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PAPER 10

Demand Controlled Ventilation Systems in Office Buildings

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Synopsis: This paper illustrates the principles of demand controlled ventilation (DCV) systems as applied to office buildings. For the purposes of this paper, DCV systems are defined as ventilation systems where the fresh air flow rate is governed by a control system measuring air borne pollutants, keeping the level of concentration below a preset value. These principles were developed during the conduct of IEA Annex 18, Demand Controlled Ventilating Systems.

Appropriate ventilation approaches and control strategies are demonstrated in this paper for small area control (ie boardrooms) and for office buildings as a whole. Findings are illustrated by the results of field experiments.

Impacts on energy consumption, indoor air quality and occupant response are examined. General conclusions and recommendations applicable to similar building types are also presented.

The principles presented are applicable only to spaces where the dominant pollutants are generated by the occupants. In many instances the potential energy savings resulting from active DCV systems will not be large although the technique of monitoring and recording CO2 levels may lead to very significant benefits.

Primary Goals: The primary goals of DCV systems on office buildings are to:

a) guarantee a higher quality of interior environment,

b) save energy or

c) a combination of both.

It is often easy to add extra fresh air to a building, but at an extra energy penalty. The intent of this Annex was to ensure that energy expenditures were more effective by only adding fresh air when needed. It was hoped that overall fresh air ventilation rates could be reduced since a DCV system would reduce fresh air rates when it was not required. Alternatively, it was hoped that instead of ventilating at a constant rate even when not needed, the ventilation rate could be shaved during periods when not required and then this "saved" fresh air could be added back into the system when the need was large, improving the quality of the environment.

Applicability of DCV systems to Office Buildings: In order for DCV related energy savings to be significant in any building, it was found that several conditions must exist:
a) the fresh air rates must be variable,
b) the occupancy must be unpredictably variable,
c) the building must spend a very significant proportion of the year in a mode where fresh air is either heated or cooled or otherwise conditioned and
d) the density of occupancy in the areas controlled must be high and the emissions from other sources must be low.

The reasoning follows.

a) If the fresh (outdoor) rates are not variable, then control is not possible.

b) If the occupancy is not variable, then alternate technologies such as a constant ventilation rate controlled by a programmable controller (ie a time clock) would be simpler, cheaper and equally effective. If the variations in occupancy are predictable, then the control strategy need only be modified to include alternate levels of ventilation.

c) This point is self explanatory. If the air is not conditioned, then the savings will be low since we are only talking about fan energy.

d) Control of ventilation in office buildings will normally be according to CO2 levels which may be considered a surrogate measure of occupancy and occupant generated pollutants. If other pollutants predominate (ie outgassing from materials in a new building), then CO2 measurements no longer reflect the building's ventilation needs. Also the CO2 related ventilation rates may only be a very small portion of the total and in the case of a very strong pollution source, it may never be possible to add enough fresh air to create occupant satisfaction, even if very few people are present.

Appropriate DCV Strategies: DCV system strategies are driven by the same forces as normal ventilation strategies. In order to understand how a DCV strategy should be tailored to any specific building, the other factors influencing ventilation must be examined. These are code requirements, thermal control of the building and control of pollutants that the DCV ventilation system is not capable of sensing. To this end, two components of ventilation must be considered which are defined here as:

a) the base rate (ventilation that not controlled by the DCV system) and

b) the portion of the ventilation that is controlled according to measured demand.

The ventilation rate controlled by demand should be seen as a wave riding on top of the base rate.

Impact of "Free Cooling" Cycles: Figure 2 illustrates how the "free cooling" in many buildings will vary over the year.

