## Technical Synthesis Report

# A Summary of IEA Annex 18

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# Demand Controlled Ventilating Systems


International Energy Agency

# Demand Controlled Ventilating Systems

Summary of IEA Annex 18
Annex 18 - Demand Controlled Ventilation Systems - Source Book

Adapted from:

Behovsstyrd ventilation i bostäder och lokaler
by Lars-Göran Månsson and Sven A. Svennberg
with further information from Martin W. Liddament

Additional Editing and Material by
Malcolm Orme

## Preface

## International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an International Energy Programme. A basic aim of the IEA is to foster co-operation among the twenty-one IEA Participating Countries to increase energy security through energy conservation, development of alternative energy sources and energy research development and demonstration (RD&D).

### Energy Conservation in Buildings and Community Systems

The IEA sponsors research and development in a number of areas related to energy. In one of these areas, energy conservation in buildings, the IEA is sponsoring various exercises to predict more accurately the energy use of buildings, including comparison of existing computer programs, building monitoring, comparison of calculation methods, as well as air quality and studies of occupancy.

### The Executive Committee

Overall control of the programme is maintained by an Executive Committee, which not only monitors existing projects but identifies new areas where collaborative effort may be beneficial. To date the following have been initiated by the Executive Committee (completed projects are identified by *):

1 Load Energy Determination of Buildings *
2 Ekistics and Advanced Community Energy Systems *
3 Energy Conservation in Residential Buildings *
4 Glasgow Commercial Building Monitoring *
5 Air Infiltration and Ventilation Centre
6 Energy Systems and Design of Communities *
7 Local Government Energy Planning *
8 Inhabitant Behaviour with Regard to Ventilation *
9 Minimum Ventilation Rates *
10 Building HVAC Systems Simulation *
11 Energy Auditing *
12 Windows and Fenestration *
13 Energy Management in Hospitals *
14 Condensation *
15 Energy Efficiency in Schools *
16 BEMS - 1: Energy Management Procedures *
17 BEMS - 2: Evaluation and Emulation Techniques *
18 Demand Controlled Ventilating Systems *
19 Low Slope Roof Systems *

20 Air Flow Patterns within Buildings *
21 Thermal Modelling *
22 Energy Efficient Communities *
23 Multizone Air Flow Modelling (COMIS) *
24 Heat Air and Moisture Transfer in Envelopes *
25 Real Time HEVAC Simulation *
26 Energy Efficient Ventilation of Large Enclosures *
27 Evaluation and Demonstration of Domestic Ventilation Systems
28 Low Energy Cooling Systems
29 Daylight in Buildings
30 Bringing Simulation to Application
31 Energy Related Environmental Impact of Buildings
32 Integral Building Envelope Performance Assessment
33 Advanced Local Energy Planning
34 Computer-aided Evaluation of HVAC System Performance
35 Design of Energy Efficient Hybrid Ventilation (HYBVENT)

**Annex 18 Demand Controlled Ventilating Systems**

It is within the ECBCS Implementing Agreement that Annex 18 (Demand Controlled Ventilating Systems) has been established.

The objective of Annex 18 was to develop actions, methods and strategies for demand controlled ventilation and to help with the introduction of such systems. The knowledge amassed from the working groups of the participating countries was summarised in a Source Book which was designed to form the basis of manuals adapted to suit individual countries. The members of the international working group unanimously support the information contained in this document.

Participating Countries of Annex 18 are Belgium, Canada, Denmark, Finland, Germany, Italy, Netherlands, Norway, Sweden and Switzerland.

## Scope

The purpose of this report is to summarise the work of IEA Annex 18 on demand controlled ventilation. It is primarily aimed at building services practitioners, designers and policy makers who require background knowledge of the operational principles and range of applicability of this approach to ventilation. The primary focus is on applications and the conditions required for the operation of such systems. This international activity has been carried out by a working group of researchers from ten countries (Appendix 1) with Sweden bearing the main responsibility as Operating Agent. More detail is available in a set of project reports, as summarised in Appendix 2.

# Contents

# 1. Introduction

## 1.1 Background

The population of industrialised countries spend at least 90% of their time either inside the home or work-place. It is therefore essential that the quality and thermal climate of the indoor air is at an optimum to ensure good health and comfort.

In general, pollutants are emitted into a space from various sources including:

- occupant metabolism (odour, moisture and carbon dioxide etc.),
- occupant activities (tobacco smoking, moisture from washing and cooking etc.),
- emissions from building materials and furnishings,
- emissions from appliances and processes (e.g. photocopiers, combustion products from unvented cookers etc.),
- poorly maintained HVAC systems (e.g. dust and fungal spores), or
- polluted outdoor air.

Indoor pollutant concentration is most efficiently reduced by eliminating the source of emission or by enclosing the source in order to isolate it from occupied spaces. When this is not possible, however, pollutants must usually be diluted and removed by means of ventilation. Unfortunately, this is an energy intensive process that can account for up to 50% of thermal conditioning (heating or cooling) load. There is much economic and environmental interest, therefore, in developing energy efficient approaches to ventilation. Demand controlled systems offer one such technique.

The purpose of this report is to summarise the research into this topic by IEA Annex 18 and to provide guidelines on the availability, performance and applications of demand controlled technology. It is principally based on the Annex 18 Summary Report (Månsson and Svennberg, 1993) with some additional updated material and a bibliography.

More comprehensive detail is presented in a series of research reports derived from this study. These cover the following topics:

- State of the Art Review
- Sensor Market Survey
- Sensor Tests
- Case Studies
- Source Book

Full publication details are given in Appendix 2. The Case Studies Report is particularly recommended because it includes operational details of successful schemes and also gives examples of (and the reasons for) poor results. Similarly, the source book is recommended for comprehensive detail covering the description and installation of DCV Systems.

### 1.2 Demand controlled ventilation

Demand controlled ventilation systems provide a means by which the rate of ventilation is continuously and automatically adjusted in response to the pollutant load.

This ensures that ventilation is applied according to need, thereby minimising unnecessary space heating or cooling losses.

Essentially, air quality is monitored by means of a sensor (or a series of sensors) which respond to the 'dominant' pollutant (or pollutants). Output from the sensor is applied to a control system that adjusts the rate of outdoor air flow through the ventilation system, thus ensuring that good air quality is continuously maintained. In its wider interpretation 'demand control' may also include simple timers, which switch the ventilation system on or off at set times, and proximity detectors and counters that can control the rate of ventilation according to the detection of occupancy and the number of occupants present in a space at any time.

The objectives of Annex 18 were to:

- evaluate demand controlled systems.
- identify applications.
- evaluate the performance of sensors and identify the most appropriate for each application.

