CO_2 Study and dependancy of Ventilation Rate on CO_2 Concentration-A Survey

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Abstract— This paper summarize the role of CO_2 in ventilation systems. A survey also helped to study the current state of the art in Co2-based ventilation control with brief discussion of technology used, its reliability and how it is best used for energy saving. The control of outdoor air intake rates in mechanically ventilated buildings based on indoor carbon dioxide (CO_2) levels, called CO_2 demand controlled ventilation (DCV). This paper gives the overall view of actual energy saving potential, ventilation system features, building occupancy, how indoor air quality impacts to implement CO_2 DCV. The report presents the art of review of CO_2 technology and applications with its literature review. In addition specifications while using CO_2 sensor are examined.

Keywords—CO_2 , CO_2 Sensors, IAQ, Ventilation rate, DCV.

INTRODUCTION

A variety of techniques are available to evaluate building ventilation and indoor air quality and some of these involve measurement and analysis of indoor CO_2 concentrations. Most HVAC (Heating, ventilation and air conditioning) systems re-circulate a significant portion of indoor air to maintain comfort and reduce energy cost associated with heating or cooling outside air. When occupants and building operators sense air coming out of an air supply duct, it's virtually impossible to judge how much of this air is simply re-circulated air and how much is outside air. Hence, carbon dioxide(CO_2) used as indicator which is relatively inexpensive measurement helps to ensure ventilation systems are delivering the recommended minimum quantities of outside air to building's occupants.CO_2 control is the first viable technology to actually measure and control outside air delivered to a space inside building, based on actual ventilation. Carbon dioxide ventilation control can typically reduce HVAC cost in most buildings by 5% to 20%.

A. Why Carbon Dioxide (CO_2)-

Carbon dioxide is a natural component of air. The amount of CO_2 in a given air sample is commonly expressed as *parts per million* (ppm). The outdoor air in most locations contains down to about 380ppm CO_2. Higher outdoor CO_2 concentrations can be found near vehicle traffic areas, industry and sources of combustion.

People exhale carbon dioxide- the average adult's breath contains about 35,000 to 50,000 ppm of CO_2.Without adequate ventilation to dilute and remove the CO_2 being continuously generated by the occupants, CO_2 can accumulate. The concentrations of CO_2 found in most schools and offices are well below the 5,000 ppm which s considered to pose no serious health threat. The CO_2 concentration above safety standard (i.e. 5,000 ppm) report drowsiness, lethargy and a general sense that air is stale. Hence using CO_2 as an indicator of ventilation, ASHRAE (American Society of Heating, Refrigeration, and Air Conditioning Engineers) Standard 62 has recommended indoor CO_2 concentrations to be maintained at-or-below 1,000 ppm in schools and 800 ppm in offices. As it is critical to measure outdoor CO_2 concentration while accessing indoor concentrations, ASHRAE recommends indoor CO_2 levels not exceed the outdoor concentration by more than 600ppm.

B. Relation between carbon dioxide and IAQ-

The relationship of CO_2 to indoor air quality (IAQ) is based on two concepts. One is that people emit CO_2 at a rate that depends on their size and their level of physical activity. The second concept is that CO_2 can be used as a tracer gas to study building ventilation when its indoor concentration is elevated above outdoors.

Indoor CO_2 is sometimes referred to as an indicator of indoor air quality without describing a specific association between CO_2 and Air quality. A number of potential relationships exist including the health effects of increased CO_2 concentrations. Carbon dioxide is not generally considered to be a health concern at the concentrations that typically occur indoors. A number of studies at elevated concentrations, about 5% CO_2 in the air or 90,000mg/m3, have been performed, and the lowest level at which effects have been seen in human and animals is about 1% i.e. 18,000mg/m3.

C. Relation between carbon dioxide and Ventilation Rate-

The relationship between CO_2 and outdoor air ventilation rates is well understood and is based on the consideration of CO_2 as a tracer gas. The Ventilation rate procedure in the standard is based on the outdoor air ventilation rates requirements, not on the maintenance of indoor CO_2 levels.

1. Calculation of percent outdoor air using CO_2:

Direct measurement of the amount of outside air entering large area handling units can be both difficult and unreliable. Measuring the concentrations of the carbon dioxide in the outside air, return air, and mixed air streams is often much easier than other methods. The values obtained are used in the following formula to determine the percentage of outside air for particular air handling unit:

% Outside Air (OSA) = (Cr-Cs/Cr-Co)* 100

Where:

Co is the CO_2 concentration (ppm) in the outside air

Cr is the CO_2 concentration (ppm) in the return air

Cs is the CO_2 concentration (ppm) in the supply air (or mixed air)

Unfortunately, the interpretation of the CO_2 data is often a more significant source of error than instrument accuracy. Hence, CO_2 values require the building or zone to be occupied long enough to allow the CO_2 levels reach balance with the ventilation rate, this balance called as *equilibrium, unity, or steady state.* Unless this steady state or equilibrium has been reached, the building ventilation rate can be overestimated.

