# DEMAND CONTROL VENTILATION AND SRI LANKAN APPLICATION – A CASE STUDY

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**Abstract:** Using Carbon Dioxide ($CO_2$) has been oftenly used as a indicator of indoor air quality, thus now is been practice all over the world. Since advance technologies for gas sensing have been developed to regulate air handling systems while continuously monitoring the occupied building area. Either too little or too much fresh air can be a problem to the building functionality, where over ventilation results higher energy usage and cost than appropriate ventilation while potentially increasing indoor air quality problems in warm, humid climates. To ensure adequate ventilation to the buildings, the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) had recommended ventilation rates in standard 62. Further, to coincide with the standards, many ventilation systems are designed to admit maximum level whenever a building is occupied, making the presumption that every area of the building is occupied, which leads towards over ventilated buildings. Adopting demand control ventilation (DCV) to a building will prevent over ventilation and secure the indoor from poor ventilation. In applications of $CO_2$ based demand control ventilation, minimum base ventilation should be provided, and system is much appropriate for the areas where human activities are held. The potential amount of energy saved due to the implementation of a DCV system will be momentous in large commercial buildings. Adopting this system will reduce the amount of energy that a ventilation system requires to accumulate in a given time that depends on the occupancy level.

**Key Words** - Carbon Dioxide ($CO_2$), Demand control ventilation, ventilation systems

## 1.0 Introduction

When HVAC is considered, the energy efficient buildings are making a rapid contribution to the building industry, where the necessity of energy conservation is a must in a modern building. In the design of ventilation practices, influence of energy conservation is conquering the conventional practices.

There are many ventilation requirements and recommendations in the form of outdoor air flow rates per person. To achieve such requirements, ventilation systems are designed to provide the minimum levels of outdoor air based on the amount of people and the floor area.

Carbon Dioxide ($CO_2$) is an achromatic and odorless gas. Building occupants are the main indoor emitters of $CO_2$ therefore; the indoor generation of $CO_2$ is dependent on the number of occupants and their level of physical activity level. In addition to simple respiration, smoking also creates $CO_2$ in large amounts. Higher than the normal levels of $CO_2$ in indoors may cause occupants to grow drowsy, get headaches, or function at lower activity levels. Indoor $CO_2$ levels could be an indicator of the adequacy of outdoor air ventilation relative to indoor occupant density and metabolic activity of those occupants.

## 2.0 Background

Demand control ventilation attempts to achieve acceptable *indoor air quality (IAQ)* at a reduced energy cost by controlling the outdoor airflow rate of an HVAC system, based on certain measured parameters. For example, indoor pollutant concentration or measures of building occupancy using different means of sensors that exemplify the building occupancy level can be used as parameters on which to base the rates of ventilation. Considering a $CO_2$ based demand control ventilation system, $CO_2$ is used as an indicator of the occupancy and the amount of ventilation achieved by the system. A sensor measuring the $CO_2$ concentration is used to control the ventilation system providing necessary ventilation to the building.

The potential advantage of a demand control ventilation system is that, it will make sure the space will have exactly the right amount of ventilation necessary thus, whether the occupancy level is high or low, the ventilation system automatically maintains IAQ of the building at the appropriate level. This process of automatic ventilation controlling will not only increase the indoor air quality but will also help to bring down the energy consumption because the system only runs at the capacity accommodate the current demand and never higher.

The demand control ventilation using $CO_2$ sensing is a combination of two technologies, the $CO_2$ sensors and the air handling system that uses the data from the sensor to regulate the ventilation system to provide necessary outdoor air to the indoors. Demand control ventilation systems operate on the premise that basing the amount of ventilation air on the fluctuating needs of the building occupants, rather than a pre-set formula. This will save energy and at the same time will help to maintain a healthy indoor air quality levels.

