to Standard 62-2001. In the previous 1989 and 2001 versions of Standard 62, ventilation requirements were based either entirely on occupancy where, for example in an office space 20 cfm per person (Standard 62-2001, Table 2) was the ventilation requirement, or on the floor area.

When employing $CO_2$-based DCV, $CO_2$ concentrations are used as a proxy measurement of the per person ventilation rate that needs controlling. This method is described by following the mass balance equation described in Appendix C of Standard 62.1. For additional information, refer to the ASTM D6245 Standard, relating ventilation rate to steady-state $CO_2$ concentration:

$$V_O = N / (C_S - C_O) \qquad \textbf{(Equation 3)}$$

Where:

$V_O$ = outdoor airflow rate per person

$N$ = $CO_2$ generation rate per person (cfm/person)

$C_S$ = $CO_2$ concentration in the space (ppm)

$C_O$ = outdoor $CO_2$ concentration (ppm)

Generally, N is assumed to be a constant for analysis purposes, where for office environments a value of .0105 cfm $CO_2$ /person is assumed.

When the older versions of Standard 62 were applicable, in which the ventilation rate per person was a constant, it was relatively straight forward to provide $CO_2$ measurement in conjunction with Equation 3 in order to ensure the design ventilation rate is met. For example, assuming the $CO_2$ generation rate per person is .0105 cfm, if the objective is to maintain a minimum ventilation rate of 20 cfm/person the $CO_2$ differential between outdoors and indoors will resolve to 525 ppm. Therefore, with this relationship, a control function could easily be applied, using 525 ppm as a setpoint in order to control an outside air damper to ensure that an average of no less than 20 cfm/person is maintained within the building.

With Standard 62.1-2007, $CO_2$-based DCV is altered by the fact that the ventilation requirements, as is described by equation 1, include both a ventilation component for building pollutants as well as for occupancy. Therefore the required ventilation rate (total cfm/person) is not fixed as occupancy varies within a zone. As such, the maximum $CO_2$ differential ($C_S - C_O$) to control to in order to ensure minimum ventilation requirements are being met varies with occupancy. To understand this problem better, assume the previous scenario where we are designing the ventilation for an office space that is 1350ft², having a design occupancy of 20 people. Based on Equation 1, as discussed previously, the design ventilation for this space would be 181 cfm. Based on Equation 3, the indoor-outdoor $CO_2$ differential at this occupancy level is as follows:

$$C_S - C_O = \frac{(.0105 cfm / person)(20 people)}{181 CFM} = 1160 ppm$$

Using this same approach, ventilation requirements and resulting indoor-outdoor $CO_2$ differentials were calculated for this example and are shown in Table 9-1. The relationship between $CO_2$ differentials and occupancy is also plotted in Figure 9-1. Here, if one were to control indoor-outside $CO_2$ differentials to the more traditional value of 700ppm, as described in Standard 62-2001, using Equation 3, the space would receive 300 cfm of outside air when occupied by 20 people, thus being over-ventilated by 119 cfm as compared to Standard 62-2007 requirements. Conversely, if one were to apply the design value of 1160ppm as a setpoint to a PI/PID controller, the space will become under-ventilated at lower occupancy conditions. For example, using Equation 3, if the space is controlled to a $CO_2$ differential ($C_S$-$C_O$) of 1160ppm when there are only eight occupants present, the environment receives only 72ppm (60% of that required).

| Pz (people) | VBZ (cfm) | CS-CO (ppm) |
|---|---|---|
| 0 | 81 | 0 |
| 2 | 91 | 231 |
| 4 | 101 | 416 |
| 6 | 111 | 568 |
| 8 | 121 | 694 |
| 10 | 131 | 802 |
| 12 | 141 | 894 |
| 14 | 151 | 974 |
| 16 | 161 | 1043 |
| 18 | 171 | 1105 |
| 20 | 181 | 1160 |

**Table 9-1. Resulting Indoor/Outdoor $CO_2$ Differentials**

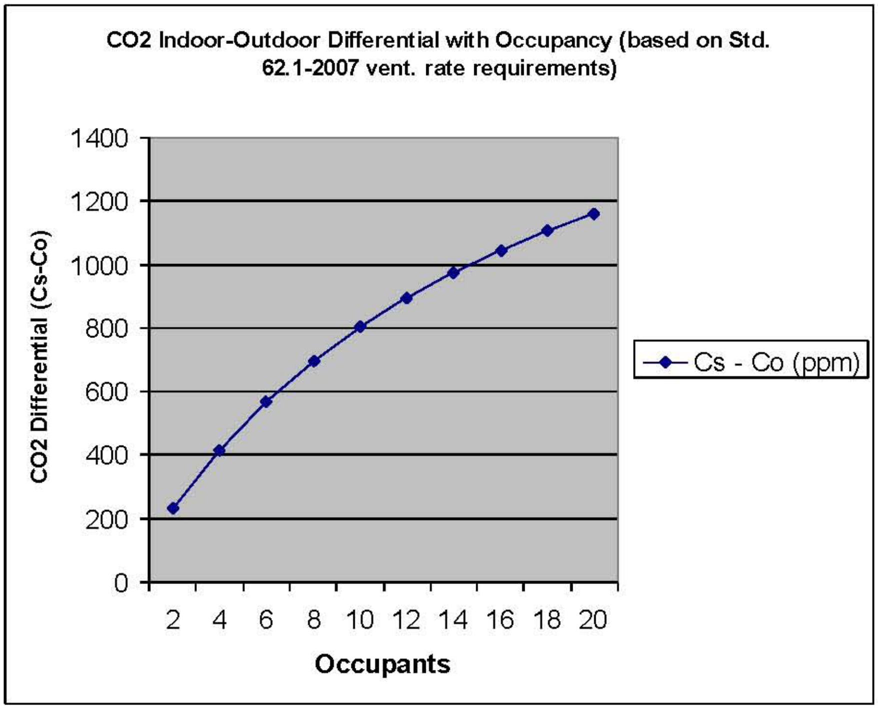

**Figure 9-1. $CO_2$ Indoor/Outdoor Differential with Occupancy**

## 9.5 Controlling Outside Air at the Zone Level - Proportional Control Approach

As shown in Table 9-1, there is a unique ventilation quantity $V_{BZ}$ prescribed for each indoor-outdoor $CO_2$ differential ($C_S$-$C_O$) as an overall function of occupancy level. Although this relationship ($V_{BZ}$ versus $C_S$-$C_O$) is nonlinear, one effective way to satisfy the present ventilation requirements of Standard 62.1 is to create a cfm control signal that is based upon the flow and corresponding $CO_2$ differentials at maximum and minimum design conditions. In the example on Table 9-1, this would involve programming a linear command signal of 81 cfm at $C_S$-$C_O$ = 0 (zero occupancy), and 181 cfm at $C_S$-$C_O$ = 1160ppm (design occupancy of 20 people). This approach is discussed with examples in the ASHRAE 62.1-2004 User's Manual. The results of this approach, plotted in Figure 9-2, show the ventilation requirements that are stipulated by the current standard. Here, the linear approximation line represents the ventilation command that would result at each value of $C_S$-$C_O$ listed in Table 9-1.

This clearly shows that ventilation requirements will be fulfilled using this simple approach, however, it results in some level of over-ventilation at partial occupancy conditions. For example, at $C_S$-$C_O$ = 802ppm (corresponding to an occupancy level of ten people), the space will be over-ventilated by 19 cfm or 14.5%. A more precise outcome is possible if one were to tabulate the flow command for each value of $C_S$-$C_O$ within a lookup table. However, going to such extents would typically not be justified, given the only incremental benefits at the cost of design complexity. Notwithstanding, in recirculating systems at the zone level, providing a flow command that is reflective of even the linear approximation shown in Figure 9-2 may seem complicated because the flow command applied to a supply air VAV box directly affects the primary flow delivered by the flow control device and only proportionally affects the outside air flow (the variable that is being attempted to control) based on the outside air fraction that is in the supply plenum. Further, in VAV systems, the outside air fraction is typically a variable.