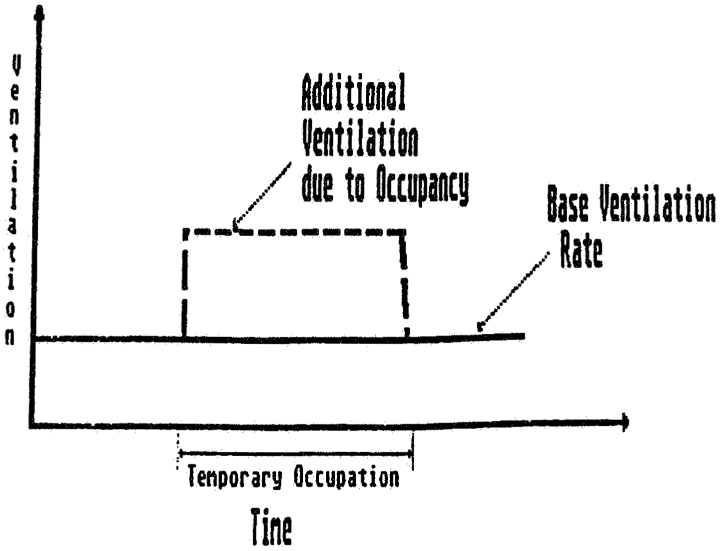

Figure 1

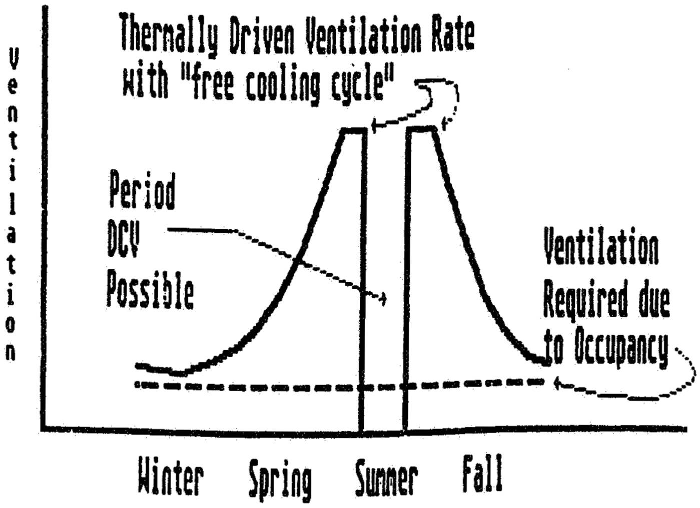

Figure 2

In order for DCV to be possible, the ventilation required for control of occupant generated pollutants must be larger than that required to cool the building. As the above diagram illustrates, this is not always the case. In the majority of large office buildings, free cooling ventilation requirements will negate any potential energy benefits from DCV systems during most of the year.

The appropriate design strategy for dealing with "free cooling" ventilation requirements is to give them precedence. When the building requires more outside air in order to save energy, it makes no sense except to receive it regardless of whether it is required to satisfy pollution purging requirements.

Impact of Air Leakage: At first glance, it might seem that in a leaky building, DCV is not possible and would not result in any benefits. This is not the case. Often in a leaky building, the mechanical ventilation strategy is based on the assumption that little or no leakage is present. Even under weather conditions where considerable leakage is present, the fresh air ventilation normally continues to function in its normal manner. If the CO2 levels are measured, then at times it may even be possible to turn the fresh air component off entirely.

The strategy illustrated in figure 3 for dealing with air leakage is to use the DCV system to monitor total effective ventilation rates and to reduce the controlled portion of ventilation as the leakage increases.

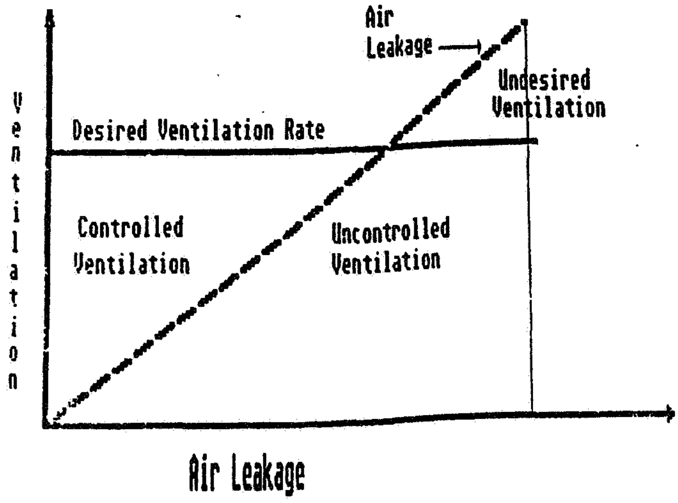

Figure 3

Of course, there is an even better strategy for dealing with air leakage: seal the building and then ventilate it properly. Uncontrolled air leakage often results in thermal control and comfort problems, building degradation due to condensation and may create air quality problems due to mould growth.