Controlling outdoor air intake rates using $CO_2$ *demand controlled ventilation* (DCV) offers the possibility of reducing the energy price of over-ventilation during periods of low occupancy, while still ensuring adequate levels of outdoor air ventilation. As discussed later in this report, depending on climate and occupancy patterns, $CO_2$ DCV may provide significant energy savings in commercial and institutional buildings. While a number of studies have suggested that extent of such savings via field studies and computer simulations, need additional work to better define the magnitude of energy savings possible and the dependence of these savings on climate, building and system type, control approach, and occupancy patterns. In addition, important issues remain to be resolved in the application of $CO_2$ DCV including how best to apply the control approach, including issues such as which control approach to use in a given building, sensor location, sensor maintenance and calibration, and the amount of baseline ventilation required to control contaminant sources that do not depend on the number of occupants.

While it is not critical to the application of $CO_2$ DCV, the emission rate of occupant generated $CO_2$ is certainly a relevant issue in this discussion. This section discusses the rate at which people generate $CO_2$. People consume oxygen and generate $CO_2$, at a rate that depends primarily on their body size and their level of physical activity. The relationship between activity level and the rates of oxygen consumption and carbon dioxide generation is discussed in the ASHRAE Fundamentals Handbook (ASHRAE 1997). The rate of oxygen consumption $V_{O_2}$, in *l/s*, of a person is given by the following equation;

$$V_{O2} = \frac{0.00276 A_D M}{(0.23 RQ + 0.77)} \qquad \text{Eq (1)}$$

where *RQ* is the respiratory proportion, i.e., the relative volumetric rates of carbon dioxide produced to oxygen consumed. *M* is the level of physical activity, or the metabolic rate per unit of surface area, in mets ($1\ met = 58.2\ W/m^2$). $A_D$ is the DuBois surface area in $m^2$, which can be estimated by the following equation;

$$A_D = 0.203 H^{0.725} W^{0.425} \qquad \text{Eq (2)}$$

Where H is the body height in *m* and *W* is the body mass in kg. For an average size adult, $A_D$ equals about 1.8 $m^2$. Additional information on body surface area is available in the EPA Exposure Factors Handbook (EPA 1997). The value of RQ depends on diet, the level of physical activity and the physical condition of the person. It is equal to 0.83 for an average size adult engaged in light or deskbound activities. RQ increases to a value of about 1 for heavy physical activity, about 5 *met*. Given the expected range of RQ, it has only a secondary effect on carbon dioxide generation rates.

Table 1: Typical Met levels for various activities (ASHRAE 1997)

| **Activity** | **Met** |
|---|---|
| Seated, quiet | 1.0 |
| Reading and writing, seated | 1.0 |
| Typing | 1.1 |

| | |
|---|---|
| Filing, seated | 1.2 |
| Filing, standing | 1.4 |
| Walking at 0.9 m/s (2 mph) | 2.0 |
| House cleaning | 2.0-3.4 |
| Exercise | 3.0-4.0 |

Emmerich et al. (1994) applied the model developed by Knoespel et al. (1991) to examine the performance of DCV systems under less favorable conditions and to study the impact on non-occupant generated pollutants. Emmerich used the same building, Madison location, and the HVAC systems described above but varied the simulated conditions to include pollutant removal effectiveness as low as 0.5 and an occupant density up to 50 % greater than design. For all cases examined, the DCV system reduced the annual cooling and heating loads from 4 % to 41 % while maintaining acceptable $CO_2$ concentrations. In addition to requiring more energy use, the constant outdoor airflow strategy resulted in $CO_2$ levels above 600 ppm for more than half of occupied hours for cases with poor pollutant removal effectiveness.

## 3.0 Case study

In the Sri Lankan context, adaptation of demand control ventilation will provide much more energy efficient buildings and will provide much better indoor air quality for the occupants in houses and also for other buildings as well. The most common type of air conditioners available in Sri Lanka is the split type air conditioner where the system has less recharge to the building from the outdoor which leaves the indoor environment is lacking adequate ventilation.

Ventilation and climate control refers to the provision of clean outdoor air and properly conditioned supply of air into the occupiable spaces of a building. Outdoor air is provided as a mean of diluting occupant generated bio effluents and other indoor contaminants, and conditioned air is provided to maintain occupant comfort. Outdoor air can be provided either mechanically or via openable windows or vents.