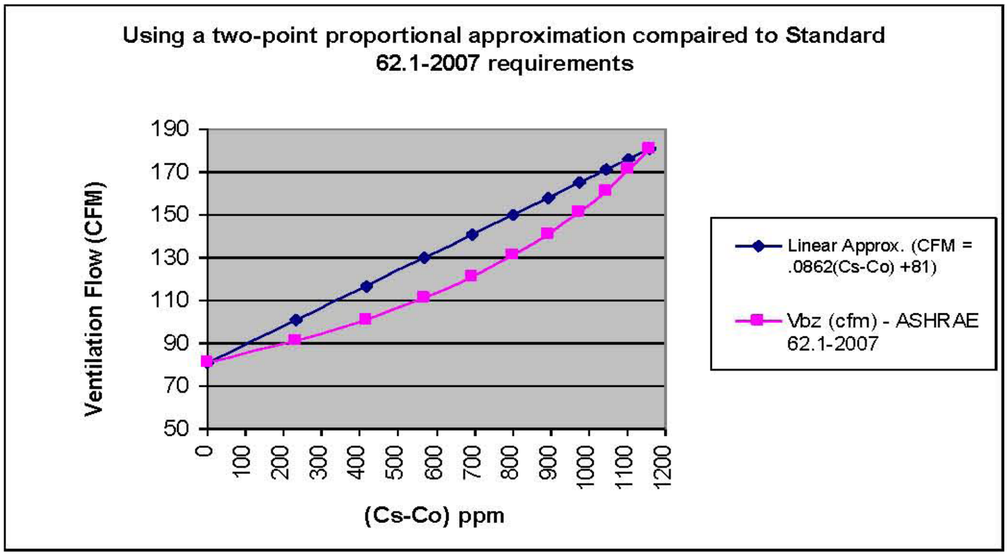

**Figure 9-2. Two-Point Proportional Approximation Comparison**

In applications using OptiNet, however, there is a very simple approach to ensuring proper ventilation is achieved at the zone level, regardless of varying outside air conditions. As long as the differential $CO_2$ measurements ($C_S$-$C_O$) are accurate, good ventilation control can be achieved, bounded by the limitations of the airflow controls. To accomplish this, the airflow control system must be capable of receiving a signal from OptiNet (either via a hard-wired 0–10 Vdc voltage or 4–20mA current signal, or through BACnet) which can provide a flow command that is proportional to the differential $CO_2$ measurement ($C_S$-$C_O$) for the monitored space. Owing to OptiNet's shared-sensor multiplexed sensing platform, it provides differential sensing with unheard of accuracy, making it an ideal choice for this type of applications. To better understand how this works, Figure 9-3 illustrates how the 1350ft$^2$ office space example is affected at various occupancy levels, including occupancies of 6, 12, and 18 people. Each of the resulting curves shows the relationship between outside air ventilation rates and the steady-state $CO_2$ differential ($C_S$-$C_O$) that results, for a given occupancy level. These curves are calculated simply by way of the mass balance equation (Equation 3). For example, this shows that under an occupancy condition of six people, with 150 cfm of outside air supplied to the space, the steady-state $CO_2$ rise in the space will be roughly 400ppm. These curves can be thought of as "load lines" against which the ventilation rate will resolve for a given occupancy level. The point at which each occupancy curve intersects with either the linear approximation or the exact value of Vb specified by ASHRAE 62.1-2007 (whichever is used) would be the ventilation operating point for each occupancy condition. For example, with six people in this zone, assuming the ASHRAE 62.1-2007 curve, the system would resolve to 111 cfm of outside air at $C_S$-$C_O$= 568ppm. In addition, as the space occupancy increases, the ventilation rates are resolved at higher flow intercepts. This concept is instructive when considering how the ventilation system performs using this approach as it helps to demonstrate how the outside air flow accuracy resolves itself as long as the $CO_2$ measurements are accurate.

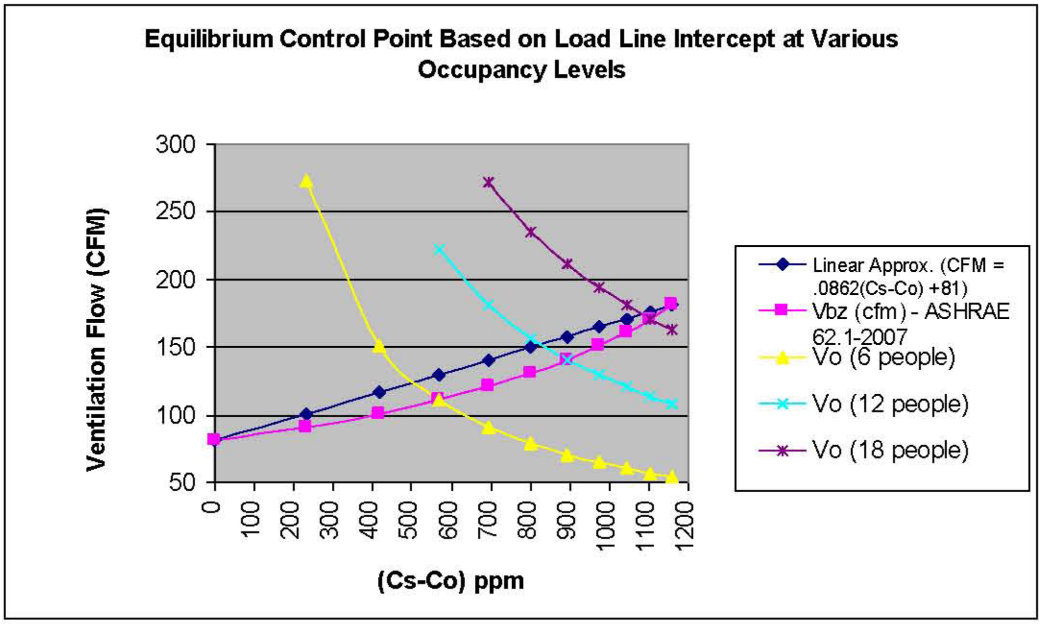

**Figure 9-3. Equilibrium Control Point**

## 9.6 DCV Applications for Standard Return Air Systems

There are a number of basic variants to $CO_2$-based DCV for standard return air systems. Some of the most common include:

- Single-zone ventilation command derived from zone $CO_2$ referenced to outside air.
- Single-zone traditional (fixed cfm/person) DCV based on $CO_2$ setpoint.
- Multiple-zone constant volume supply DCV.
- Multiple-zone DCV based on supply air and outside air $CO_2$
- Multiple-zone ventilation command based on critical zone $CO_2$ with zone ventilation reset.
- Ventilation Control in Dedicated Outside Air Systems (DOAS).

## 9.7 Application No. 1 - Single-Zone Ventilation Command Derived from Zone CO2 Referenced to Outside Air

This application provides a means to, with a single-zone ventilation system, meet the ventilation requirements outlined within the current ASHRAE 62.1 standard. Figure 9-4 is a simplified schematic of a single zone topology, which is representative of a system using a package rooftop unit. These systems generally incorporate a common linkage that ties the return air, outside air, and building exhaust dampers together, allowing them to be driven by one actuator assembly. The complexity of single zone systems varies in terms of outside air control options which, aside from economizer controls, will include position-based damper actuator assemblies and in some cases, for bigger systems, include OA flow measurement. Of these, by far, the most common approach involves a position-based damper assembly in which, for a given static pressure OA flow rate is roughly correlated to damper position. These systems generally provide constant volume supply operation to the single zone that they serve.