Impact of Other Pollutants: For the purposes of this paper, it is assumed that there are three basic categories of pollution sources:

a) building materials,
b) ventilation systems, and
c) people and their direct activities.

As will be seen, these three behave quite differently with respect to time. Their impact on any ventilation strategy must therefore be considered separately.

In the absence of other information, it has also been assumed that the requirements for ventilation resulting from various pollutants sources will be additive. It is acknowledged that the most effective means of dealing with pollutants is not by ventilation but by reducing source strengths. However, this will never be completely possible and significant pollutant sources of each category will always remain.

Building Materials: Building materials tend to emit pollutants at all times. They emit more when new and may sometimes work as a sponge, absorbing pollutants and odours during the day and releasing them at other times.

Often to save energy, building systems are turned off at night. Pollutants from building materials will build up. These must be at least partially cleared out before occupancy or the impression of the occupants will be that of a poorly ventilated building with stale air.

Unfortunately, these pollutants are generally difficult to measure and their source strengths are also difficult to predict. They must still be considered in any ventilation strategy whether related to a DCV system or not. In the case of a DCV system, the base ventilation rate must purge these contaminants.

The most usual strategy for dealing with these pollutants is to preventilate, flushing the building out just before occupancy. The amount of preventilation required will depend on the outgassing characteristics of the materials and the time that the pollutants have been left to build up. In general, new materials will require more preventilation as will longer unventilated periods such as weekends, especially if they are long or hot. Of course, some post ventilation after occupancy will also help.

Figure 4 illustrates the general concepts of how these pollutants will respond to a constant ventilation rate over a portion of the day. As you can see, the pollution levels will build overnight, perhaps eventually reaching a steady state level but will decay quickly once fresh air is introduced, perhaps eventually reaching a much lower steady state level.

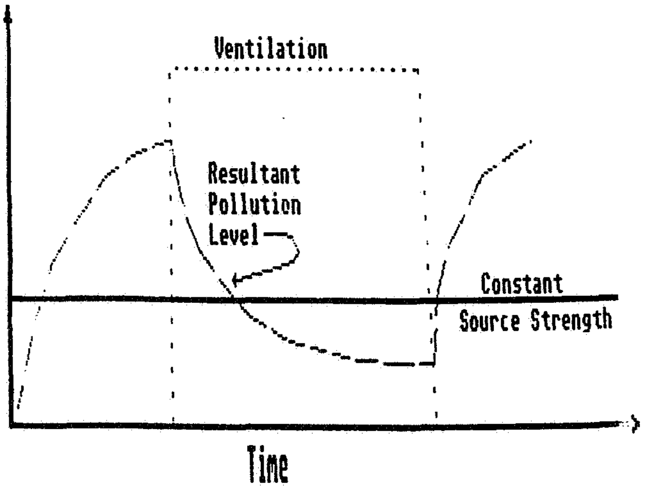

Figure 4

If the hours of occupancy are limited to certain general periods but are not precisely predictable, an alternate ventilation strategy exists. In this case, it is most effective to flush the area of concern quickly to rid it of accumulated pollutants and to then use a low base rate of ventilation to maintain these pollutants at a low level so that when occupancy does occur, the air quality will be judged as acceptable. An example of where this would be an appropriate strategy is a boardroom. It will generally be used only during working hours, but will tend to be occupied by different numbers of people at different times in an unpredictable manner.

Figures 5 and 6 illustrate the ventilation profile and resultant pollution concentrations with and without people present. In the second case, if the pollution concentrations rose too high, the ventilation rate could be stepped to the high level or perhaps to some intermediate setting. Where CO2 were used as a controlling contaminant in a boardroom, the whole building would be flushed early in the morning. A constant low rate of ventilation into the boardroom would serve to keep it as "fresh" as the rest of the building. A CO2 controller could cause extra ventilation in the room to come into play at some preset level such as 800 ppm. In this manner, the boardroom would always receive an acceptable rate of ventilation whether few or many people were present.