A case study was carried out in the main computer room of Department of Civil Engineering, University of Moratuwa, Sri Lanka, with a floor area of 125 $m^2$ which is entirely run on active means of ventilation.

The room has about 50 computers, three laser printers, four line printers and three severs. Usually it is occupied by 40 students and five staff members, at a given time. A questionnaire survey was conducted in order to investigate whether the occupants have any sickness or discomfort related to the indoor environment.

It was found that the occupants who spend around six hours in this room have sicknesses such as head ache, drowsiness and lethargy, mainly in the afternoon.

The room was fitted with three split type air conditioners which are in full operation during the day time. The air conditioners are located in the places indicated in Figure 1.

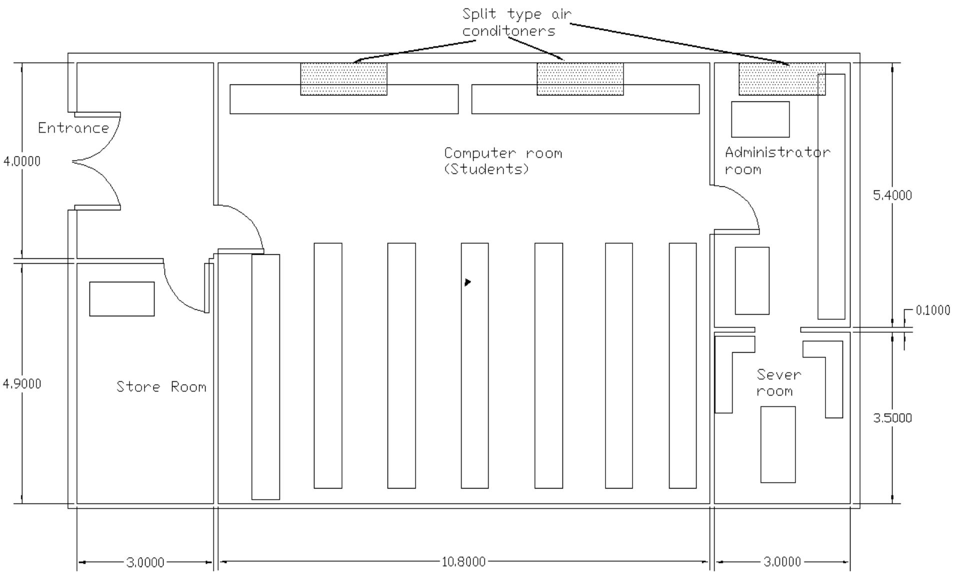


Figure 1: Plan view of the computer room

The levels of $CO_2$, CO, $SO_2$ and $NO_2$ were measured inside the room together with temperature and relative humidity. It was found that only $CO_2$ levels are relatively high and CO, $SO_2$ and $NO_2$ are negligible. Measurements were taken in every 15 minutes for a period of 3 days.

The observations revealed that the $CO_2$ levels are higher than the recommended ASHRAE standards for an indoor environment.

Due to these findings the room was fitted with two exhaust fans with a discharge rate of 180 cfm bringing in the fresh air from the outdoors to the indoors. A similar set of measurements were taken in the computer room after improving the ventilation system.

The outdoor air flow rate of the space without the exhaust fans;

$O_2$ consumption per person = $V_{O2} = \frac{0.00276 A_D M}{(0.23RQ+0.77)}$

Where, $A_D$ = 1.8 $m^2$ (for an average person)
M = 1.1 (a person Typing, seated)
RQ= 0.83 (for an average person)

Using the formula $V_{O2} = \frac{0.00276\times1.8\times1.1}{(0.23\times0.83+0.77)}$

$= 5.69\times10^{-3}$ *l/s*

The $CO_2$ generation per person $V_{CO2} = 0.83\times5.69\times10^{-3}$ *l/s*
$= 4.73\times10^{-3}$ *l/s*