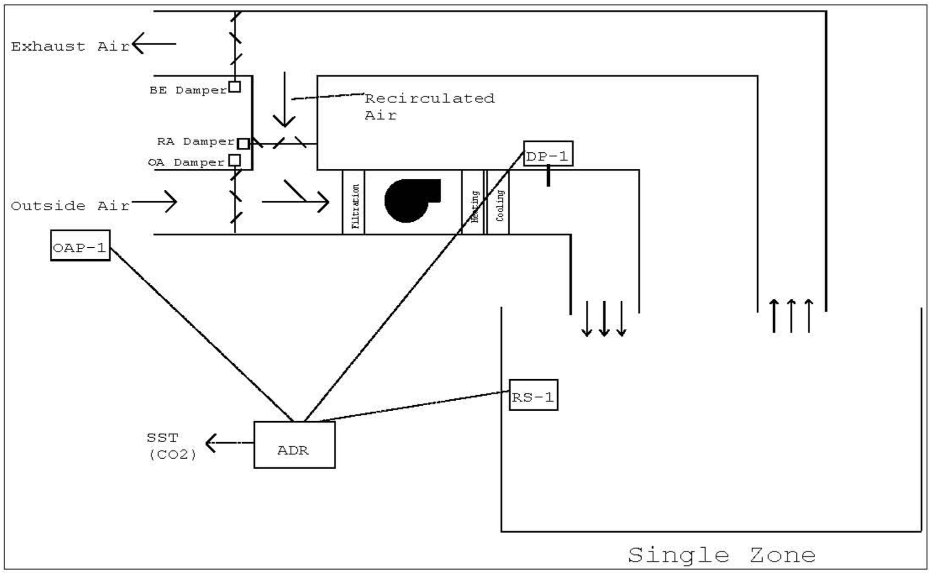

**Figure 9-4. Single Zone Topology Schematic**

Assuming that in most cases, true OA flow measurement is not provided, the ventilation command will be configured (using a two point proportional approximation) so that it is proportional to the minimum and maximum positions of the OA damper, based on the design range of $C_S$-$C_O$. At a minimum, for the DCV function to be carried out, a secondary controller must be provided (which is often provided with the RTU) that will receive the proportional signal from OptiNet and perform the damper position control operation.

In this application, a cfm ventilation command is created using sampled $CO_2$ values from Room Sensor RS-1 that are referenced to outside air values taken from outside air probe OAP-1. See Figure 9-3.

### *Example 1*

- Assume that the system in Figure 9-4 is designed to support an office space with 5000ft$^2$ of floor area and a design occupancy of 40 people. This single zone is served by a rooftop unit that includes a controller capable of receiving a 0-10V signal to proportionally position the OA damper from a minimum to a fully open position. The ventilation requirements for this system are determined from Equation 1 as follows:

  $R_p$ = 5 cfm/person

  $R_a$ = .06 cfm/ft$^2$

Both of the above are taken from Table 6-1 ASHRAE 62.1-2007.

At maximum occupancy,

$V_{bz}$ = (5 cfm/person)*(40 people) + (.06 cfm/ft$^2$)*(5000ft$^2$) = 500 cfm

When unoccupied,

$V_{bz}$ = (.06 cfm/ft$^2$)*(5000ft$^2$) = 300 cfm

Assume that the zone air distribution effectiveness is 1 ($E_z$ = 1). Therefore $V_{OZ} = V_{bz}$. From Equation 3 at maximum occupancy and steady-state:

$$C_S - C_O = \frac{(.0105CFM / person)(40 people)}{500CFM} = 840 ppm$$

Again, assuming the rooftop unit is capable of receiving a 0-10V signal to control its OA damper, in this scenario OptiNet will be configured to provide a 10V signal when the difference between the CO2 level measured in the zone (via RS-1) and that of the outside air (OAP-1) is 840ppm. It will usually be a field commissioning matter (typically by a balancer) to adjust the damper setting to ensure 500 cfm of OA flow is delivered at full command (10V). Likewise, at a 0V command the system will be configured to deliver the unoccupied flow of 300 cfm ($C_S$-$C_O$ = 0 ppm).

## 9.7.1 Summary Sequence for Single Zone AHU/RTU

- Obtain the minimum ($V_{bzmin}$) and maximum ($V_{bzmax}$) ventilation required for the zone, based on Equation 6-1 of ASHRAE std. 62.1-2007/2010.
- Using Equation 3 (mass balance equation), calculate the ppm rise $(C_s\text{-}C_o)_{max}$ in zone $CO_2$ levels at maximum occupancy and at Vbzmax
- OptiNet can be configured to provide a minimum and maximum ventilation command to the outside air damper controls at minimum and maximum zone $CO_2$ levels, respectively.
- Adjust the outside air damper so that it delivers $V_{bzmin}$ at zero $CO_2$ levels and $V_{bzmax}$ at maximum $CO_2$ levels $(C_s\text{-}C_o)_{max}$

## 9.8 Application No. 2 - Single-zone Traditional (fixed cfm/person) DCV Based on $CO_2$ Setpoint

There may be cases where a customer insists on providing $CO_2$-based DCV assuming a fixed cfm per person approach. This is the older approach that's described in ASHRAE 62.1-1989 to -2001 in which typically, a PI controller is used to adjust ventilation rate as the zone $CO_2$ concentration (referenced to outside air) exceeds a value that correlates to the minimum cfm/person ventilation rate that is stipulated by the aforementioned older standards. For example, Table 2 of 62.1-2001 stipulates an outdoor air requirement of 20 cfm/person in office buildings. Based on Equation 3, this correlates to a $CO_2$ differential ($C_S$-$C_O$) of 525 ppm. (However, Section 6.1.3 of the standard does state that *"comfort (odor) criteria with respect to bioeffluents are likely to be satisfied if the ventilation results in indoor $CO_2$ concentrations less than 700ppm above outdoor air concentration.")*

Even though this method of control is based solely on occupancy, the PI control function can result in added cost (cost of the controller), not including the hidden costs, owing to the complexities of tuning a PI/PID controller in the field. Nevertheless, OptiNet provides highly reliable and accurate differential CO2 measurements ($C_S$-$C_O$) for this application in which, similar to Application #1, the CO2 measurements are made at the zone level (RS-1) with respect to outside values (OAP-1).

### *Example 2*

Assuming the same setup shown in Figure 9-5 and occupancy loading as in Example 1, if constant ventilation rate DCV is applied in order to meet the requirements of ASHRAE 62.1-1989 to -2001, we have the following:

Ventilation Rate = 20 cfm/person (Table 2 of 62.1-2001)

CO2 setpoint ($C_S$-$C_O$) = 550ppm (Equation 3).

Figure 9-5 is a plot of ventilation rate with occupancy for this example and, for comparison purposes, includes a plot of the minimum ventilation rate required at various occupancy levels, assuming the requirements of ASHRAE 62.1-2004 to -2007. As can be seen from this graph the constant cfm/person approach will result in significant over-ventilation at design occupancy when compared to 62.1-2004, and insufficient ventilation at lower occupancy level.