## 2. Principles of Demand Controlled Systems

### 2.1 Applicability of demand controlled ventilation

It can be notoriously difficult for humans to assess the quality of air, especially if acclimatised to a space. While unpleasant odour is readily identified and causes discomfort, non-odorous gases, such as carbon monoxide and radon, are highly toxic and can give injury without warning. (Bacteria and viruses are also not readily detectable but can result in poor health. Low ventilation rates, combined with high occupancy density are known to cause discomfort and can increase the risk of infection.)

Apart from specific industrial applications and the ventilation of enclosed car parks and road tunnels, demand controlled ventilation systems are essentially aimed at situations in which harmful concentrations of toxic pollutants are not present. In other words they are aimed at minimising the concentration of common pollutants that may be found in a space and that could result in poor indoor air quality.

Subject to the above, demand controlled ventilation is most effective when one or more of the following apply:

- the building is sufficiently air tight for air flow to be controlled by the ventilation system (i.e. the intended ventilation performance is not impaired by excessive air infiltration).
- the space requires thermal conditioning (i.e. heating and mechanically cooling).
- pollutant emission rate is transient (e.g. variable occupancy).
- while the maximum pollution emission rate is known, the emission rate at any instant is unpredictable.

Since many pollutants can be present at any one time, the planner must devote some effort into selecting the pollutant or indicator which is considered to be the most significant (i.e. requiring the greatest rate of ventilation for dilution and removal).

Generally, if the need of the dominant pollutant is met, then all other pollutants should remain at acceptable concentration levels.

## 2.2 The role of ventilation

The main task of a ventilation system is to remove unavoidable pollutants from the area served by the system. This is usually accomplished either by 'dilution' ventilation, in which the incoming air is uniformly mixed with the air already present in the space, or 'displacement' ventilation in which the incoming fresh air displaces the stale indoor air with the minimum of mixing.

The choice of ventilation strategy depends on many factors and is covered in more detail in a companion publication (Dickson 1997). Regardless of choice of strategy, the following ventilation principles apply for good indoor quality:

- ***Occupation of a new or refurbished building:*** Pollutant concentration from new building materials, fabrics and furnishings tend to be high. A continuous high rate of air change is needed for several weeks to purge the building of pollutants (e.g. by window opening). Demand controlled strategies are not implemented during this period.

- ***Basic 'background' ventilation (during unoccupied periods):*** After the initial period of construction or refurbishment venting, residual emissions from furnishings etc., reduce to a 'background' level. Either a small rate of continuous basic ventilation must be applied (e.g. ASHRAE Standard 62, 1996, proposes a basic rate of 0.35 $l/s.m^2$ of floor area for offices) or pre-occupancy ventilation must be used to clear the air of pollutants that might have built up overnight. The ventilation, in this instance, is required to dilute and remove volatile organic compounds (VOC's) and other substances, that are given off by the materials in the building, so that the level of pollutants in the air is acceptable when the work period commences. To minimise the requirement for basic ventilation, the first rule to be observed in building design is to ensure that materials are selected so that the need for basic ventilation is as small as possible, right from the time a building is put to use.

- ***Occupancy and/or transient (peak time) ventilation:*** During periods of occupancy, additional ventilation is required to dilute and remove metabolic pollutants (primarily odour) and to meet the needs of polluting activities which arise as a result of occupancy. It is this aspect of ventilation that can benefit most from demand control. During demand controlled periods, the minimum ventilation rate should not fall below that required for 'basic' ventilation, while the maximum ventilation rate should be capable of satisfying the peak design pollutant load.

  The second rule to be observed to achieve energy efficient ventilation, therefore, is to ensure that the pollutant load produced by people, animals and equipment is kept to a minimum. This not only benefits the amount of ventilation that needs to be applied but may also enable the ventilation plant itself to be reduced in size.

  A summary of optimum strategies according to pollutant characteristics is presented in Table 3.1 for the base ventilation rate, and in Table 2.2 for the occupancy ventilation rate.

***Table 2.1 Choice of strategy for base ventilation rate***

| Characteristics | Control Strategy | Possible Applications | Remarks |
|---|---|---|---|
| • Continuous 24-hour occupancy | Constant 24-hour base ventilation | Hospitals, dwellings | |
| • Considerable emissions from building materials<br>• Continuous occupancy during known periods | Constant part-time base ventilation | Offices, schools, cinemas, theatres, dwellings | • Does not solve "sick building" problem<br>• Might improve controllability of system |
| • Low emissions from building materials<br>• Continuous occupancy during known periods | Pre-ventilation with higher ventilation rate | Offices, schools, cinemas, theatres | • Gives more emphasis to occupancy ventilation |
| • Low emissions from building materials<br>• Discontinuous occupancy | Intermittent forced ventilation | Meeting rooms, department stores, schools, auditoriums | Forced ventilation periods in accordance with source strength, air change rate and occupancy profile |

*Table 2.2 Choice of strategy for occupancy ventilation rate*

| Characteristics | Control Strategy | Possible Applications | Remarks |
|---|---|---|---|
| • Known source strength<br>• No fluctuations of pollutant loads | Constant ventilation rate | Storehouses, archives, offices with constant occupancy load | |
| • Known source strength<br>• Predictable fluctuations of pollutant load | Clock control | Classrooms | • Information flow crucial<br>• System cannot handle unforeseen changes in occupancy |
| • Known source strength<br>• Unpredictable occupancy<br>• User willing to take responsibility | Manual control | Classrooms, meeting rooms | • Simple installation<br>• User must be trained<br>• Does not guarantee acceptable indoor climate |
| • Constant load during occupancy periods<br>• Unpredictable occupancy periods | Presence sensor control | One-person offices, classrooms | • Cannot handle load fluctuations<br>• Pre-ventilation not possible |
| • One dominant pollutant<br>• Unpredictable fluctuations of pollutant loads | Continuous monitoring and control (indicators are $CO_2$, RH, VOC) | Auditoriums, dwellings, offices, meeting rooms | Sophisticated solution Crucial to recognise dominant pollutant Only strategy for true control of IAQ |

## 2.3 Appropriate selection conditions

The decision diagram (Figure 3.1) illustrates the conditions under which demand controlled ventilation is most appropriate. It should be noted that a draughty building does not provide the useful savings which a non-draughty building is able to because it is not possible to control the pattern of air flow or the rate of air change. There are 6 steps indicated in the Figure and these are discussed in the sub-sections below.

### 2.3.1 Step 1: Compliance with Regulations

A preliminary question to be solved is whether the DCV system to be adopted will comply with existing regulations. For instance, when regulations require fixed (non-closeable) openings in rooms where individual gas heaters are placed, it will not be possible to adopt humidity-controlled devices. In other cases regulations not only do not prohibit DCV systems, but actually encourage their use, whenever, for instance, they ask for a certain amount of ventilation per person.