Using the formula $Q_0 = \frac{1.8\times10^6 G}{(C_{in,eq}-C_{out})}$

The average indoor $CO_2$ level is 1201 ppm (2161.31 mg/$m^3$), and the outdoor concentration of $CO_2$ is 410 ppm (737.83 mg/$m^3$)

$$Q_0 = \frac{1.8\times10^6\times4.73\times10^{-3}}{(2161.31-737.83)}$$

= 5.98 *l/s* (per person)

In ASRAE standards 62.1-2007, it is sated that the outdoor air flow rate per person in a computer lab in an educational facility should be 5 *l/s* (Table 6-1 of ASRAE standards 62.1-2007), where it is not valid in isolation. But considering the single space, the breath zone outdoor air flow rate using ASHRAE standards 62.1-2007, (Equation 2, Equation 6-1 of ASRAE standards 62.1-2007 ),

$$V_{bz} = R_p.P_z + R_a.A_z \qquad \text{Eq(3)}$$

Considering the lab to be fully occupied at its maximum capacity of 45 occupants,

$R_p$ = 5 *l/s* (Table 6-1 of ASRAE standards 62.1-2007)
$P_z$ = 45
$R_a$ = 7.4 (Table 6-1 of ASRAE standards 62.1-2007)
$A_z$ = 125 $m^2$
$V_{bz} = R_p.P_z + R_a.A_z$
= 5×45 + 7.4×125
= 1150 *l/s*

The total ventilation rate per person = 25.56 *l/s*

It is clear that the ventilation rate required per person is not met in the computer lab. Due to the inadequate ventilation rates, the space always has a high $CO_2$ concentration and there is evidence that occupants spending more than 4 hours inside have had symptoms of breathing unhealthy indoor air.

Figure 2 shows the ventilation requirement to the single space with the occupant density per single person according to the ASHRAE standards.

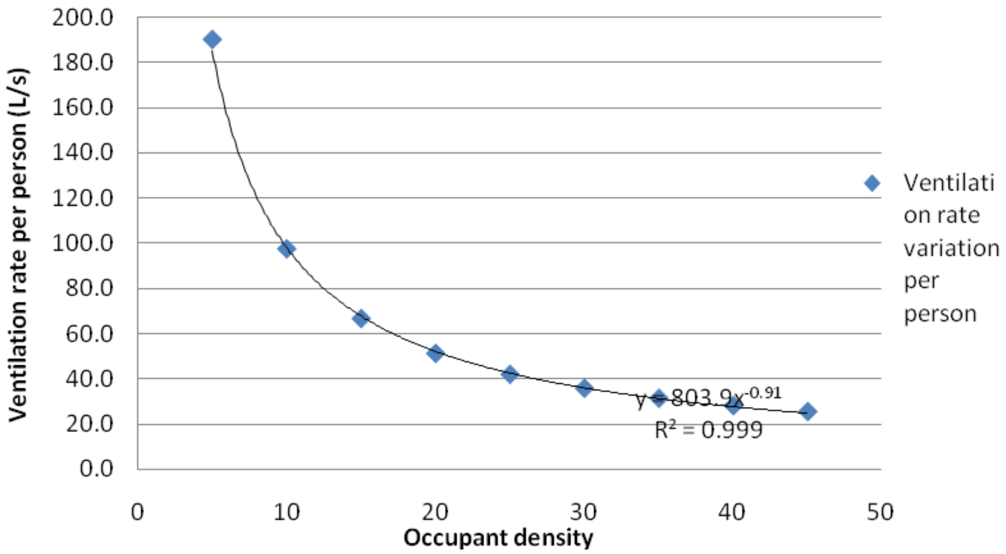


Figure 2: Variation of outdoor air flow per person with the variation of occupancy density in the activity space (computer lab)