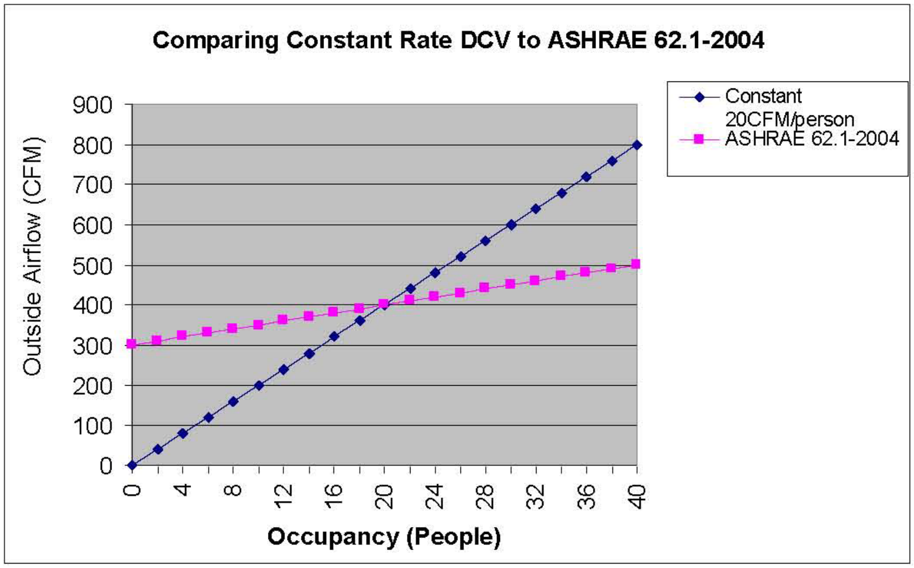

**Figure 9-5. Comparing Constant Rate DCV to ASHRAE 62.1-2004**

## 9.9 Multi-Zone Systems and System Ventilation Efficiency

One important concept to understand regarding recirculating systems is that because of the unvitiated component that is returned from the over-ventilated zones, the effective outside air fraction that's delivered to each zone is greater than the actual outside air fraction due to outside air entering the air handler. To account for this, ASHRAE Standard 62.1-2004 to 2010 discuss the terms **zone ventilation efficiency** and **system ventilation efficiency.** [Previous standards 62.1-1989-2001 addressed this in an almost identical way using the multiple space equation (Equation 6-1 of these standards).] Equation A-1 of the standard defines the zone ventilation efficiency as follows:

$$E_{VZ} = 1 + X_S - Z_d \qquad \textbf{(Equation 4)}$$

Where,

$E_{VZ}$ = zone ventilation efficiency.

$X_S$ = uncorrected outdoor air fraction.

This represents the total demand (expressed as a fraction) for outside air for all zones.

$Z_d$ = required discharge air fraction required at the critical zone.

This is also known as the critical zone ventilation fraction. For example, if the critical zone requires 300 cfm of outside air and the total supply flow (also called primary supply flow) is 600 cfm, then the required discharge air fraction will be .5.

ASHRAE further defines the system ventilations efficiency EV as the smallest of the zone ventilation efficiencies throughout the system. This will be the critical zone.

The concept of system ventilation efficiency allows us to estimate the effective outside air fraction as a function of actual outside air and unvitiated air that is recirculated. System ventilation efficiency can be used to directly calculate the outside air percentage that must be mixed at the air handler. As an example, assume a system with 8000 cfm of primary airflow that has zones which demand 2000 cfm of outside air and a critical zone with a primary airflow of 1200 cfm that requires 600 cfm of outside air. The required outside air fraction of that zone is therefore .5. From Equation 7, the system ventilation efficiency is:

$$E_V = 1 + \frac{2000CFM}{8000CFM} - .5 = .75$$

From this, the outside air fraction required at the airhandler to satisfy the demands of these zones is:

$$\frac{X_S}{E_V} = \frac{(2000CFM / 8000CFM)}{.75} = .3333$$

Which means with this example, 2666 cfm (8000 cfm *.3333) of outside air is required to address the 2000 cfm of ventilation demand at the zone level.

## 9.10 Application No. 3 - Multiple-zone Constant Volume Supply DCV

In many cases, a simple rooftop unit is used to provide a constant source of conditioned supply air not only to one zone such as in Figure 9-4 but to several zones. Depending on the occupancy patterns and flow settings, it is often the case that the ventilation in a number of these zones is ample at all times in comparison to that realized at times in other space(s) (the critical zones) that may be either subject to large occupancy fluctuations or contain the largest number of occupants. If there is for example, only one critical zone, $CO_2$ may be chosen to monitor in that space and control the outside air for the entire system from there. One of the problems with this approach, and with controlling ventilation for multiple-zone systems in general is that it can cause less occupied zones to be over-ventilated, thus leading to poor ventilation efficiency. In some cases, where the system's first cost needs to be minimized thus preventing sensing in multiple zones, then supply air $CO_2$-based DCV may be a more suitable option. See Application No. 5. However, in other cases, particularly those in which occupancy in one or more zones can change significantly such as in Conference Rooms or reception areas, the best choice is to at least monitor and control off of those critical zones.

## 9.10.1 Practical Considerations when Controlling Outside Air in Multi-Zone Constant Volume Supply Systems

One way to automatically control a common outside air damper from multiple critical zones is to establish a differential $CO_2$ reading ($C_Z$-$C_O$) for each critical zone and to apply a high-select calculation function provided by OptiNet to control the common outside air damper based on the zone that has the highest $CO_2$ levels, in order to limit maximum levels to a predetermined value. In order to also address the ventilation requirements for building pollutants according to ASHRAE 62.1 – 2007/2010, it is important that the outside air minimum setting at the air handler (typically a physical limit) be adjusted to ensure adequate outside air fraction within the supply plenum under unoccupied conditions. As was illustrated in the graph of Figure 9-5, using a fixed $CO_2$ setpoint approach to control outside air, can often lead to overventilation at higher occupancy levels. The COAF and Return Air $CO_2$ rise control approaches listed below address this while providing good ventilation efficiency.

In multi-zone constant volume (CV) supply systems, the primary flow delivered to each zone is fixed. Therefore, if the outside air fraction required by a critical zone exceeds the outside air fraction established in the supply air, the critical zone ventilation requirement can only be satisfied if the outside air at the air handler is increased by an appropriate amount. As mentioned above, one way to accomplish this is by way of an automatic control function which utilizes the highest of the zone $CO_2$ levels as the control loop feedback term.

**FAQ:** What is the Critical Zone?

The critical zone is one that requires the highest outside air fraction. Most multi-zone ventilation strategies whether they are based on design or control techniques focus around the critical zones which ultimately determine the outside air settings at the air handler. As a general rule, spaces which are comparatively small should not be allowed to drive outside air levels in multi-zone systems. This could result in very inefficient and costly ventilation performance.

## 9.10.2 Determination of Control Setpoint and Strategy (Fixed Setpoint Approach)

Occupancy levels and the zone with the largest outside air fraction requirement (the critical zone) ultimately determine the "setpoint" for controlling the outside air damper. One could choose to control the outside air damper (using traditional proportional or PI techniques) against a predetermined $CO_2$ setpoint, using the highest level of zone $CO_2$ values from the critical zones as the control loop feedback. For example, after analyzing the ventilation requirements of the critical zones, one could determine a maximum $CO_2$ differential ($C_z - C_o$) to ensure that these zones are never under-ventilated. Such an approach tends to drive the outside air damper to its lowest position until individual critical zones exceed the setpoint value. Once the setpoint has been exceeded (as $CO_2$ levels build in the critical zone), the P-PI loop come out of saturation and the outside air damper is opened until the critical zone $CO_2$ levels are satisfied. Note that, because we are directly sensing the $CO_2$ rise within the critical zones, this approach accounts for the unused air that is recirculated at the air handler. However, since the objective is to control to a fixed setpoint, this method generally leads to overventilation at higher occupancy conditions.

### 9.10.2.1 Summary Sequence for Multiple Zone CV Supply DCV (Fixed Setpoint Approach)

- For each critical zone, obtain the minimum ($V_{bzmin}$) and maximum ($V_{bzmax}$) ventilation required for the zone, based on Equation 6-1 of ASHRAE std. 62.1-2007/2010.
- For each zone, using Equation 3 (mass balance equation), calculate the ppm rise ($C_s$-$C_o$) max in zone $CO_2$ levels at maximum occupancy and at Vbzmax. Observe the zone which yields the minimum ppm $CO_2$ rise at full occupancy. This will become the $CO_2$ setpoint for the outside air damper controls.
- OptiNet can be configured to measure the ppm rise in $CO_2$ in each of the zones ($C_z - C_o$) and high-select these values in order to provide a single feedback term to the BAS or directly to the outside air damper control loop.