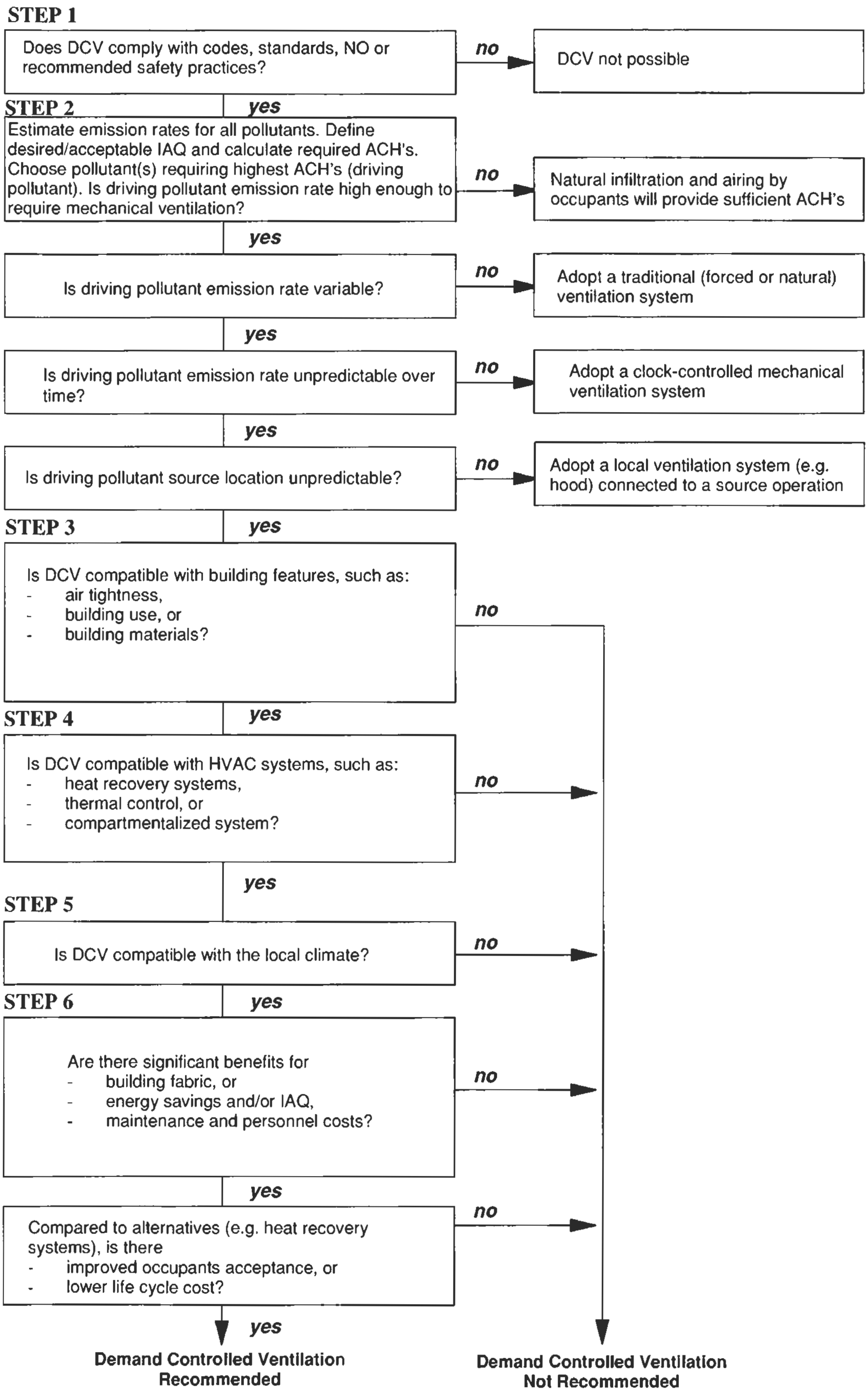


*Figure 2.1 The most appropriate conditions for demand controlled ventilation*

### 2.3.2 Step 2: Pollutant Analysis

Among the pollutants and the indicators generated into the building, there is one which will require the highest average ventilation rates in order to maintain its concentration below the required acceptable limit. This can be defined as the driving pollutant.

The main prerequisite for installing a DCV system in a building is that the driving pollutant emission rate should meet the following criteria:

- High level: high enough to require the installation of additional (natural or mechanically assisted) ventilation in combination with that provided by natural infiltration.
- Variable: the level varies significantly over time.
- Unpredictable: the time and location of the pollutant source cannot be scheduled.

As there are many pollutants produced within the building, it should be stressed that all three criteria must apply simultaneously to the driving pollutant.

### 2.3.3 Step 3: Building features

The main building-related factors which may be relevant for adoption of a DCV system are:

- the airtightness of the envelope of the building,
- the building use, and
- emission/adsorption of pollutants by building materials.

It should also be considered that there is an obvious intersection between IAQ and indoor thermal comfort, in that natural or forced ventilation may be used, both in the cooling and in the heating season, to control room temperature, thus influencing also IAQ. In this sense, the ability of the building to maintain an acceptable indoor climate (e.g. factors such as thermal inertia, window area) will be influential to IAQ.

**Airtightness:** If a building is so leaky that natural infiltration gives sufficient ventilation or even more than required, there will be no real possibility to control the ventilation rates using a DCV system. However, the adoption of a DCV system may result in significant energy savings even when considerable air infiltration takes place in the building.

**Building use:** The characteristics of pollutant emissions listed in Step 2 (intensity of sources, variability and unpredictability) are mostly determined by the use of the building. Buildings generally offering these requisites are:

- residential buildings,
- school buildings,
- auditoriums,

- office buildings and
- other buildings such as commercial buildings or stores.

**Building materials:** If building materials are strong sources of noxious pollutants, such as formaldehyde, a high base rate or even a constant flow mechanical ventilation system should be used to permanently keep their concentration at an acceptable level. Such a situation is often found at the beginning of use of a building, upon completion or refurbishment. Later on, the decay of emission may call for a more energy saving way of operation, and a DCV system may become suitable and profitable.

### 2.3.4 Step 4: HVAC Systems

**Ventilation systems:** Once the source of noxious pollutants have been removed as far as possible, energy costs can be reduced by a careful design of the ventilation system, for example by:

- adopting heat recovery systems,
- improving the efficiency of ventilation, or
- adopting DCV systems.

In some cases these three options may be conflicting. For example, a DCV system as a complement to system with a highly efficient heat recovery installation might be found not profitable. Conversely, when a DCV system has been already installed, a proposed later installed heat recovery system may turn out to be unprofitable.

**Heating/cooling systems:** Heating and cooling are often achieved using ventilation air. In this case, the system must be carefully designed so that thermal control is not lost. In some cases, this will not be practical. In some buildings, outdoor air is used to provide "free" cooling. In moderate climates or in the case of very large buildings, this may exclude the possibility of reducing outdoor air rates for a large portion of the year since to do so would result in increased energy consumption.