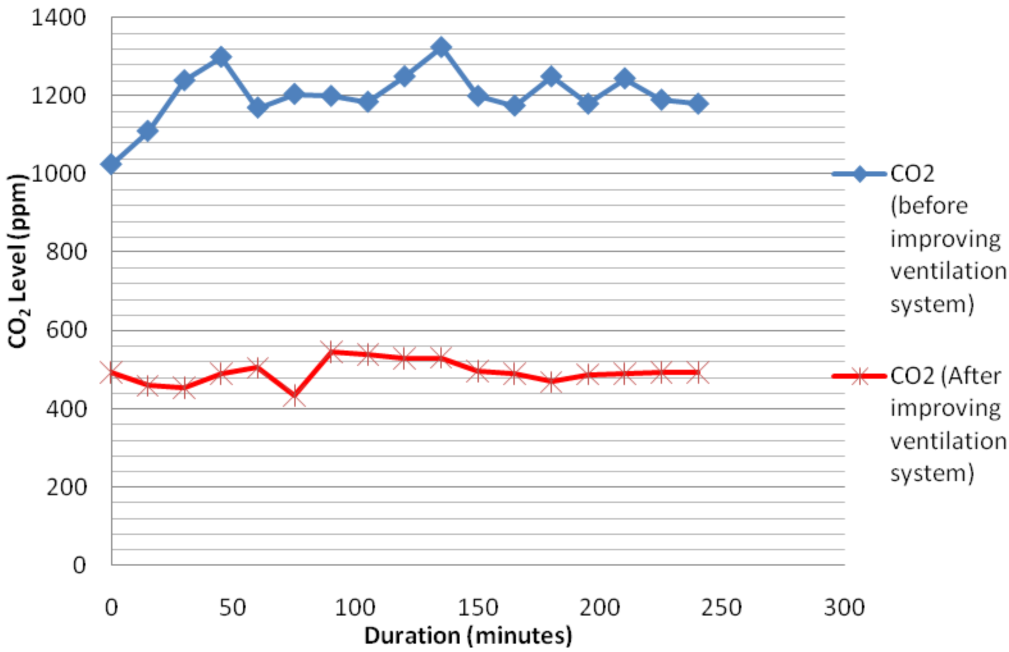


Figure 3: The $CO_2$ variation with time

The $CO_2$ levels before and after improving the ventilation system is shown in Figure 5.3 and it can be clearly seen $CO_2$ levels are higher than 1000ppm recommended by ASHRAE before the improvement. After the improvements it had come down to about 400 – 500 ppm.

## 4.0 DCV for Sri Lanka

The use of demand control ventilation to Sri Lankan buildings will help to develop healthy environments in the buildings while making the system energy efficient. Currently the amount of buildings that used this system is very low where they tend to use the split type air conditioners or central system. When considering the split type air conditioners the amount of air recharge to the building is very low, and it is clearly shown by the case study. However in the case of central air conditioning systems the indoor air tends to be recharged continuously which increases the amount of energy consumed by the system even when the occupancy levels are low.

Considering the previous case study in an air conditioned space it is clear that when the space is recharged with outdoor air the $CO_2$ levels comes down, but when the occupancy levels is low the amount of air recharge needed is less. A system which can identify the occupancy level in a given space will be much more efficient at recharging the indoor with the necessary outdoor air to build up a good indoor environment. Furthermore, recycling the indoor air up to a level that the occupants can tolerate will minimize the amount of energy spent on cooling the air brought from the outdoors.

There are very few studies which have been done on the use of demand control ventilation in tropical climates, but with advent of “green concepts” and “sustainable development”, it is necessary to conserve energy consumption in buildings. Developing algorithms to control the ventilation process will provide the means to control the ventilation system when the occupancy density is varying with time. Three different occupancy estimation algorithms are available to consider when adopting the demand control ventilation to a building, which are; steady state, approximate dynamic detection, and exact dynamic detection.