## 9.10.3 Corrected Outside Air Fraction (COAF) Estimation Approach

Depending on the size of the ventilation system and the occupancy patterns within the critical zones, the previous method of controlling outside air fraction in the supply plenum against a predetermined $CO_2$ setpoint can have performance issues that may lead to temporary underventilation. This might occur as the critical zone(s) becomes occupied, and is primarily due to the controller integral- term windup during times when $CO_2$ levels are below the setpoint value. There are anti-windup techniques that can be employed to temper this, however, an alternative is to apply a technique that estimates the outside air requirement and directly positions the outside air damper to achieve those flow levels or, likewise, the desired estimated outside air fraction. With constant volume supply systems, there is a fixed correlation between the outside air damper's position and the outside air fraction in the supply. Therefore, if the desired outside air fraction is known the outside air damper can be commanded to the position which correlates to that value. This is a straightforward matter using commercially available electric damper actuators that provide position feedback.

### 9.10.3.1 Estimating Critical Zone Outside Air Fraction

In order to satisfy the outside air requirements of the critical zone, the outside air fraction of the supply air being delivered to that zone needs to meet or exceed the outside air fraction demand (critical zone ventilation fraction $Z_d$) for that space.

$$Z_d = \frac{Zone\ \ Ventilation\ \ Demand\ \ V_{oz}}{Zone\ \ Primary\ \ Flow\ V_{pz}} \qquad \textbf{(Equation 5)}$$

The zone primary flow is a constant, because this is a constant volume system, leaving Voz as the only variable.

Here, $V_{OZ}$ can be determined by combining Equation 6-1 of ASHRAE Standard 62.1 – 2007/2010 with the $CO_2$ mass balance equation to get the following expression that calculates outside air (ventilation) demand with zone $CO_2$ rise:

$$V_{OZ} = \frac{R_a * A_z}{E_Z * \left(1 - R_p\left(\frac{C_z - C_O}{.0105 * 10^6}\right)\right)} \qquad \textbf{(Equation 6)}$$

Where,

$R_a$ = .06 cfm/ft$^2$ = airflow rate per square foot described in Table 6-1 of Standard 62.1.

$R_P$ = cfm/person ventilation rate described in Table 6-1 of ASHRAE 62.1

= 5 cfm/person is typical

$A_Z$ = zone square footage

$E_Z$ = 1 = zone air distribution effectiveness (Table 6-2 of ASHRAE 62.1)

$C_Z$ = $CO_2$ concentration of the zone from OptiNet system

$C_O$ = $CO_2$ concentration of the outside air from OptiNet system

Using Equation 5 and Equation 6, the BAS can estimate the outside air fraction demand per critical zone.

### 9.10.3.2 Estimating the Corrected System Outside Air Fraction

Because this is a recirculating system setting, the outside air damper to deliver an outside air flow fraction (uncorrected outside air fraction) equal to what is demanded by the most critical zone usually results in the overventilation of the building because of the unused portion of outside air that is constantly being recirculated at the air handler. To account for this, the system ventilation efficiency equation can be applied (Equation 4 from ASHRAE Standard 62.1). This is accomplished with the following equation (base on the multiple space equation from ASHRAE Standard 62.1) to establish the corrected outside air fraction for the system:

$$\text{Corrected Outside Air Fraction} = \frac{X_{Se}}{1+X_{Se}-Z_d} \qquad \textbf{(Equation 7)}$$

Where,

$Z_d$ = critical zone ventilation fraction (Equation 5)

$X_{se}$ = estimated uncorrected system outside air fraction

The uncorrected outside air fraction $X_{se}$, above can be calculated directly by using OptiNet to measure the CO2 rise in the system return air and performing a calculation identical to Equation 6, while using an estimate of the square footage served by the air handler. For example, if $X_{se}$ = .3, but $Z_d$ = .6, from Equation 7, the required outside air fraction while accounting for the unused portion of the recirculated air is .43. That is a significant difference and, in larger systems, accounting for this can translate to significant energy savings.

### 9.10.3.3 Summary Sequence for Multiple Zone CV Supply DCV (COAF Approach)

Following is the COAF approach to the summary sequence for multiple zone CV supply DCV.

- For each critical zone, program the BAS to calculate the zone outside air fraction as a function of $CO_2$ differential measured via OptiNet, using Equations 6 and 5.
- Using OptiNet to measure the return air $CO_2$ levels, estimate the system outside air fraction, using the knowledge of the square footage served by the Air Handler, its total primary flow, and Equations 5 and 6.
- Calculate the corrected outside air fraction using Equation 7, and use this to directly command the outside air damper position.

*Example 3*

Assume the critical zone within a multi-zone recirculating system has the following properties:

$R_a$ = .06 cfm/ft$^2$ = airflow rate per square foot described in Table 6-1 of Standard 62.1

$R_p$ = cfm/person ventilation rate described in Table 6-1 of ASHRAE 62.1

= 5 cfm/person

$A_Z$ = zone square footage = 5000 ft$^2$

$A_{Ztot}$ = total of all zone square footage = 20000 ft$^2$

$E_Z$ = 1 = zone air distribution effectiveness (Table 6-2 from Standard ASHRAE 62.1)

$C_Z$ = $CO_2$ concentration of the zone from OptiNet system =1500ppm

$C_O$ = $CO_2$ concentration of the outside air from OptiNet system = 380ppm

$C_{RA}$= $CO_2$ concentration in the return air plenum = 550ppm

$V_{pz}$ = Zone primary flow = 1600 cfm

$V_{Ptot}$= total system primary flow = 5400 cfm

Using Equation 6, the BAS can dynamically calculate the critical zone ventilation demand as follows:

$$V_{OZ} = \frac{R_a * A_z}{E_Z * \left(1 - R_p\left(\frac{C_z - C_O}{.0105 * 10^6}\right)\right)} = \frac{(.06CFM/ft^2)*(5000\,ft^2)}{\left(1 - 5CFM/person\left(\frac{1500\,ppm - 380\,ppm}{.0105 * 10^6}\right)\right)} = 642CFM$$

Next, using Equation 5, the critical zone outside air fraction can be calculated as follows:

$$Z_d = \frac{V_{OZ}}{V_{PZ}} = \frac{642CFM}{1600CFM} = .4$$

Next, the ventilation demand for the system can be estimated using Equation 6 as follows:

$$V_{OZtot} = \frac{R_a * A_{ztot}}{E_Z * \left(1 - R_p\left(\frac{C_{RA} - C_O}{.0105 * 10^6}\right)\right)} = \frac{(.06CFM/ft^2)*(20000\,ft^2)}{\left(1 - 5CFM/person\left(\frac{550\,ppm - 380\,ppm}{.0105 * 10^6}\right)\right)} = 1305CFM$$

The uncorrected outside air fraction for the system (XS) is then calculated as follows:

$$X_{Se} = \frac{V_{OZtot}}{V_{Ptot}} = \frac{1305CFM}{5400CFM} = .24$$

Finally, using Equation 7, the corrected outside air fraction is calculated as follows:

$$Corrected\ Outside\ Air\ Fraction = \frac{X_{Se}}{1 + X_{Se} - Z_d} = \frac{.24}{1 + .24 - .4} = .29$$

This is the estimated value of outside air fraction where the outside air damper would be commanded (Figure 9-6).