The relationship between CO_2 level and outside air ventilation rate can be best illustrated by the following table:

Ventilation and Resultant CO_2 Concentrations

Carbon Dioxide	Outside Air (cfm per person)	CO_2 Differential (inside/outside)
800 ppm suggests about	20 cfm (or less)	500 ppm
1,000 ppm suggests about	15 cfm (or less)	650 ppm
1,400 ppm suggests about	10 cfm (or less)	1,050 ppm
2,400 ppm suggests about	5 cfm (or less)	2,050 ppm

The relation between CO_2 level and outside air ventilation rates can also be described using simple two chamber model. This illustrated in fig 1.

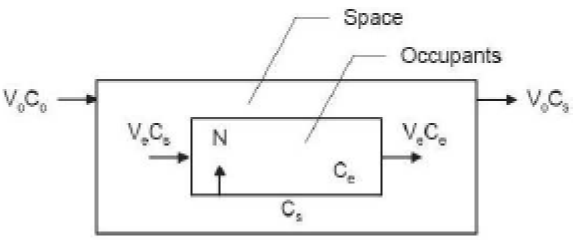


Fig.1. Two Chamber Model/6

The given Formula shows mass-balance equation to predict the difference between indoor and outdoor concentrations at steady state conditions, given a constant ventilation rate per person and a constant CO2 generation rate:

$$Vo = N/ (Cs-Co)$$

Where:

Vo- outdoor airflow rate, dm3/s*person;

N- CO_2 generation rate, dm3/s*person;

Cs- indoor CO_2 concentration, ppm;

Co-outdoor CO_2 concentration, ppm.

The Equilibrium level (Ceq) for a particular ventilation rate can be calculated as:

$$Ceq = Cs = Co+ (N/Vo)$$

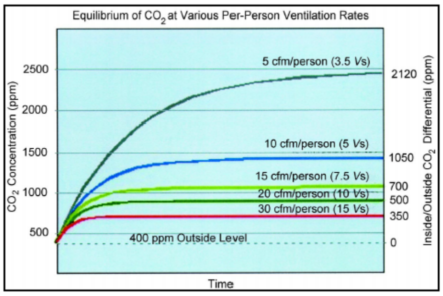
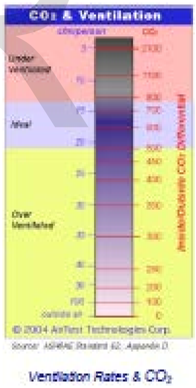


Fig.2. Equilibrium of CO_2 at various per-person ventilation rates/4

The relation between CO_2 level and airflow rate per person is satisfied when following steady state conditions are satisfied:

1. The CO_2 generation rate N should be constant.
2. Co i.e. outside air CO_2 concentration must be introduced when Vo (cfm or L/s per person).
3. The indoor CO_2 level: Cs should be accurately measured.

D. CO_2 control as an Air Balancing System:



CO_2 ventilation control is a real time air balancing system that ensures the right amount of ventilation is provided at all parts of your building to ensure acceptable indoor air quality. This approach called automatic ventilation control.

E.CO_2 Measurement Technology:

Different Technologies governing measurement of CO_2 control have been developed since at least 1916,but reliably and cost effective technology is recent development.

There are two technologies used in HVAC system, having low cost and distinctly different operations:

1. Non-Dispersive Infrared Detection (NDIR)
2. Photo-Acoustic CO_2 sensor

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1. Non-Dispersive IR detection CO_2 Sensor:

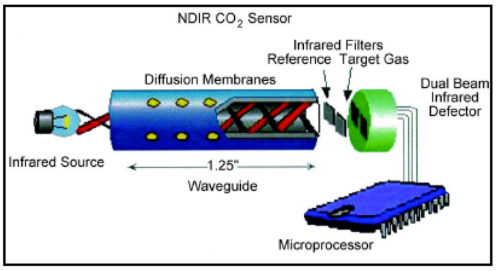


Fig.3. Non-dispersive infrared detection (NDIR) CO_2

NDIR Sensor is based on principal for increase or decrease of light that occurs at the wavelength where CO_2 is absorbed. The light intensity is then correlated to CO_2 concentrations.