Steady-state $CO_2$ concentrations can be determined for a given ventilation rate based on a single-zone mass balance analysis. Assuming that the $CO_2$ concentration in the building or space of interest can be characterized by a single value C, the mass balance of $CO_2$ can be expressed as follows:

$$V\frac{dC}{dt} = G + QC_{out} - QC \qquad \text{.............................. Eq(4)}$$

Where:

V = building or space volume (mass) in $m^3$ (mg)
C = indoor $CO_2$ concentration in $mg/m^3$ (ppm)
$C_{out}$ = outdoor $CO_2$ concentration in $mg/m^3$ (ppm)
t = time in s
G = indoor $CO_2$ generation rate in mg/s ($m^3$/s)
Q = building or space ventilation rate in mg/s ($m^3$/s)

$O_2$ consumption per person = $V_{O2} = \frac{0.00276 A_D M}{(0.23RQ+0.77)}$

Where $A_D$ = 1.8 $m^2$ (for an average person)
M = 1.1 (a person Typing, seated)
RQ = 0.83 (for an average person)

Using the formula $V_{O2} = \frac{0.00276 \times 1.8 \times 1.1}{(0.23 \times 0.83 + 0.77)}$
$= 5.69\times10^{-3}$ L/s

The $CO_2$ generation per person $V_{CO2} = 0.83\times5.69\times10^{-3}$ L/s
$= 4.73\times10^{-3}$ L/s

Using the formula $Q_o = \frac{1.8\times10^6 G}{(C_{in,eq} - C_{out})}$

Assuming the indoor $CO_2$ level is at a constant of 500 ppm (899.79 $mg/m^3$), and the outdoor concentration of $CO_2$ as 410 ppm (737.83 $mg/m^3$)

$$Q_o = \frac{1.8\times10^6\times4.73\times10^{-3}}{(889.79-737.83)}$$
= 56.03 L/s (per person)

When the computer lab occupancy is at full capacity the maximum capacity total outdoor air flow rate } 56.03 × 45 = 2521.35 L/s

When the computer lab occupancy is at half the capacity the maximum capacity, total outdoor air flow rate } 56.03 × 22= 1400.75 L/s

Assuming the outdoor air temperature to be 30$^0$C and the indoor temperature is maintained at 27$^0$C

The heat gain due to the ventilation $= q_v = 1200\times V_r$
Where $V_r$ is 2521.35 L/s for maximum $= 1200\times2.52135$
$= 3025.62$ W/K

The total energy gain $= q_v\times\Delta T$
$= 3025.62\times3$
$= 9076.86$ W

The total energy gain is the equivalent of the total energy needed for the air conditioner to cool the system. Hence, when the occupancy level comes down the total energy requirement comes down proportionally.

## 5.0 Conclusion

Applying the demand control ventilation system to the computer lab will make sure that the amount of energy required for the building will go down relevant to the occupant density. Demand Controlled Ventilation has been seen to offer new technical and administrative tools for the operation of complex buildings. In particular, the energy budget for cooling and ventilation may typically be halved by careful design, thus considerably lowering the running expenses. However, the improvements in indoor air quality that follow as a free bonus of DCV are equally important, since air quality is measured and controlled against set standards wherever and whenever people are present. Health personnel concerned about bad indoor climate for the workforce need not any longer argue against the perceived high cost of securing much better indoor air quality. DCV strategy calls for less outdoor air over the course of the cooling seasons than does a regulatory ventilation strategy, then the annual energy required to heat or cool the outdoor air decreases. In addition, lower outdoor air requirements decrease the fan energy expended to introduce and expel the air from the building. It is widely believed that actual occupancy levels in U.S. buildings are significantly lower than the design occupancy levels that conventional ventilation systems are set to handle. Buildings and spaces with large swings in occupancy, e.g., movie theatres and conference rooms, tend to realize the largest savings. DCV reduces peak electricity demand when actual occupancy levels fall below design occupancy levels during peak demand periods. Lower levels of outdoor air translate into decreased cooling loads and, therefore, air-conditioning power draw. In some cases, DCV may allow building operators to close fresh air dampers for short periods during the hottest hours typically coinciding with peak electric load. In general, peak reductions vary from building to building, depending on occupancy patterns. Consequently, the average peak demand reduction likely will mirror the cooling energy savings potential.

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