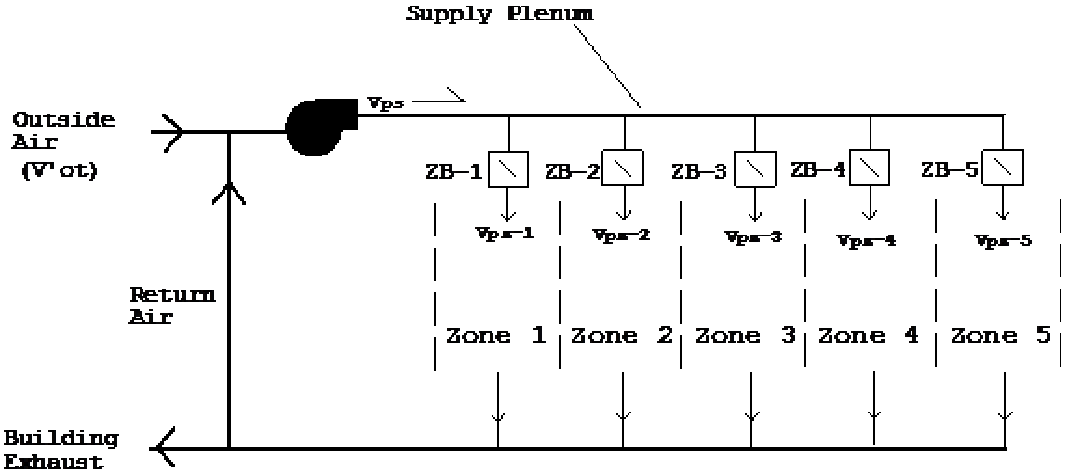

**Figure 9-6. Estimated Value of Outside Air Fraction**

## 9.10.4 Return Air $CO_2$ Control with Reset (RACCR Approach)

Normally, controlling the outside air intake based solely on return air $CO_2$ rise is not advised, because it can lead to underventilation within individual zones. However, the following is a technique that ensures that nominal levels of outside air are provided at the system level while also ensuring that the critical zone ventilation requirements are satisfied. This is a fairly simple approach to implement through OptiNet which can result in good ventilation efficiency and speed of response to changing occupancy conditions. This approach involves:

- Monitoring the return air $CO_2$ rise (CR – CO).
- Controlling the outside air damper based on a proportional signal derived from a two point approximation of ventilation demand as a function of $CO_2$ levels.
- Monitoring the $CO_2$ rise (CZ – CO) in each of the zones, or at least the critical zones.
- Providing a reset term via OptiNet to the outside air damper control to prevent critical zones from becoming under-ventilated.

### 9.10.4.1 When to Use the RACCR Approach

The RACCR approach is most appropriate for use when the outside air damper controls can receive a proportional command, either a cfm flow command or an outside air percentage command. In constant volume systems, this is not a problem, given the fixed relationship between damper position and flow. In variable volume systems, however, this relationship is not the same, because outside intake flow varies as the AHU’s total flow changes. Typically, in VAV systems, outside air flow measurement capabilities is only found in larger air handling systems. Even when this is the case, the performance of these systems can be problematic, due to the very low airflow velocities that are common at outdoor air intakes. The effectiveness of RACCR, therefore, can be hampered by these non ideal aspects.

Figure 9-7 schematically illustrates the control approach. Here, the outside air damper controls receive a primary command signal that is derived from the $CO_2$ rise within the return air plenum. This signal is based upon a two point approximation of the ventilation requirements for the building, identical to the technique described for single zone systems. This approximation is calculated by the BAS based on the $CO_2$ rise measurement performed by OptiNet, which can be communicated either via BACnet or through a hard-wired analog signal.

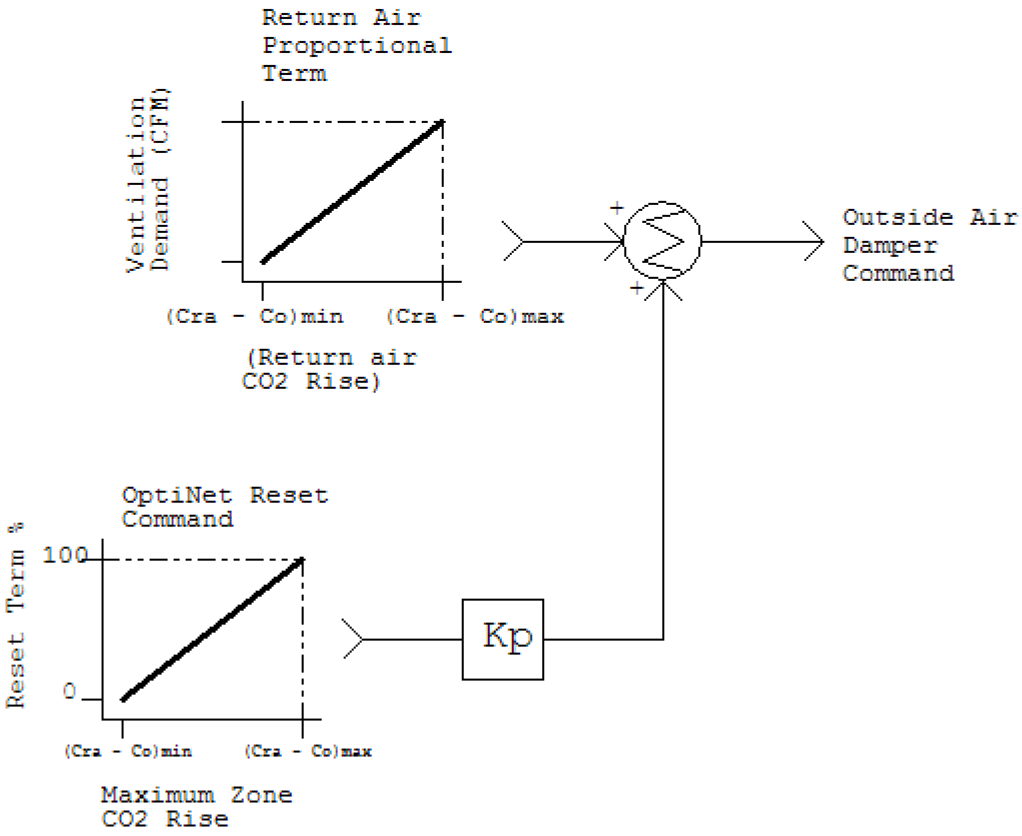

**Figure 9-7. Illustration of the Control Approach**

## 9.10.4.2 Return Air Proportional Term

The return air proportional command signal is based upon an approximation of the ventilation requirements for the portion of the building served by that air handler, and the expected $CO_2$ rise within the return air plenum, based on the minimum and maximum occupancy conditions. The ventilation requirements are established using Equation 6-1 of ASHRAE std. 62.1 for minimum and maximum occupancy conditions, and then the mass balance equation (Equation 3) is used to estimate the $CO_2$ rise under conditions of maximum occupancy. This allows us to construct a two point linear approximation of ventilation demand as a function of return air $CO_2$ rise.

As an example, assume that an air handler serves a 15,000 $ft^2$ area of commercial office space which is designed for a maximum occupancy of 400 occupants. Determine the minimum and maximum ventilation requirements and the maximum $CO_2$ rise in the return air plenum:

From Equation 6-1:

$$V_{OZRA} = (R_p * N) + (R_a * A_Z)$$

Where,

$V_{OZRA}$ = ventilation requirements according to equation 6-1 of ASHRAE std. 62.1

$R_a$ = .06 cfm/$ft^2$ = airflow rate per square foot described in Table 6-1 of Standard 62.1

$R_p$ = cfm/person ventilation rate described in Table 6-1 of ASHRAE 62.1

= 5 cfm/person is typical

$A_Z$ = zone square footage

**Ventilation Minimum:**

$V_{OZRA\text{-}min} = R_a * A_Z = (.06\ cfm/ft^2)*(15{,}000 ft^2) = 900\ cfm$

**Ventilation Maximum:**

$$V_{OZRA-max} = (R_p * N) + (R_a * A_Z) = (5\,CFM/person * 400) + \ 900\,CFM$$
$$= 2900\,CFM$$

**Maximum Return Air CO2 Rise:**

Using the mass balance equation, the maximum $CO_2$ rise is as follows:

$$(C_{RA} - C_O) = \frac{(.0105 * 400people)}{2900CFM} * 1{,}000{,}000 = 1448ppm$$

As a result of the above analysis, the proportional ventilation command derived from return air $CO_2$ measurements would have a linear output that varies between 900 cfm and 2900 cfm as the ppm rise in return plenum $CO_2$ levels vary between zero and 1448 ppm.