Fig.3. shows the arrangement of NDIR sensor where the chamber contains a light source at one end and a light detector at other. An optical filter is placed over light detector to select light at specific wavelength where CO_2 absorbs light. A second detector and filter together are used to correct sensor drift. An important consideration in the design of this type of sensor is to minimize sensor drift. This drift occurs due to practicle buildup in the sensor or aging of light source. Aging of the infrared source is one of the significant factors in sensor drift. It can be reduced by selection of sources with stable characteristics. The dual beam approach shown in fig is one method of compensating for changes to the sensor optics resulting from both aging and particle buildup.

The second approach to compensate drift is the sensor calibrates itself on a nightly basis when the space is unoccupied, and inside level drops to baseline outside levels.

2. Photo-Acoustic CO_2 Sensors:

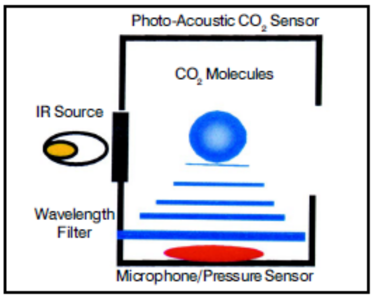


Fig.4. Photo-acoustic CO_2 Sensor/4

Photo-Acoustic sensor uses a chamber open to the atmosphere. It also exposes air in the chamber to flash IR light to wavelength for CO_2 that absorbs gas. In this chamber due to flashing light CO_2 gas molecules vibrate as they absorb infrared energy. Here, a small microphone is used to monitor the vibrations and then microprocessor in the sensor calculates the CO_2 concentration.

Fig.4. shows the schematic of Photo-Acoustic sensor. The advantage of this type of sensor is that it is not sensitive to dirt and dust. The accuracy of Photo-Acoustic sensor is maintained by using pressure sensor to correct for range of pressure found in HVAC measurement applications.

F . CO_2 Sensor Specifications:

CO_2 sensors have specific sensitivities, unresolved issues application consideration including following selection specifications:

• Drift;
• Overall accuracy;
• Temperature effects;
• Water vapor;
• Dust buildup;
• Aging of the light source;
• Frequency of calibration;
• Mechanical vibration;
• Electrical noise;
• Sensor location in the space;
• Number of sensors required;
• Method of averaging multiple sensors; and
• Compounded error rates from multiple sensors.

Some other specifications are:

- Range: 0-2,000 ppm
- Accuracy (which includes repeatability, non-linearity and calibration uncertainty): +/- 50 ppm
- Stability (allowed error due to aging): <5% Full Scale for 5 years
- Linearity (maximum deviation between a reading and the sensor's calibration curve): +/- 2% Full Scale
- Manufacturer recommended minimum calibration frequency-5years

G . Concept of Demand Control Ventilation (DCV):

The ventilation system based on registration of increasing CO_2 concentration which consumes minimum amount of energy and controls minimum supply air is called CO_2 based demand control ventilation (DCV).

A building has two contaminants that lead to unsatisfactory indoor air quality without proper ventilation. One source is building itself and another is body odor of occupants in building that produces CO_2. Carbon dioxide in any space can be reliable indicator and cheap instrument of the air quality and ventilation rate. The concept of using CO_2 input for DCV makes sense and can save money on building operating cost under specific circumstances.

CO_2 based DCV controls the amount of supply outdoor fresh air in a building depending on a number of people and their activity. This type of system is more useful in buildings where a number of people continuously changes, in the extreme climate conditions or when electricity cost is quiet high.

CO_2 based demand control ventilation is combination of two technologies:

1. Monitoring of CO_2 level by using CO_2 sensor in the interior of the building.
2. An air handling system that employs data from sensors to regulate the amount of supply air.

CO_2 sensors continually monitor air in a conditioned space. Since people exhale carbon dioxide, the difference between the CO_2 concentration in the interior of the building and the level in the exterior of the building indicates the occupancy and activity level in a space and, thus, its ventilation requirements. The sensors send carbon dioxide data to the ventilation controllers, which automatically increase ventilation when carbon dioxide concentrations exceed a certain level in a space

CO_2-based DCV provides a possibility to monitor both occupancy and ventilation rates in a building all the time. Most ventilation systems are often regulated and adjusted only at the time they are installed. DCV provides a higher level of control when monitoring conditions in the space and constantly adjusts the system to the respond to the change of parameters.

H. Benefits of CO_2 based DCV over conventional ventilation system:

Compared to conventional ventilation system, DCV provides considerable advantages.