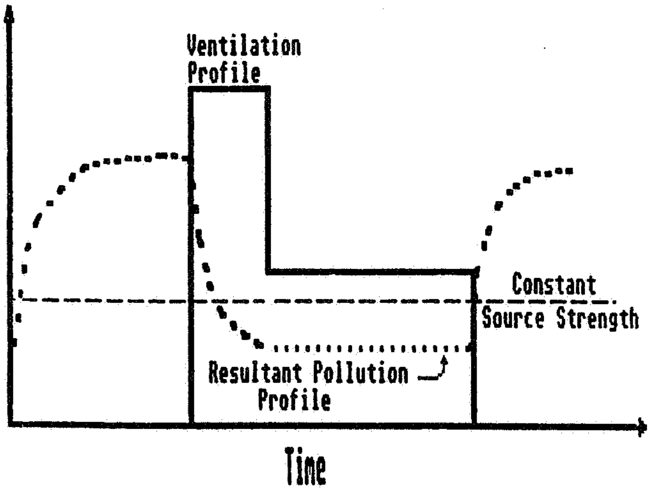

Figure 5

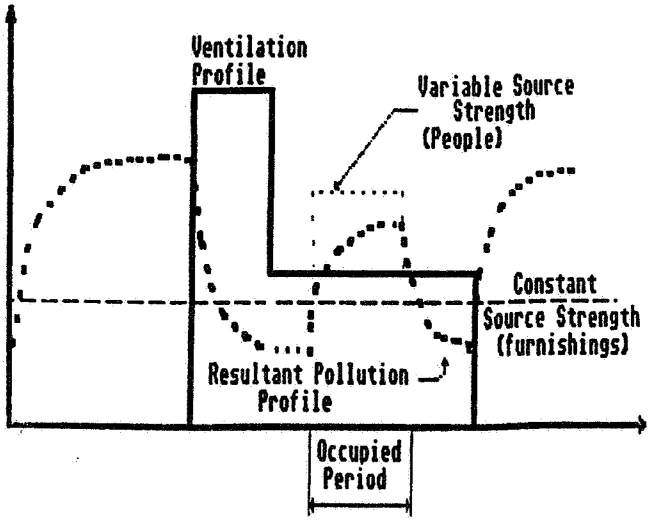

Figure 6

Of course, if the hours of occupancy are completely unpredictable, then it will be necessary to maintain a base rate of ventilation at all times if good IAQ is desired at all times. There are very few office buildings which fall into this category.

Ventilation system: The ventilation system itself may very often be a major source of building pollutants. It is assumed that the pollutants generated in the system itself should not enter the building except when the system is in operation. Like building materials related pollutants, these are very difficult to measure or to predict in terms of impact. They must be accounted for, however, in the base rate of ventilation.

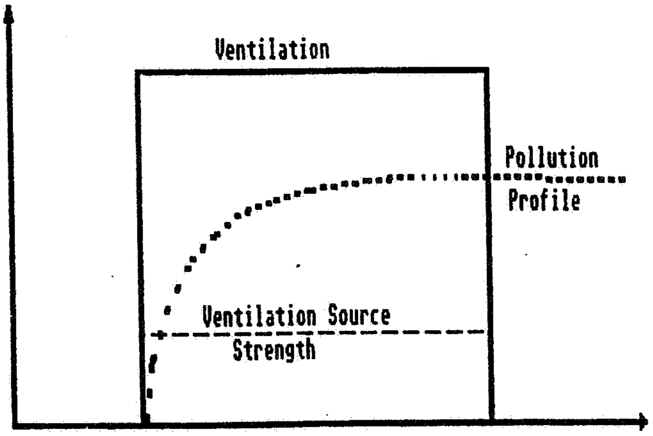

Figure 7

As illustrated in figure 7, the general strategy for dealing with these pollutants must be to eliminate or to reduce them or to increase the outdoor ventilation rate accordingly. Since a dirty ventilation system may produce biological contaminants, elimination as effectively as possible is the strongly preferred option.