### 9.10.4.3 OptiNet Reset Command

The reset command term shown in Figure 9-7 is established via OptiNet as a function of the highest of the differential $CO_2$ values ($C_Z - C_O$) for all of the monitored zones. OptiNet can provide the necessary high-select function so that the signal or BACnet point provided to the BAS is reduced to only one term. This term is additionally scaled by OptiNet taking the highest of the zone $CO_2$ measurements ($C_Z - C_O$) and subtracting the zone $CO_2$ rise at which reset is required to the outside air command. This value is also clamped to not go below zero. Therefore, if the objective is to limit any zone's $CO_2$ differential so that it does not exceed 1200ppm for example, then no reset will be provided for zone levels below 1200ppm.

In addition, the gain term $K_p$ should be provided by the BAS in order to be able to fine tune the reset function during commissioning. Generally, the value used for $K_p$ should be determined by looking at the zone with the highest cfm per ppm $CO_2$ characteristic. This is a function of the size (directly proportional to) of the critical zone, and relates to the cfm per ppm rise in the most critical zone. Typically, a value of .2 cfm per ppm should be sufficient for a critical zone that's $5000ft^2$ in size. A zone that is twice that size may require .4 cfm per ppm as a value for $K_p$.

## 9.11 Application No. 4 - Multiple-zone DCV Based on Supply Air and Outside Air $CO_2$

Supply air DCV is a basic ventilation control scheme whereby supply air $CO_2$ concentrations from the air handler are monitored with respect to outside air concentrations, and the outside air damper is controlled in order to ensure that the outside air fraction in the supply is sufficient to meet the needs of the critical zone. This is accomplished by limiting (typically via proportional- or proportional-integral control) the ppm rise of $CO_2$ in the supply plenum to a value (the control setpoint) that corresponds to that minimum required outside air fraction.

### 9.11.1 Determining the Supply Air $CO_2$ Rise Control Setting

There are a number of ways to establish the supply air $CO_2$ rise setting to control the outside air damper. These methods involve different levels of detail to their approximations, offering trade-offs between complexity and performance. Since the setpoint assumes the full occupancy of the critical zone, over-ventilation can result when the actual occupancy is lower than the full design value.

### *Method No.1*
### *Supply Air CO2 Rise Assuming Critical Zone Design Conditions*

Method No. 1 is the simplest method and calculates the supply air $CO_2$ ppm rise by assuming a hypothetical condition of full occupancy in which the entire multi-zone system is perfectly ventilated when the outside air fraction requirements of the critical zone are met. In short, this assumes that the return air ppm $CO_2$ rise will exactly mimic the ppm rise in the critical zone. The supply air $CO_2$ setpoint is then calculated as follows:

$$[1 - Z_d] * \left[\frac{(\#\ of\ people\ *0.0105)}{V_{bz}}\right] * 1{,}000{,}000 = supply\ air\ ppm\ Rise \qquad \textbf{(Equation 8)}$$

Where,

\# of people – Pertains to the maximum design occupancy of the critical zone.

$V_{bz}$ – Pertains to the ventilation requirements in the critical zone at full occupancy. This is calculated using Equation 6-1 of ASHRAE Standard 62.1. It is also often approximated based on a fixed cfm/person value. For example, if the objective is to deliver 15 cfm/person and the design occupancy is ten people, this number becomes 150 cfm.

Zd – The design outside air fraction of the critical zone at full occupancy, assuming the minimum design primary flow setting for that space. For example, if the design primary flow minimum value for the critical zone is 600 cfm and the required outside air flow to that space at full occupancy (calculated using ASHRAE Standard Equation 6-1) is 318 cfm, then Zd is .53.

### *Example*

Assume a critical zone with the following characteristics:

- Ventilation requirement at maximum occupancy = 318 cfm (Vbz)
- Minimum primary flow = 600 cfm
- Maximum occupancy = 17 people

First, calculate Zd:

$$Z_d = \frac{318CFM}{600CFM} = .53$$

Calculate the supply air $CO_2$ setpoint ($C_S$-$C_O$):

$$\begin{aligned} Supply\ CO2\ setpoint &= [1 - .53] * \left[\frac{17\ people * .0105}{318CFM}\right] * 1{,}000{,}000 \\ &= 264\ ppm \end{aligned}$$

*Method No. 2*
*Using the BMS to dynamically calculate the Supply Air $CO_2$ Rise (setpoint) based on actual critical zone flows.*

Method No. 2 can provide better efficiency than the Method 1 approach, but it does require more analysis to arrive at the desired supply $CO_2$ setpoint, which must be performed by the BMS. This method involves:

- Determining the actual primary flow (total zone flow) delivered to the (assumed) critical zone and dynamically calculating Zd assuming full occupancy.
- Dynamically calculating the supply air $CO_2$ ppm rise (setpoint) based on Equation 8. This setpoint is then applied to limit the supply air $CO_2$ concentration.

**WHEN TO USE SUPPLY AIR DCV**

Supply Air DCV is usually considered when, due to financial or access constraints, it is not possible to directly monitor the individual zones, or at least the critical zone, in a multi-zone ventilation system. For example, in some retrofit projects it may not be possible to take air samples directly at the zone level. Supply air DCV simply ensures that the AHU supply air always contains a high enough percentage of outdoor air to ventilate ANY space served by the system. While this approach is beneficial compared to non-DCV approaches, it can lead to conditions of over-ventilation but will ensure that spaces will never be under-ventilated.

## 9.12 Application No. 5 - Multiple-zone VAV Supply DCV (Control of Outside Air without Zone Primary Flow Reset)

Multiple-zone VAV Supply DCV is similar to multiple-zone CV supply DCV, except the zone primary flows ($V_{PZ}$) varies, as VAV boxes are used to control the supply air to each space. As primary flows are allowed to vary in each zone (typically for the sake of temperature control), it can have significant impact on the outside air fraction within the supply air which, in turn means that variations in primary flows within one zone can have an impact on the ventilation performance of that and other zones. This makes for more challenging ventilation dynamics than that shown in constant volume systems. As a result, applying demand control ventilation using OptiNet to monitor the multiple zones has a significant positive impact on ventilation performance.

Figure 9-6 is a generalized view of a multi-zone recirculating system with individual zone boxes (ZB-1, ZB-2, ZB-3, ZB-4, and ZB-5) used to supply air per zone. If this is a VAV system, each of the zone boxes modulates, typically from an independent temperature signal. As this occurs, the total system primary flow (Vps) also varies. VAV systems are usually configured to provide supply flow distribution at 55° F, where at the zone level the primary air temperature is adjusted as needed via reheat coils. In addition, the zone primary flow is adjusted based on the cooling load for that space, where generally when the zone is being heated it is at its minimum primary flow and, as the thermal demand for cooling in these spaces increases, the zone primary flow is increased. Therefore, with increased cooling demand for a given occupancy level, zone outside air fractions decreases resulting in improved ventilation efficiencies. However, the same magnitude of outside air ($V_{OT}$) is required.

### 9.12.1 Fixed Setpoint Approach

Using the Fixed Setpoint Approach to control outside air supplied to multi-zone VAV systems, apply the same sequence that is used to support multiple-zone CV supply DCV applications.

### 9.12.2 Corrected Outside Air Fraction Estimation Approach

The COAF approach is used to control outside air as described for multiple-zone CV supply DCV applications. Account for the fact that the primary flows, both at the zone level and at the system level are variable. In order to correctly calculate outside air fractions $Z_d$ and $X_{se}$, these flow values must be monitored via the BAS. The COAF estimation approach is not recommended if these quantities cannot be measured, or at least approximated.

