Introduction

Demand controlled ventilation using CO$_2$ is an effective energy saving strategy for buildings that can both ensure good indoor air quality and save energy by controlling ventilation based on actual occupancy. This is a ventilation strategy that is now recognized by most building codes as well as the LEED certification program for green buildings. Since outside air measurement of CO$_2$ is mentioned in the LEED certification documentation there have been a lot of questions about the reasons for this. This white paper provides a background on CO$_2$ measurement and possible approaches to measuring outside air.

CO$_2$ as it is used in building ventilation control is not a contaminant with a specific danger threshold not to be exceeded. Rather, it is an indicator of the outside air dilution rate of a space where the outside CO$_2$ levels provide a baseline reference for outside air. Indoors CO$_2$ levels will increase beyond this baseline as people exhale CO$_2$ with normal activity. A basic principal in CO$_2$ measurement and control is that CO$_2$ levels in an indoors will rise to a point where the amount of CO$_2$ produced by occupants is balanced with the amount of outside air being introduced for dilution of contaminants. This is often called a equilibrium level. Depending on what the ventilation rate is, this balance point will vary. Figure 1 below shows the balance point or equilibrium level that will occur based on various ventilation rates assuming an outside level of 400 ppm. The balance point will vary based on the actual outside concentrations. Assuming an activity level typical of office or classroom environments, a general rule of thumb is that a differential of 700 ppm between inside and outside levels is indicative of a ventilation rate of 15 cfm/person a differential of 500 ppm is indicative of 20 cfm per person.

A few years ago it was generally assumed that outside levels of CO$_2$ where roughly about 300 ppm. Unfortunately with global industrialization over the past 50 years, background levels of CO$_2$ have steadily risen so that in most urban areas, outside concentrations are in the 400 to 500 ppm range. These rising levels have been used by many as an indicator of global warming trends.

This increase in the baseline outside CO$_2$ levels has affected the calculation of the ventilation balance point. For example, until a few years ago and indoor level of 1,000 ppm was generally considered an acceptable upper limit. The 1000 ppm value was derived from calculation of the
balance point for 15 cfm/person (700 ppm differential) based on an outside level of 300 ppm (300 ppm + 700 ppm = 1000 ppm).

If levels are actually 400 ppm the balance point for 15 cfm/person becomes 1100 ppm (400 ppm + 700 ppm = 1100 ppm). Rather than establish a new rule of thumb based on a higher assumed outside level, many guidelines express the relationship between ventilation and CO₂ levels as the inside/outside CO₂ differential.

**Demand Controlled Ventilation Explained**

CO₂ based demand controlled ventilation (DCV) is a dynamic method of ventilation control that is able to consider the actual occupancy in a space and the outside air dilution rate of a space. This approach, recognized both by ASHRAE Standard 62 and the International Mechanical Code (IMC) allows for ventilation based on real time occupancy rather than ventilating buildings based on an assumed maximum occupancy. The result is that target ventilation rates per person are maintained at all times, and during periods of intermittent or variable occupancy the total ventilation rate can be safely reduced and energy can be saved.

The actual control strategy for DCV can vary based on the occupant density and volume of the space. Critical to the strategy is that the upper point of the control modulation is the balance point or equilibrium level for the cfm per person ventilation rate targeted as shown in Figure 1. The objective of the strategy is to ensure that the target per person ventilation rate is maintained at all times base on actual occupancy. Most successful control strategies modulate ventilation as CO₂ levels rise in the space from outside background levels. This approach ensures minimal lag time between changes in occupancy and subsequent adjustment of the ventilation rate. A setpoint-based control approach has the drawback that lag times may be unacceptably long, compromising air quality until CO₂ levels reach set point.

The basis for CO₂ control of buildings date back as far as 1916 when in a Engineering Handbook of that time, co-authored by Willis Carrier, established the fundamental relationship between CO₂ and outside air ventilation. It is interesting to note that it is only with the recent development of low cost reliable CO₂ measurement technology has this well-established relationship between CO₂ and ventilation rates been able to be utilized in building control.