### 2.3.5 Step 5: Climate

**Outdoor climate:** There are a number of factors which may affect the choice of a DCV system because they influence one or more of the following:

- indoor climate,
- natural infiltration, or
- humidity controlled ventilation systems.

**Indoor climate:** Outdoor temperature, solar radiation, wind velocity, etc., are all factors that influence indoor microclimate, eventually inducing a need for airing or ventilation, when this may be used to control room air temperature. For example, in mild climates airing by occupants during mid-seasons may outdo the performance of the ventilation system, either controlled or not.

**Natural infiltration:** Natural climatic factors such as wind and temperature difference, together with envelope characteristics, contribute to the air infiltration. The higher the wind speed and temperature difference across the building envelope, the higher the infiltration rate will be.

**Climatic factors influencing hygrocontrolled ventilation systems:** Outdoor climate will exert a primary influence on the behaviour of ventilation systems designed to maintain indoor relative humidity below a certain level (a rather frequent case for residential buildings). In this case its importance will be second only to that of indoor vapour production indoors.

### 2.3.6 Step 6: Potential Savings

**Evaluation of potential energy savings:** Evaluation of potential energy savings is a necessary step to assess the viability of a DCV system. Unfortunately, only a few experimental data are known about existing DCV systems performance; these data do not allow generalisation, because the resulting energy consumption and IAQ is always specific to the climate, the building and the installed ventilation system. Therefore, to evaluate the potential energy savings and/or the improvement of IAQ, simulation techniques should be used.

**Calculation of energy savings:** A simplified approach for the evaluation of energy savings in DCV systems is provided in the Annex 18 Source Book. (See Appendix 2 for bibliographic details.)

**Cost/benefit analysis:** One essential part of the DCV energy conservation strategy is to use the ventilation system only when there is a need for it. In most cases it is quite possible to present values on energy savings achievable by using a DCV system. Large savings (up to 60%) can be shown for some ventilation systems where the energy consumption has been high due to continuous operation. Increased demands for improved air quality can result in little or no savings for other systems.

## 2.4 Demand controlled systems

An example of a demand controlled system is illustrated for a conventional office HVAC configuration in Figure 2.2. The essential elements are:

- a sensor (or group of sensors), designed to monitor the dominant pollutant(s).
- a control system for adjusting the ventilation rate in response to need.
- a conventional (usually mechanical) ventilation system.

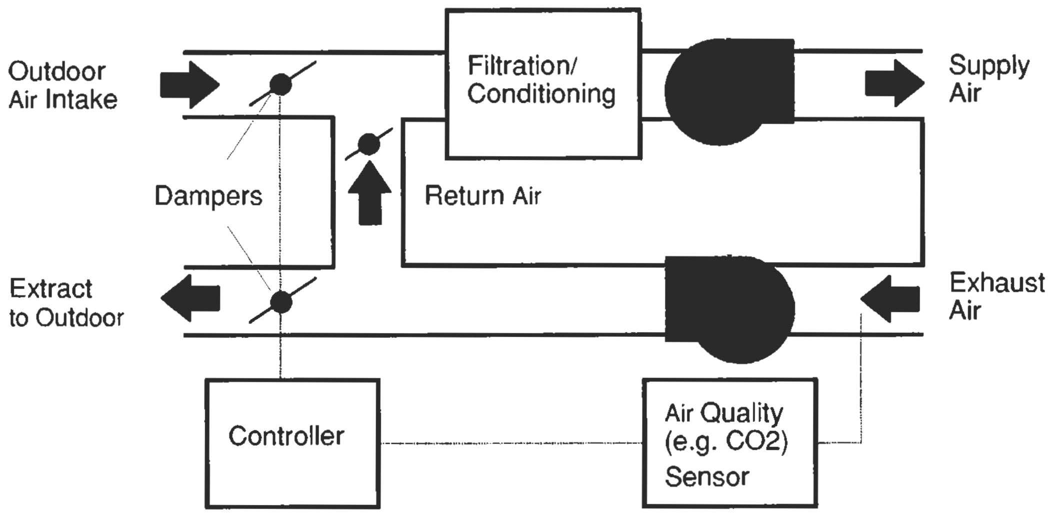


***Figure 2.2 An example of a configuration of a demand controlled ventilation system***

Key factors are concerned with:

- ***Identifying the dominant pollutant:*** Since many pollutants can be present in a space, it is important to identify the contaminant or contaminants that are the most significant. Very often the key pollutants relate to occupants and moisture production.
- 
- ***Selecting the appropriate sensor:*** The main types of sensors are outlined in Section 6. The sensor must be selected to respond to the dominant polluting source or sources.

- ***Optimising the location of sensors:*** Sensors must be located where they accurately reflect air quality conditions in the vicinity of occupants. In buildings with good mixing ventilation, sensor location is not too critical. Possible choices include placing the sensor in an exhaust plenum or, alternatively, close to ceiling level, above the occupied space. If the exhaust plenum location is chosen, however, continuous extraction must be applied (e.g. basic ventilation or conventional return air) to ensure that the room air is always in contact with the sensor. Pollutants are intentionally far more unevenly distributed in a space served by a displacement ventilation system. It is essential, therefore, that the sensor is located downstream of the pollutant source, otherwise the pollutant will not be detected and a false indication of good indoor air quality may be given. Subject to the continuous flow requirement, location in an exhaust plenum is again acceptable or close to the exhaust terminal device. Alternatively, it should be located in proximity of the breathing zone. In all circumstances, sensors must accurately reflect the condition of indoor air quality in each room, especially when occupancy density varies between rooms. In other words, air quality averaging throughout an entire building could result in excessive pollutant concentrations at some locations balanced by low levels of pollution elsewhere. For this reason, independently controlled fresh air supply and air quality monitoring in each room may be necessary.

- 
- ***Demonstrating the cost benefit:*** The cost benefit must be clearly understood before implementing demand controlled ventilation. The advantage is the avoidance of excessive ventilation and hence unnecessary thermal conditioning of the space. Depending on the type of ventilation system, fan energy may also be reduced. Cost benefit is covered in further detail in Section 7.

# 3. 'Dominant' or 'Control' Pollutants

## 3.1 Indoor pollutants and their dominance

An important part of the work of Annex 18 work, was to carry out an investigation and laboratory analysis of sensors and types of system available on the market. This was undertaken at the National Testing Institute in Sweden in conjunction with an assessment of key pollutants. Although many pollutants may be found in a space, the following were specifically reviewed and assessed, as part of this study. They were each reviewed in relation to dominance, sensor availability and sensor performance.