## 9.12.2.1 Summary Sequence for Multiple Zone VAV Supply DCV (COAF Approach)

Following is the summary sequence for the multiple zone VAV Supply DCV (COAF Approach:

1. For each critical zone, program the BAS to calculate the zone outside air fraction as a function of $CO_2$ differential measured via OptiNet using Equations 6 and 5. Use the actual zone box flows measured by the BAS to calculate zone outside air fraction.
2. Using OptiNet to measure the return air $CO_2$ levels, estimate the system outside air fraction, using the knowledge of the square footage served by the Air Handler, its total primary flow (obtained from the BAS), and Equations 6 and 5.
3. Calculate the corrected outside air fraction using Equation 7, and use this to directly command the outside air damper position. If the outside air damper controls are not equipped to receive a percentage command or a direct flow command (if OA flow is not being measured) utilize supply air $CO_2$ control with a variable setpoint based on the $CO_2$ rise calculated from the corrected outside air fraction.

## 9.12.2.2 Simplified Sequence for Multiple Zone VAV Supply DCV (COAF Approach)

Following is the simplified summary sequence for the multiple zone VAV Supply DCV (COAF Approach):

1. Use OptiNet to provide the highest of the critical zone $CO_2$ differentials (Cz – Co) to the BAS, and program the BAS to scale this term over a predetermined range of outside air fractions, in direct proportion to the differential value.
2. Using OptiNet to measure the return air $CO_2$ levels, estimate the system outside air fraction, using the knowledge of the square footage served by the Air Handler, its total primary flow (obtained from the BAS), and Equations 6 and 5.
3. Calculate the corrected outside air fraction using Equation 7 to directly command the outside air damper position. If the outside air damper controls are not equipped to receive a percentage command or a direct flow command (if OA flow is not being measured) utilize supply air $CO_2$ control with a variable setpoint based on the $CO_2$ rise calculated from the corrected outside air fraction.

## 9.12.2.3 Return Air $CO_2$ Control with Reset (RACCR) Approach

Use the RACCR approach to control outside air in simpler, constant volume systems. However, in a variable volume system do not consider this approach unless the damper controls can receive a proportional command, either in terms of a cfm flow command or an outside percentage command. This requires an effective flow measurement of the outside air flow rates, which is often difficult to achieve due to the systems low intake velocities which makes reliable flow measurement challenging. As a result, the COAF or Fixed Setpoint approaches may be more effective with many VAV systems.

## 9.13 Application No.6 - Multiple-zone VAV Supply DCV with Primary Flow Reset Approach

The basic principle behind this approach is to apply a dual component DCV control function that first adjusts the zone primary flow as well as outdoor air intake flow ($V_{OT}$) in order to more efficiently deliver ventilation to the critical zones in response to varying occupancy conditions. With this VAV approach, a flow command can be provided to the zone VAV box that is high-selected with the zone's thermal demand to conditionally drive the VAV box open in response to a sensed increase in ventilation demand within that zone.

To understand the benefit of "resetting" the primary flow delivered to a zone in response to occupancy levels in that zone, consider the system of Figure 9-6, where at first it is a variable volume supply system without zone primary flow reset. Let's assume that Zone 5 is the critical zone and that the operating state of it and the rest of the system are initially as follows:

$V_{OZ5}$ = Zone 5 Ventilation Demand = 300 cfm

$V_{PZ5}$ = Zone 5 Primary Flow = 450 cfm

Therefore, the critical zone required outside air fraction is:

$Z_d$ = 300 cfm/450 cfm = .67

If we also assume that the system's total primary flow ($V_{Ptot}$) is 7000 cfm and the uncorrected outside air fraction ($X_{se}$) is .2, then the corrected outside air fraction that will satisfy the ventilation requirements for Zone 5 is, from Equation 7:

$$\mathit{Corrected\ Outside\ Air\ Fraction} = \frac{X_{Se}}{1 + X_{Se} - Z_d} = \frac{.2}{1 + .2 - \ .67} = \ .377$$

Given the system total primary flow of 7000 cfm, based on an outside air fraction of .377, 2639 cfm must be brought into the building (outside air) in order to provide the correct outside air fraction in the system to satisfy the critical zone (zone 5).

Next, consider the scenario where the critical zone's primary flow is allowed to vary in response to the zone's ventilation demand (from CO2 based measurements). In this scenario involving primary flow reset, assume that the zone box ZB-5 (Figure 9-6) can be opened from 450 cfm to a maximum flow of 1000 cfm. The required outside air fraction for the critical zone then becomes:

$Z_d$ = 300 cfm/1000 cfm = .3

Given the increase in critical zone (Zone 5) primary flow by 550 cfm, the uncorrected outside air fraction ($X_{se}$) drops to .185 and the corrected outside air fraction becomes the following:

$$\mathit{Corrected\ Outside\ Air\ Fraction} = \frac{X_{Se}}{1 + X_{Se} - Z_d} = \frac{.185}{1 + .185 - \ .3} = \ .21$$

With primary flow reset, the new system total primary flow will be 7550 cfm, and based on an outside air fraction of .21, 1586 cfm must be brought into the building (outside air) in order to provide the right level of outside air fraction in the system to satisfy the critical zone (zone 5). Thus, by providing primary flow reset, the system's outside air requirements drop from 2639 cfm to 1586 cfm. This is a 1053 cfm reduction in outside air, at the cost of a 550 cfm flow increase at the zone level.

### MULTIPLE-ZONE VAV SUPPLY DCV:

**When to use Primary Flow Reset:**

Primary flow reset (modulating the zone supply flow) is most effective when applied to the more densely populated areas or areas (the critical zones) that are subject to highly variable occupancy within a facility. This technique is generally not applied to the more consistently occupied locations, as it is often less of a challenge to provide proper ventilation to these locations. Further, the unused (unvitiated) air that circulates back to the air handler tends to come from these locations which often are over-ventilated. This "unused" air is better utilized by the critical zones via primary flow reset. If all zones were to use primary flow reset, it could result in a situation where the total flow from the AHU fan is raised by an unnecessary amount, thereby wasting energy, as the building's CO2 baseline increases during the course of an active occupancy schedule.

**What is Generally Required to Provide Primary Flow Reset to a Zone?:**

Typically, this requires the supply flow to a zone to be controlled by a variable volume zone box that can be configured to receive a flow command either via an analog signal (0–10V or 4–20mA) or by way of the BAS, which would interface directly with OptiNet through BACnet. The zone box is required to "high-select" this flow command with any local temperature signal that it might be driven from.

## 9.13.1 The Complete Solution – Controlling Outside Air in Conjunction with Primary Flow Reset

The outside air intake at the AHU in Multi-zone VAV systems with zone primary flow reset may be controlled using either the fixed setpoint approach or the COAF approach described for VAV systems without primary flow reset; however, in most cases, the simplest method is to use the Return Air $CO_2$ Control with Reset approach, as it can provide good ventilation efficiency, is relatively simple to commission, and provides good speed of response to the dynamic conditions that result as zone box flows are reset.

### MULTIPLE-ZONE VAV SUPPLY DCV:

**What Do I do if most of the Zones within my Application are Subject to Highly Variable Occupancy or Occupant Density?**

In some cases, such as in buildings with high occupancy teaching areas, numerous high occupancy conference rooms, and other high occupancy or highly variable occupancy spaces may represent a large portion of the zones served by an air handler. In such cases, providing flow reset simultaneously at all zones can result in a situation where the total flow from the AHU fan is raised by an unnecessary amount, thereby wasting energy. The techniques to compensate for this can be complex as, ideally, flow reset should not be provided unless the outside air fraction required per zone is very different than the uncorrected system outside air fraction. This could be controlled through the BAS by calculating the outside air fraction per zone and providing reset only to those zones that fall outside the system's uncorrected outside air fraction by a predetermined amount. Again, while such an approach could be highly efficient, the amount of field program required to support this will usually be prohibitive.

As an alternative, the BAS could be programmed to keep track of the total reset being provided at the zone level, and to limit this total by a predetermined value by adding an extra reset component at the AHU level. This would work by driving the outside air damper open in proportion with the amount by which the total primary flow exceeds a predetermined value. In turn, this would increase the outside air fraction within the supply plenum, which in turn will reduce the amount of reset required at the zone level.