An important component of any DCV control strategy is to provide a minimum ventilation rate at all times to control other non-occupant related sources of contaminants. This base ventilation rate must be determined by the system designer. A general rule of thumb is that 20% of the design ventilation rate should be provided as a base ventilation rate for sources in buildings that have been in use for a year or more. Newer spaces, or spaces with a high density of non-occupant related sources may want to consider higher base ventilation rates. ASHRAE standard 62 also includes a base ventilation rate based on a cfm/square foot indication. In actual practice the establishment of a base ventilation rate is an operational parameter that may be higher for new buildings that are subject to high levels of out-gassing building components, and may be much lower older buildings where most out-gassing has taken place.

**Variations In Outside CO₂ Concentrations**

On a regional basis CO₂ levels tend to remain fairly constant on a year round basis. This is primarily due to the fact that CO₂ molecules like most gases, tend to rapidly diffuse and equalize throughout the atmosphere. Generally, ambient levels of CO₂ should not vary more than 50 ppm, a value that will have negligible effect on a CO₂ control strategy.
On a very localized basis CO₂ levels may vary if a significant source of CO₂ is nearby. For example, if a building air intake is near a kitchen cooking exhaust, a furnace flue or near a source of vehicle exhaust such as a loading dock outside levels may be elevated. Combustion fumes contain a wide range of contaminants considered harmful. It also contains CO₂ in concentrations that are 200 to 500 times the levels normally measured in outside air. As a result, very high levels of CO₂ measured outside (600-900+ ppm) may indicate a localized source of combustion fumes.

DCV Control Based On Inside/Outside Differential

There are three possible approaches that can be used to take into account outside levels when applying a DCV strategy. Two are applicable to all CO₂ control strategies and one is related to the specific capabilities of the AirTest CO₂ sensor/controller. These approaches are:

1) Assume A Value For Outside Air
2) Use The Automatic Background Calibration embedded in the AirTest CO₂ control.
3) Measure Outside Air

Each of these approaches is detailed further below.

1. Assumption Of Outside Levels

In most areas designers can utilize a strategy where outside ambient concentrations are assumed for the purpose of implementing a control strategy. The key is to pick a level that represents average regional concentrations. This level can be determined by making periodic measurements throughout the day over a number of days with a hand held CO₂ sensor. Alternatively, a safe assumption is that outside levels are 400 ppm.

It is unlikely that concentrations in any urban area will be lower than 350 ppm. If a control approach assumes a outside level of 400 and outside levels are actually 50 ppm lower, the net result will be that cfm/person ventilation rates may be lower by about 1 cfm per person. This error is generally well within the tolerances of any HVAC control system and will have a negligible effect on indoor air quality.

If CO₂ levels tend to be slightly higher, the net effect is that for every 50 ppm the actual outside level is over the assumed outside level, the space will be slightly over ventilated by 1 cfm/person. It is highly unlikely that outside levels will ever be over 500 ppm, unless a localized source of combustion exists. If outside levels are higher by 100 ppm, the result is over ventilation by about 2 cfm per person again a negligible amount that errors on the side of more ventilation.

If a control strategy is based on an assumed baseline of 400 ppm or derived from local measurements, variation in outside levels will never result in a significant impact on cfm per person ventilation rates that might impact indoor air quality..

2. CO₂ Sensor Self Calibration That Considers Outside Air

All AirTest CO₂ sensors have a self calibration method that also considers outside air CO₂ concentrations. Its primary function is to maintain sensor calibration over the life of the sensor. An additional benefit of the algorithm is that the sensor calibrates itself relative to outside levels on a regular basis, without having to place a CO₂ sensor in the outdoor environment.

This approach is called Automatic Background Calibration (ABC). The ABC approach takes advantage of the fact that when buildings are unoccupied, CO₂ levels will tend to drop to outside baseline levels. The algorithm in the sensor is designed to note the lowest concentration that occurs in a 24 hour period. If that low level falls
within certain qualification criteria, the sensor will remember the level for future reference (e.g. if levels do not appear to drop close to the known baseline the sensor will assume that the space was occupied during that evening and will not count that point). After collecting baseline data over approximately 3 weeks, the sensor will calculate if any statistically significant trend has occurred in the baseline concentrations that might indicate sensor drift. Figure 2 provides an example of how the sensor works.