The influence of common pollutants which may be dominant in buildings are summarised in Table 3.1 and are reviewed in further detail below.

***Table 4.1 Relative influence of common pollutants***

| Pollutant | | Relative significance for | | Notes |
|---|---|---|---|---|
| | | Humans | Buildings | |
| 1. | Moisture | Small | Great | Mould and decay damage |
| 2. | Volatile organic substances | Depends on VOC | Small | VOC's should be avoided |
| 3. | Particles | Moderate | Staining of surfaces | Serious for sensitive people |
| 4. | $CO_2$ | None | – | Indicator of metabolic activity |
| 5. | Odours/exhalation | Small (irritant) | – | More noticeable to 'visitors' |
| 6. | Tobacco smoke | Great | Great (staining) | Health risk |

## 3.2 Occupant pollutants (heat, moisture $CO_2$ and odour)

Provided issues relating to toxicity have been separately addressed, air quality is often subjectively assessed by identifying the proportion of occupants who are satisfied with the odour content of the air. In buildings in which emissions of odorous volatile organic compounds (VOC's) are at a minimum, discomfort odour can usually be related to occupant density and metabolism (bioeffluents). Measurable bioeffluents are heat, moisture and carbon dioxide. While in themselves, these are non-odorous, they provide indicators to the level of metabolic activity and probable odour intensity. The approximate amounts of heat, metabolic carbon dioxide and moisture emitted by adult humans is indicated in Table 4.2. These emission rates are largely dependent on the level of activity, although ambient air temperature and atmospheric relative humidity also affects moisture emission rates.

Extensive analysis shows that it is not possible to achieve 100% odour and comfort satisfaction among occupants. 'Visitors' to a space are more susceptible to odour intensity than are occupants who are already present in that space. Typically, the basic acceptable odour threshold for enclosed spaces is set at 80% or more of 'visitors' to a space being satisfied (i.e. unaware of odour). A relationship between ventilation rate and odour acceptability for 'visitors' and for 'acclimatised' occupants is illustrated in Figure 4.1. For 80% satisfaction of visitors to an occupied space, a ventilation rate of approximately 8 l/s.p is needed. For those occupants who are 'acclimatised' to a space, the odour tolerance is less dependent on the rate of ventilation.

*Table 3.2 Metabolic data as a function of level of activity*

| Activity | Pulm. vent., l/min per person | $CO_2$ production, l/h per person | Vapour, g/h per person | | | Metabolism (heat dev.), W per person |
|---|---|---|---|---|---|---|
| | | | 18°C | 20°C | 22°C | |
| Resting | < 7 | 12 | 30 | 35 | 45 | 75 |
| Office work (typing) | < 10 | 18 | 35 | 40 | 50 | 110 |
| Standing | 10-15 | 21 | 45 | 50 | 60 | 130 |
| Walking (4 km/h) | 15-25 | 39 | 160 | 180 | 190 | 240 |
| Tennis, digging | 40-50 | 110-150 | 250 and above | 270 | 330 | 350-500 |
| Intensive activity | > 50 | 110-150 | approx. 1000 | | | 700-800 |

Unfortunately, despite promising developments, a suitable universal electronic odour sensor does not, as yet, exist.

Hence demand controlled through odour monitoring is currently not possible but must be recognised as a future potential technique.

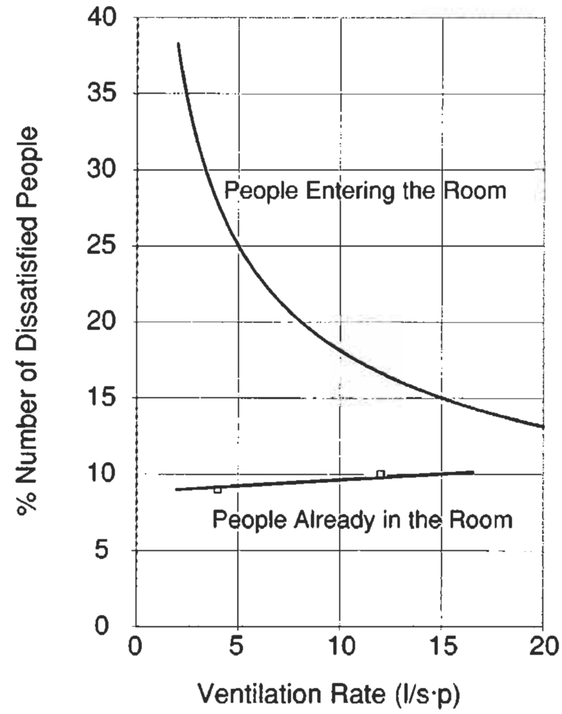


***Figure 3.1 Relationship between ventilation rate and odour dissatisfaction for 'visitors' to a space and occupants***

### 3.3 Metabolic carbon dioxide

Carbon dioxide is the principle gaseous product emitted by man as a result of metabolism and, in general, correlates well with metabolic odour intensity. It is only considered to be a risk factor when its concentration over an eight-hour period exceeds 5000 ppm, i.e. 0.5%, in accordance with *Arbetarskyddsstyrelsen* [National Board of the Swedish Occupational Safety and Health] requirements. This corresponds to a reduction of the oxygen content in the air from approximately 21% to 20.5% (see Table 3.2 for the physical characteristics of carbon dioxide). When occupant generated $CO_2$ is the only source of carbon dioxide, there is a clear correlation to the steady state concentration in a space and the outdoor air ventilation rate provided to each occupant (see Figure 3.2). For this reason much research has taken place on the monitoring of metabolic $CO_2$. Carbon dioxide demand controlled systems have become widely available and are used in many types of buildings.

### 3.4 Moisture and water vapour

Moisture, in the form of very high humidity (>70%) and condensation causes mould growth and can exacerbate health problems such as asthma. Generally, it is not possible for humans to immediately detect the relative humidity of the air if it is between approximately 15% and 75%, although extended periods of below about 30% can result in discomfort caused by drying of the skin. Low humidity also creates problems with static electricity. In the home, especially, moisture can be the dominant pollutant caused by production from cooking, washing and drying. It is also emitted from occupants. Significant humidity characteristics are summarised in Table 3.3.