Occupants and their Activities: By monitoring for the presence of people, we have a good chance of controlling occupant generated pollutants. Unfortunately, we have no guarantee that we will likewise control activity generated pollutants (ie photocopier effluents).

The most often used means of detecting occupants is to measure CO2. If we can assume their level of activity, we can get an idea of not only when people are present, but how many there are. In addition, other pollutants and odours produced directly by the occupants themselves will tend to increase and decrease directly in proportion to the CO2 levels.

An alternate for measuring CO2 levels is to use motion detectors. Although these are readily available, reliable and inexpensive, they are limited since they do not detect the number of people present, nor do they sense presence if people are inactive for long periods.

If a constant fresh air ventilation rate is present, CO2 build-up will follow a curve similar in nature to that of the ventilation system pollutants. It will not start to increase until the occupants are present. In the building as a whole, it will rise over several hours, usually hitting a peak just before noon. If the area of concern is smaller (ie a boardroom or a classroom), then it will take much less time for a peak to be reached.

Ideally, a CO2 driven controller might take into consideration both the absolute level and the rate of rise of CO2 to calculate occupancy. In a small area where the peak level is attained quickly, control to shave peak levels only is often considered acceptable.

If we were concerned about controlling CO2 levels only, then we would not turn ventilation systems on until the building had been occupied for some period of time and the levels had risen to some preset value. Figure 8 illustrates this principle.

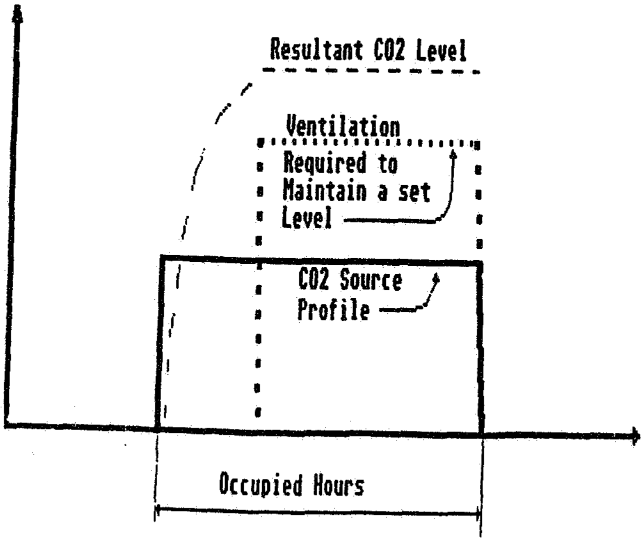

Figure 8

Of course, if we followed such a ventilation strategy in isolation, we would create great problems. We would be ignoring the predominant pollution and odour sources. High levels of complaint would be sure to follow. The design of a proper ventilation strategy must take all pollution sources and other ventilation requirements such as code and thermal control into consideration.

Combinations of Strategies: Taking the above into consideration, how do we arrive at an appropriate DCV strategy for any particular building?

a) DCV will not be possible most large office buildings during much of the year in cool climates. We must use this information when calculating possible benefits. During those portions of the year when "free cooling" is called for, its requirements must be given precedence.

b) A pre and post occupancy ventilation strategy must be chosen to purge building materials generated pollutants. In some cases, this will also require a steady ventilation rate even when no one is present just to ensure that the controlled are is reasonably "fresh" when occupants do arrive. This must be included in the base ventilation rate.

c) Ventilation systems generated pollutants must also be acknowledged in the choice of a base ventilation rate.

d) The DCV system may now be used to control additional ventilation according to occupancy.

Figure 9 shows how pollutants might build up and decay in a building with no people present. The ventilation rate is constant but is turned off at the beginning of time. As can be seen, the pollution levels initially build to a level higher than the desired pollution level. Once the building's ventilation system starts, contaminants drop to below the predetermined critical level.

In this case, some of the ventilation energy might be considered to be wasted since the environment is better than desired. It might be possible to reduce ventilation rates once the desired pollution levels have been attained, thereby saving energy. The following diagram shows how pollution levels might follow such a strategy. In the paragraphs which follow, the ventilation profile in this diagram is the base rate since it is the ventilation rate necessary to adequately control pollutants which are not monitored.