The figure shows varying concentrations of CO$_2$ that would occur over 14 days in a typical building. The lower horizontal line is drawn through the lowest points measured over each of 14 - 24 hour periods. As can be seen the line shows that there is a slight but consistent downward trend to the line that is indicative of gradual sensor drift. Based on 14 days of data, the algorithm calculates what correction factor would be necessary to establish a level baseline as shown by the upper horizontal line. The drift over 14 days of the sensors is generally a ppm per less so only minor corrections are made. The algorithm updates itself on a daily basis, picking up an extra day and dropping the last to determine if there is drift that needs to be corrected.

One of the features of the algorithm is that it assumes that the baseline concentration, representative of outside levels is 400 ppm. This means that even if the baseline is 500 ppm, the sensor will assume it is actually 400 ppm. This means that if the sensor control strategy is based on the assumption of outside levels being at a 400 ppm baseline, the sensor will indicate an absolute differential measure from the baseline measurement. As a result the ABC Logic™ calibrates the sensor to the ambient outdoor baseline during the evening and can provide control based on differential as long as the control algorithm assumes a 400 ppm outside level.

An important consideration in using this approach is to ensure that the ventilation system actually allows CO$_2$ concentrations to drop to baseline levels during the unoccupied hours. This can be assured by implementing strategies such as a periodic pre-occupancy-purge, or operation of the system on a timer for an additional one or two hours to provide a minimal level of ventilation to ensure CO$_2$ concentrations reach baseline.

### 3. Direct Measurement Of Outside Air

The most obvious approach to control ventilation based on CO$_2$ is to actively measure outdoor levels and active control based on the real time CO$_2$ differential measured. In this type of application a CO$_2$ sensor must be selected that is capable of withstanding the wide range of conditions found in outside air. This approach is the most expensive of the three approaches examined and for most applications overkill. Outside air sensors are best considered when outside levels at the air-intake are found to vary significantly due to localized sources of combustion. In if high variations of CO$_2$ are measured it is a strong indication that other harmful combustion related contaminants are also present. Excessive levels of CO$_2$ in outdoor air may be used as trigger to close down air intakes until a localized source is dissipated.
AirTest offers an outside air CO₂ transmitter (model EE82) that can provide a voltage or 4-20 mA output to a building control system. The sensor is designed to operate in outside air down to -4°F (-20°C). It is available with a snap-in mounting bracket (Model No HA020304) and plug-in wiring connector that makes installation very easy. It is recommended that the EE82, when mounted outside, be shielded by a hood or overhang that protects the device from direct sunlight and rain. Suitable locations include mounting inside an existing air intake hood. Avoid locations near flue vents and building exhausts. Also avoid areas where there is a high levels of vehicle activity like drop off areas, loading docks parking garage exhausts or other combustion based equipment (e.g. stand-by generators). Contact AirTest to select the best version of EE82 for your application.

**Conclusion**

There are a number of approaches that can be used to measure outside air as part of a CO₂ ventilation control strategy based on CO₂ differential values.

If using a AirTest CO₂ sensor indoors the self calibration feature built into the sensor will naturally consider outside concentrations as part of its operation.

If you want to assume an outside concentration of say 400 ppm, and levels are really 450 ppm or 500 ppm, the result will be a slight over ventilation of the space of under 1 cfm per person. It is highly unlikely that most HVAC systems actually have this resolution of control anyway.

Finally if you want to measure outside levels and included this information as part of a real time CO₂ differential calculation the EE82 available from airtest is a good choice for a transmitter that is designed for rugged environments.

**Further CO₂ References**

CO₂ Control Products Website:  
https://www.airtesttechnologies.com/product/co2-ventilation/index.html

AirTest CO₂ Ventilation Control Reference Reading List (With Links)  

One Page Overview Of CO₂ Control:  

CO₂ Ventilation Control In Schools:  

AirTest Ventilation Calculator Based On Inside/Outside CO₂ Differential (excel based tool)  
https://www.airtesttechnologies.com/support/sw/AirTestVentCalc.xls

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