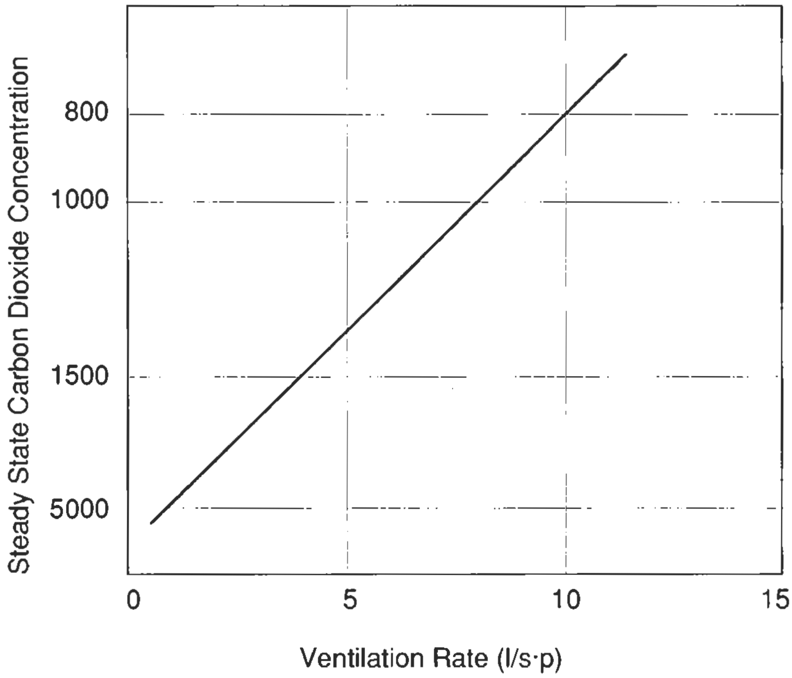


***Figure 3.2 Relationship between steady state metabolic $CO_2$ level and ventilation rate (assuming sedentary occupation and 350 ppm outside $CO_2$ concentration***

***Table 3.3 Characteristics of carbon dioxide***

| Situation | $CO_2$ concentration, total ppm | Notes |
|---|---|---|
| Risk of death | 50 000 | By oxygen depletion |
| Medical limit | 20 000 | Sheltered room ventilation |
| Hygienic limit | 10 000 – 15 000 | 15 min. value |
| Hygienic limit | 5 000 | Average for 8-hour shift |
| Quality level | 800 – 1 500 | From metabolism |
| Outdoor | 350 – 400 | |

Since the concentration of water vapour can easily be measured, humidity controlled systems are becoming increasingly popular. Demand controlled ventilation using moisture sensors should be the first choice for dwellings where they have been found to be effective in preventing moisture damage to the building fabric.

## 3.5 Particles and tobacco smoke

Particles are ever present and exist in variable concentration (Figure 3.3). Under normal (non-smoking) circumstances, particulates are unlikely to represent the dominant source of pollutant and, therefore, particulate detection would usually be an inappropriate ventilation control approach. A more appropriate control strategy, especially for individuals who are allergic to normal concentrations of particulates, would be high efficiency (HEPA) recirculatory filtration. Other sources of particulates (such as from vehicle exhaust) are a cause for concern but are not directly controllable by a demand controlled ventilation strategy. Instead, external sources can only be reduced by filtration or, if transient, perhaps by temporarily closing fresh air supply dampers, vents and windows etc.

***Table 3.4 Characteristics of moisture***

| **Value of Relative Humidity** | **Effect** | **Notes** |
|---|---|---|
| 30% - 60% | Approximate ASHRAE Comfort Range | |
| < 30% | Drying of skin, static electricity generated. | Aircraft cabin relative humidity is often below this value. It is often difficult to exceed 30% in cold dry climates. |
| > 55% | Propagation of house dust mites | |
| > 75% | Growth of mould due to condensation or a high percentage of moisture in building components and fabrics. | In poorly insulated buildings, the relative humidity can vary dramatically between interior spaces and cold surfaces. This makes humidity control systems unreliable. |

As illustrated in Figure 3.4, particulate concentration will become dominant in locations where smoking is permitted. Products of tobacco smoke also have a tendency to be adsorbed on to clothing, furniture and equipment. This induces a long-term effect, since volatile organic substances are released gradually from the surfaces to which tobacco products have been adsorbed.

Usually, it is not worth considering demand controlled fresh air ventilation if smoking is permitted since air renewal must be increased at least twenty-fold in order to dilute the smoke at a sufficient rate. However, where smoking is permitted, it may be beneficial to use high efficiency particulate and gaseous filtration based on combined electrostatic and carbon filter systems should. In transiently occupied spaces these could be controlled by switch operation, presence sensors or elementary smoke detectors.

## 3.6 Volatile organic compounds (VOC's)

Volatile organic substances contain carbon and, in most cases, hydrogen and oxygen as well. Many varieties of substances in this group may be found in buildings. New building materials often emit greater amounts of volatile organic substances than older materials, thus indicating the need for a temporarily higher rate of ventilation when first occupied. Detergents and cleaning compounds also often emit such great quantities of volatile organic substances that the ventilation air flow should be increased when cleaning is carried out.

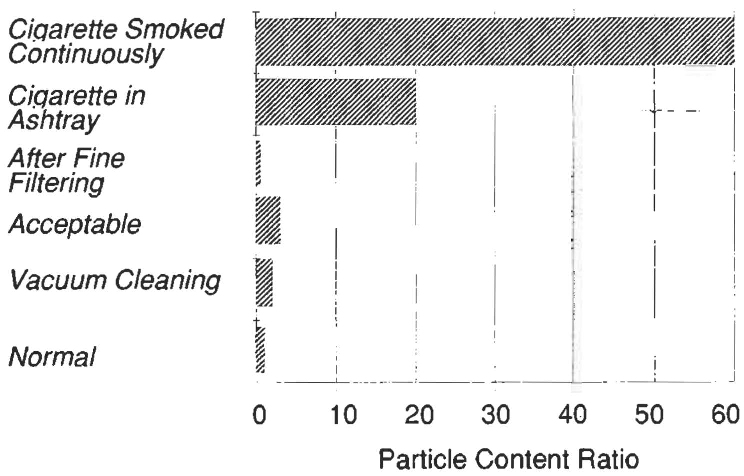


*Figure 3.3 Particulate concentration under various circumstances*

The sensitivity of humans to volatile organic substances is known only in the case of a few of these substances, while 'safe' threshold concentrations for many VOC's is still unknown. Although the concentration of individual volatile substances found in non-industrial buildings (i.e. offices, dwellings etc.) is often well below the hygienic limit values (as applied to industrial environments) the resultant odour intensity may still prove to be unacceptable. Where acceptable concentrations are specified, they vary considerably according to the type of VOC.

In addition, susceptibility to VOC's very much depends on the individual. Furthermore, the composition of volatile organic substances varies from building to building, and also depends on the age of the building materials and how they have been treated.

These factors make the control of ventilation based on measuring VOC concentration an almost impossible task. It is much more satisfactory, therefore, to minimise the emission rates of such chemicals in buildings.

# 4. Selecting a Sensor

Having identified the most likely pollutants, it is necessary to select an appropriate sensor. The most common types of demand controlled sensors and their applications are summarised below.