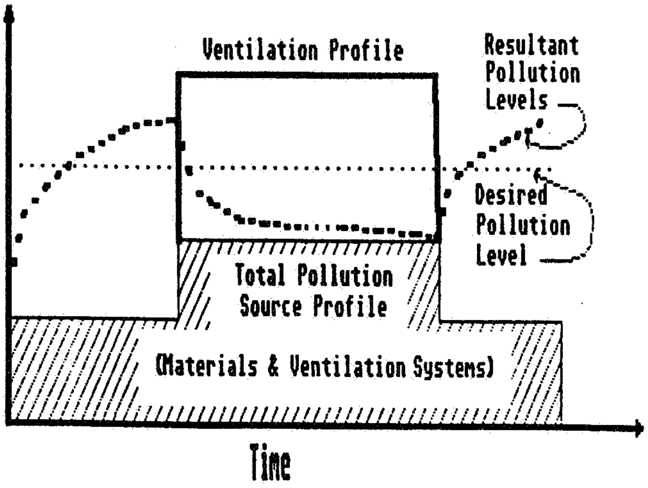

Figure 9

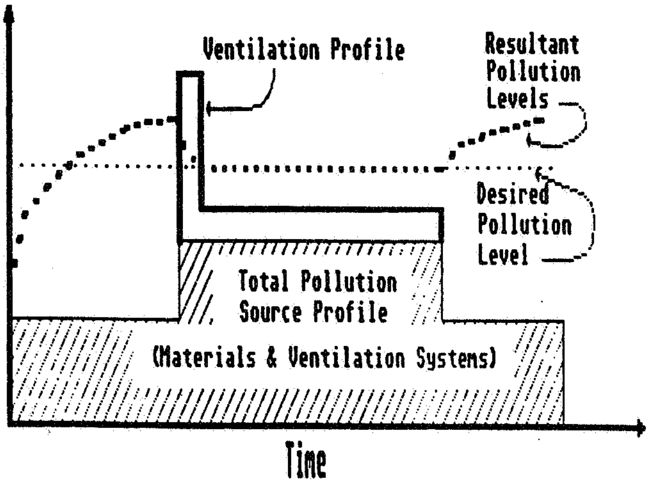

Figure 10

Of course, the building in this illustration is a good one. If the building is not clean or if it is new, the pollution levels may never drop to the desired pollution level depending on how it is defined. In this case, it will never be possible to reduce ventilation rates - in fact, if possible, they should be increased still further.

What happens to our example if we now add people? Figure 11 illustrates such an example. In this case, we have sufficient ventilation before occupancy that the occupants will think their building is fresh before they enter. The ventilation rate then drops to another level in this example at about the same time as the occupants arrive. This second level is higher than the base ventilation rate developed in figure 10. As a result, the materials and systems related pollutants will continue to drop as the occupant generated pollutants start to rise. If we could choose our ventilation rates perfectly, the two effects would counterbalance and the resultant total pollution level would remain exactly as desired. The building would be neither over nor under ventilated. In figure 11, ventilation continues after occupancy in order to help flush out remaining contaminants.

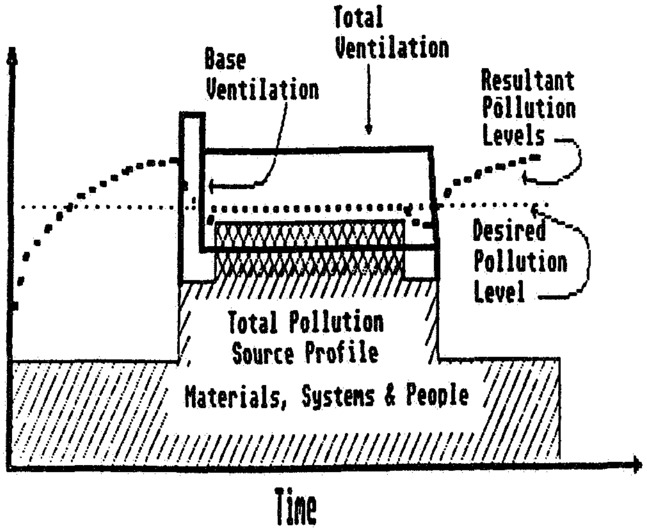

Figure 11

The above arguments have been presented without the inclusion of numbers in order to convey the general principles of DCV in office buildings. What happens when we look at "real life" examples? How significant are the pollutants generated by materials, ventilation systems and the occupants? Unfortunately little is known about their relative values except from an odour point of view. Work by Fanger and Clausen has shown that in office buildings, the occupant generated portion of the odour load may normally be less than one third of the total.