- Over-ventilation is avoided maintaining IAQ. It also provides the required cfm-per-person outside air requirements specified by codes and standards
- CO_2 based DCV has ability to save energy range from about 5% to 80% versus a fixed ventilation strategy.
- The payback from CO_2 DCV will be greatest in higher density spaces that are subject to variable occupancy.
- A CO_2 control strategy can ensure the position of the intake air dampers is appropriate for ventilation needs and occupancy of the ventilated space at all times.
- A CO_2 sensor considers contribution of infiltration air and only requires mechanism to meet required ventilation levels.
- A CO_2 control strategy is used to maintain any per-person ventilation rate.
- CO_2 DCV can provide the building owner/manager with valuable information about occupancy trends.
- CO_2 based DCV is relatively simple and reliable in design.

I. Deficiencies of Indirect Ventilation Control:

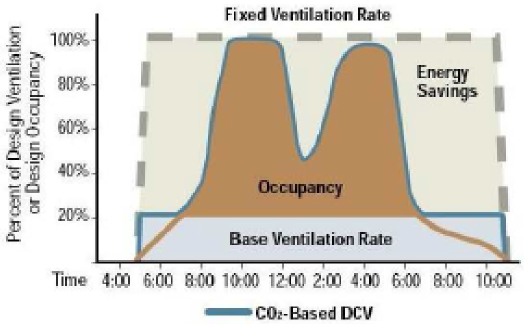
Along with benefits there are some limitations of current CO_2 sensor technology. Some of the limitations are listed below:

1. DCV is not applicable in mild climate
2. DCV is not used in spaces with significant sources other than people.
3. Both types of CO_2 sensors NDIR and Photo Acoustic are respectively affected by aging by practical build up and vibration or atmospheric pressure changes.
4. DCV sensors are not used near doors, windows, intakes or exhausts, or in close proximity to occupants.
5. Higher outdoor levels of CO_2 will result in over ventilation

J. Energy Efficiency and Energy saving potential of DCV:

CO_2 Based demand control ventilation is one of the methods to save energy in buildings where occupancy changes continuously. It saves maximum energy by providing appropriate amount of ventilation. For ex. If building is occupied 50%, then only 50% of air for ventilation is required. DCV saves energy by avoiding heating, cooling and dehumidification. The energy saving potential of demand control may vary depending on climate, type of building, type of HVAC system and occupancy in which DCV is implemented. Human capability to maintain and operate equipment properly also affects energy saving potential of DCV.

The Fig. illustrates the actual occupancy ventilation rate.



K. Applications of DCV:

DCV has number of applications in various types of buildings:

1. DCV is applied in buildings where occupancy changes continuously whole day.
2. DCV provides enough amount of fresh air per person all time in building with a more stable occupancy.

3. DCV is more convenient to use in spaces where heating and cooling for most parts of the year are required.
4. DCV is used in areas with high utility rates, high energy demand and energy costs.
5. DCV is mainly used buildings as office centers, governmental facilities, banks, shops and shopping malls, cinemas, auditoriums, lecture halls, schools, hotel atriums or lobbies etc which have automated adjusting of air supply.
6. DCV is applied in spaces where CO_2 from human respiration and human activity is the main source of pollution.
7. The buildings where there is poor indoor air quality related with under or over- ventilation or excessive humidity, DCV is more appropriate system.

The energy saving is best explained in table below which are estimated by DCV meter.

Application	Energy-cost savings range
Schools	20 % to 40 %
Day nurseries	20 % to 30 %
Restaurants, canteens	20 % to 50 %
Lecture halls	20 % to 50 %
Open-plan offices (40 % average occupancy)	20 % to 30 %
Open-plan offices (90 % average occupancy)	3 % to 5 %
Entrance halls, booking halls, airport check-in areas	20 % to 60 %
Exhibition halls, sports halls	40 % to 70 %
Assembly halls, theatres, cinemas	20 % to 60 %

Conclusion

The measurement and interpretation of indoor CO_2 concentrations can provide information on building indoor air quality and ventilation. Hence CO_2 based DCV, when applied in spaces subject to variable or intermittent occupancy in spaces where actual occupancies are greatly below design occupancy, reduces unnecessary over ventilation while assuring that target per person ventilation rates are met. DCV reduces electricity requirements when an actual occupancy level is below than the design occupancy level during the demanded periods. CO2 demand control ventilation is a real-time, occupancy based ventilation approach that can offer significant energy savings over traditional fixed ventilation approaches. Demand controlled ventilation creates improved indoor air quality by increasing ventilation, when CO2 level rises to an unacceptable level. One of the most important aspects of designing DCV is correct control strategy selection. It is possible to determine the number of sensors and to select types of sensors, when a control strategy is chosen correctly.

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