## 4.1 Humidity sensors

Humidity sensors can be used to operate extract fans to boost ventilation when moisture levels are high. They may also be incorporated into supply and extract grilles to provide automatic adjustment to the area of opening according to ventilation need. The most basic of sensor is based on the dimensional change characteristics of fibres such as hair, plastic or wood. Although inexpensive, this device requires frequent re-calibration and have substantial hysterisis. More accurate sensors are based on the electrical impedance characteristics of various materials or on the measurement of dew point temperature.

Annex 18 case study results, based on humidity control systems, were found to be variable. Canadian analysis showed that humidistats of the type that were commonly employed for relative humidity control in dwellings were often grossly inaccurate, subject to drift over time and were lacking in any convenient means of re-calibration.

Various systems based on humidity controlled air supply and exhaust, however, showed considerable promise. Successful implementation is described in the Case Study Report for an apartment building located in Les Ulis in France. This was based on the use of humidity controlled air supply grilles installed in the living room and bedrooms of each apartment and humidity controlled air extraction device located in the bathrooms and toilets. Successful humidity control was also demonstrated for a German dwelling in which the strategy was based on the careful monitoring of temperature as well as humidity. Failures tended to be associated with inadequate airtightness, poor flow control and insufficient extraction of moisture laden air.

## 4.2 Carbon dioxide sensors

Carbon dioxide sensors detect the presence of people by virtue of metabolic carbon dioxide concentration. Common measurement methods rely on the infra-red absorption properties of carbon dioxide although other techniques are also possible. A steady state maximum concentration of approximately 1000 ppm correlates to generally acceptable odour levels and hence represents the typical threshold setting. This concentration is approximately equivalent to a fresh air ventilation rate of 8 l/s.p. An advantage is that demand controlled ventilation based on carbon dioxide sensing can be readily incorporated into variable air volume ventilation systems.

Observations from case study analysis and elsewhere has indicated the risk of significant long-term instrument 'drift' resulting in a loss of set-point accuracy.

Depending on the environment, reliability can be lost within a few months, resulting in a space becoming inadequately ventilated. Sensors must therefore contain provision for simple re-calibration and this task must be undertaken regularly. This need for regular calibration was emphasised in the case study work of Fläkt AB, Sweden who concluded that these sensors should be recalibrated at least every second year.

$CO_2$ sensors are particularly useful in large variable occupancy buildings in which their added cost represents only a marginal increase in the total plant cost. The results of the Annex 18 Case Studies showed that $CO_2$ controlled systems worked well in transiently occupied buildings such as theatres, class-rooms, conference rooms and board-rooms. In practice, chosen set-points varied from between 600 ppm to approximately 1000 ppm. In general, because of instrument drift and variations in outside $CO_2$ concentrations, a safety margin (e.g. 100 ppm) was suggested when selecting a threshold value. This approach, however, is only acceptable when occupant metabolism represents the main source of odour and pollutant. Results also demonstrated that $CO_2$ systems could work well in housing but that the unit cost of the sensor was relatively high.

## 4.3 Infra-red presence detectors

Infra-red sensors can be designed to detect movement or heat radiation, or a combination of both. They therefore provide an indication of whether or not there are occupants in the area in question. Where the entry and exit location of people is well defined, automatic counters based on infra-red detection may be used to identify the actual number of people present in a space and hence modulate the rate of ventilation accordingly. Presence sensors can be used to start and stop a ventilation system, but, if precise counting is not possible, they may have to be supplemented with another type of air quality sensor (e.g. $CO_2$) to control the ventilation requirement while people are in the area in question. Supplementary sensors are not necessary when the occupant density and level of activity remains constant or where presence detectors can maintain an accurate count of occupant numbers. Presence detectors are very inexpensive and can be readily adapted to provide ventilation control.

## 4.4 Oxidisable gas sensors (general 'air quality' and 'VOC' sensors)

These react to a whole range of gaseous pollutants that can be oxidised. Examples include volatile organic compounds, methane and carbon monoxide. The difficulty is that they are non-discriminatory and hence it is not possible to identify the pollutant to which the sensor may be responding to at any particular time. (In addition, the sensor cannot give an absolute value.) In some instances the cocktail of detected gases might be representative of the dominant pollutants while, at other times, it might not. There is a risk, therefore, of false security in that the chosen threshold setting for system control may allow other pollutants to reach undesirable concentrations without warning. The case study of the Swedish National Testing and

Research Institute concluded that these sensors were quite sensitive to the presence of occupants, tobacco smoke and other pollutants produced in a room, but they are also very sensitive to changes in temperature and humidity, and to changes in the contamination level of outdoor air. Different sensors were found to have quite different outputs for the same air samples. It was concluded that oxidisable gas sensors have a potential for demand controlled ventilation, especially when the main pollutant load is not derived from heat sources or metabolically produced carbon dioxide. However, further development of these sensors and/or the associated control software is recommended.

### 4.5 Particle/smoke detectors

Inexpensive smoke detectors may be used to operated high efficiency recirculatory filtration systems to assist in reducing particulate concentration and odour intensity resulting from tobacco smoking. This approach is appropriate for board-rooms, clubs or designated areas where smoking is permitted. More complex particle detection methods are unlikely to be of value under normal conditions.

## 5. Other Issues

### 5.1 Steady state versus transient concentrations

A potential problem with demand controlled sensing is that the system may only operate once the sensor detects that the pollutant concentration has reached a pre-set threshold value. Until this concentration is reached, the fresh air supply could be very low or shut off completely. In turn, this may result in the concentration of other untracked pollutants increasing to unacceptable levels. It is for this reason that a basic 'background' ventilation rate should be applied to deal with emissions from other sources. Using basic dilution analysis as outlined, for example, in the AIVC Guide to Energy Efficient Ventilation (Liddament 1996), it is possible to estimate the time that it will take to reach a set-point concentration from the onset of a pollutant being emitted.

For carbon dioxide, assuming that before any period of occupancy the indoor concentration is the same as the outdoor concentration, then the transient concentration equation is given by:

$$c_t = c_e + \left(\frac{q}{q+Q}\right)\left[1 - e^{-\left(\frac{q+Q}{V}\right)t}\right]$$

where occupancy starts at time t = 0. In this equation,

$c_t$ is the indoor concentration of carbon dioxide ($m^3/m^3$) after time $t$ (s) from the start of occupancy,

$q$ is the indoor generation rate of carbon dioxide ($m^3/s$),
$Q$ is the volume flow rate of the outdoor air ($m^3/s$),
$V$ is the volume of the ventilated space ($m^3$), and
$c_e$ is the concentration of carbon dioxide in the outdoor air ($m^3/m^3$).

By means of an example, Figure 6.1 illustrates the consequences of a simple control strategy in which basic ventilation is continuously applied at 0.35 $l/s.m^2$ of floor area and a typical ceiling height of 2.75m is assumed. By applying the concentration equation, the time it takes to reach any given threshold concentration may be readily calculated.