Taking these factors into consideration, an analysis of many buildings will show that the DCV system may only control a relatively small portion of the ventilation for a relatively short period in the year.

Field Study - Whole Building Control: A CO2 driven DCV system was installed in a Canadian Office Building of about 30,000 m2 floor area in order to test the practicality of the DCV approach. The system was carefully commissioned and was verified to be fully capable of ensuring the building achieved desired ventilation rates (10 liters per second per person).

In fact, the system never controlled the building's ventilation rate. More air than 10 liters per second per person were supplied all year round. Outdoor temperatures were never low enough in the winter for the building to go off its "free cooling" cycle. In the summer, it was found that leakage past the fresh air dampers was more than sufficient to control CO2 levels. Since the warm months tend to coincide with summer holidays this may have been partially due to fewer people being present than expected. The net result was that CO2 based control was not possible. No energy savings could be achieved.

An analysis of CO2 data from other office buildings showed that this is normally the case in buildings with variable fresh air rates. It also shows that there is much more fresh air going into most buildings than is recognized. Simple measurement of CO2 levels and careful adjustment of dampers may lead to significant energy savings - with or without a CO2 driven DCV system. The monitoring of the CO2 levels may be very useful, however, as a means of proving that required ventilation levels were maintained. In the event of a dispute, this data could be very valuable.

Field Study - Board Room: A board room in a large Canadian office building was equipped with supplemental ventilation controlled alternately by a light switch, a motion sensor and a CO2 driven controller.

In all cases, the whole building was preventilated before occupancy to purge odours and a base ventilation rate existed even when no one was in the boardroom. Sometimes the light switch controlled the extra ventilation fan, sometimes the fan ran all the time regardless of the switch position and sometimes the fan was disconnected. In the case of the CO2 sensor, the fan was energized at 800 ppm CO2 and shut off at 600 ppm CO2. The occupants were not informed which mode of control was in operation.

A questionnaire was used to determine occupant response.

The findings indicated that in terms of air quality, the occupants could not distinguish if the fan was connected or not or if it was controlled by the motion sensor. They rated the CO2 driven system very highly - even better than when the extra ventilation was running continuously. It is hypothesized that this may be because they could sense the change whereas if the air quality only slowly got worse or remained the same, they could not tell and gave the system a medium rating. Interestingly, they were able to tell the difference in terms of thermal control.

Although the CO2 driven DCV system was rated highest, the air quality would have not been as good as when the fan ran all the time. At the current costs of controls, the CO2 driven DCV system would not pay for itself. An inexpensive and humane approach was to let the occupants turn the extra ventilation on themselves if they felt they needed it. It was found in practice that they did not turn the fan on unless a large number of people were present.

A disadvantage of the motion sensor system was that once people a meeting started, the sensor was no longer capable of detecting presence. Also, if even one person entered the room for a very short period of time, the fan would start up.

The manual and sensor driven DCV systems in this case resulted in energy savings since the fan was not energized when not needed. Since it exhausted into the return air plenum and did not bring extra fresh air into the building as a whole, the energy savings were not large.

Conclusions:

- CO2 driven DCV systems are technically feasible.
- In many buildings, they will not be cost effective.
- They provide no guarantee of good indoor air quality, since that is more dependant of other factors.
- In buildings with an existing computerized energy monitoring and control system, the addition of such a system may not be costly and, at the least, will serve as a warning when under or over ventilation exists and will provide a proof that code requirements were met.
- In boardrooms, CO2 driven systems worked and were well received by the occupants.
- In boardrooms, a manually controlled fan giving supplemental ventilation was responsibly used by the occupants, resulting in excellent environmental control for a low cost investment.