In the example, occupancy densities of (i) 1 person/10 $m^2$ of floor area (e.g. an office space) and (ii) 1 person/5$m^2$ (e.g. a classroom or theatre) are assumed. For the low occupancy density, a metabolic $CO_2$ concentration of 800 ppm is reached after approximately 55 minutes and a concentration of 1000 ppm of $CO_2$ is reached after approximately 75 minutes from the start of occupation. When the occupant density is increased to the higher level, set-point is reached after approximately 20 minutes at 800 ppm and 35 minutes at 1000 ppm.

In each case, until the chosen threshold concentration is reached, the 'basic' ventilation rate must serve to deal with materials emissions while the space itself can be considered to act as an 'air quality' reservoir to cope with the initial impact of metabolic emissions.

If the time it takes to trigger occupancy related ventilation is considered to be too long, then either the sensor threshold level must be reduced (possibly resulting in over ventilation) or a more complex control strategy must be applied in which the ventilation system is triggered by the rate of change of measured $CO_2$ concentration. More detailed thoughts and solutions to dealing with pre-steady state conditions are covered by Persily (1996) and Madurri (1996).

## 5.2 Ventilation system – a source of pollution?

Various pollutants may be associated with the ventilation system itself. These include volatile organic compounds and, sometimes, fungal spores, dust or other material that may collect within the ductwork. To avoid such contamination, the system should be regularly cleaned and the supply air should be filtered. Exhaust air must also be filtered when it is used as return air or, in any event, to reduce the risk of breakdowns caused by an increase in pressure in coated duct walls.

An 'EU 7' standard 'fine' filter should ensure sufficient duct cleanliness to prevent the need for regular duct cleaning. Efficiently cleaned ducts and effective filtration of the air supplied to the duct system are criteria for efficient functioning and low costs throughout the service life of the system.

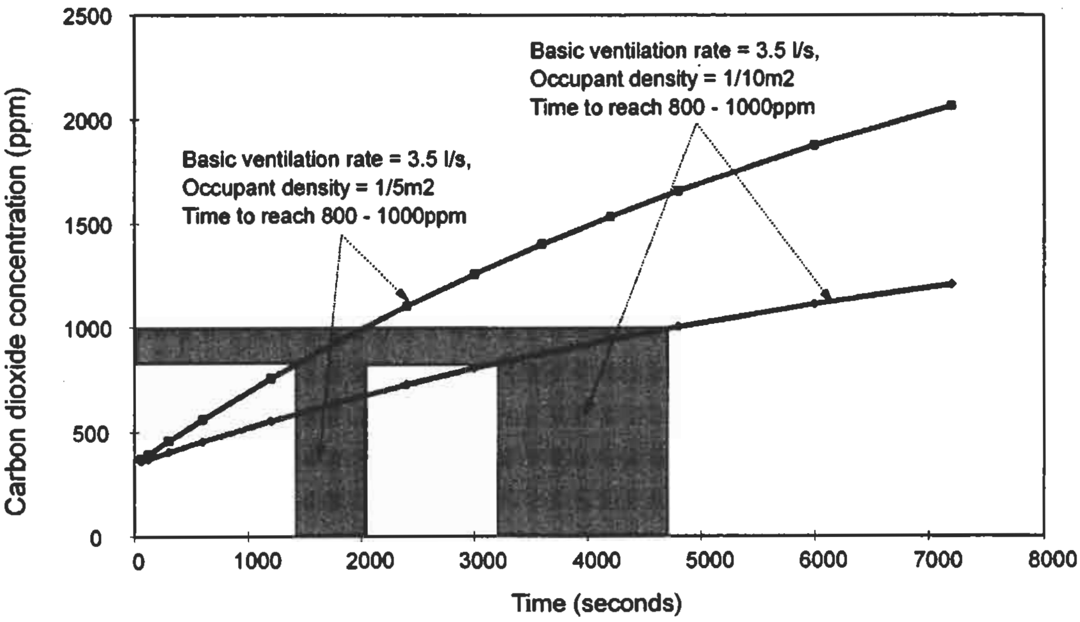


*Figure 5.1 Estimating the time to reach 'threshold' metabolic $CO_2$ concentration (assuming an outdoor concentration of 350 ppm)*

## 6. Applications and Case Studies - Dwellings and Work Premises

The following types of building are dealt with in the Source Book and the Case Studies Report:

- Dwellings,
- Schools,
- Day-care Centres,
- Assembly Halls, Theatres, Auditoria etc., and
- Offices, Conference Rooms etc.

These cover almost 90% of all buildings and essentially all of the building types that are appropriate for demand controlled ventilation.

### 6.1 Dwellings

Demand controlled ventilation can be introduced in most ventilation systems for dwellings on the condition that the building shell is airtight (i.e. typically less than 3 air changes/hour at an artificially induced pressure of 50 Pa). This ensures that the pattern of air flow is controlled entirely by the ventilation system.

The dominant pollutant is usually moisture which is generated in the 'wet' rooms (i.e. kitchens, bathrooms and WC's). Depending on the number of occupants and their level of activity, moisture generation can amount to between 6-14 kg/day (e.g. British Standard BS5925).

Systems are typically based on humidity sensors which either control the fan or passively adjust the size of air inlets and outlets in these rooms. As indicated in Section 6, case study results suggested that the simplest of humidistats tended to be unreliable.

Carbon dioxide can reach high concentrations in bedrooms (e.g. as much as 5000 ppm) but this is indicative of inadequate or improper ventilation provision in such rooms. For dwellings, $CO_2$ sensing is relatively expensive and recalibration unlikely.

This method, therefore should not normally be a necessary strategy for the home unless, for some reason, bioeffluents are considered critical.

## 6.2 Schools

Demand controlled ventilation can be introduced in most ventilation systems for schools on the condition that the building shell is not too draughty (i.e. for schools and all other non-domestic buildings, the air leakage at an artificially induced pressure of 50 Pa should not exceed about $5m^3/hr$ for each $m^2$ of envelope surface area).

The most vital function for a classroom ventilation system is to maintain the air quality at an acceptable level for the occupants. There is no reason to select an air flow sufficiently large such that 'visitors' to the space are unaware of odour (i.e. the need should be set for occupants and not visitors to a space).

Typically, the following control mechanisms should be applicable:

- Basic ventilation should be in operation when classrooms are not in use.
- If a fan-controlled system is used for demand controlled ventilation, the system is best controlled using carbon dioxide or presence sensors.
- Subject to outside climate conditions (temperature, humidity, air quality, noise etc.) the opening of windows to air rooms during breaks is recommended for both natural ventilation and forced ventilation systems.

The effect of various ventilation strategies on the energy requirement for schools is shown in Figure 7.1 and Table 7.1.

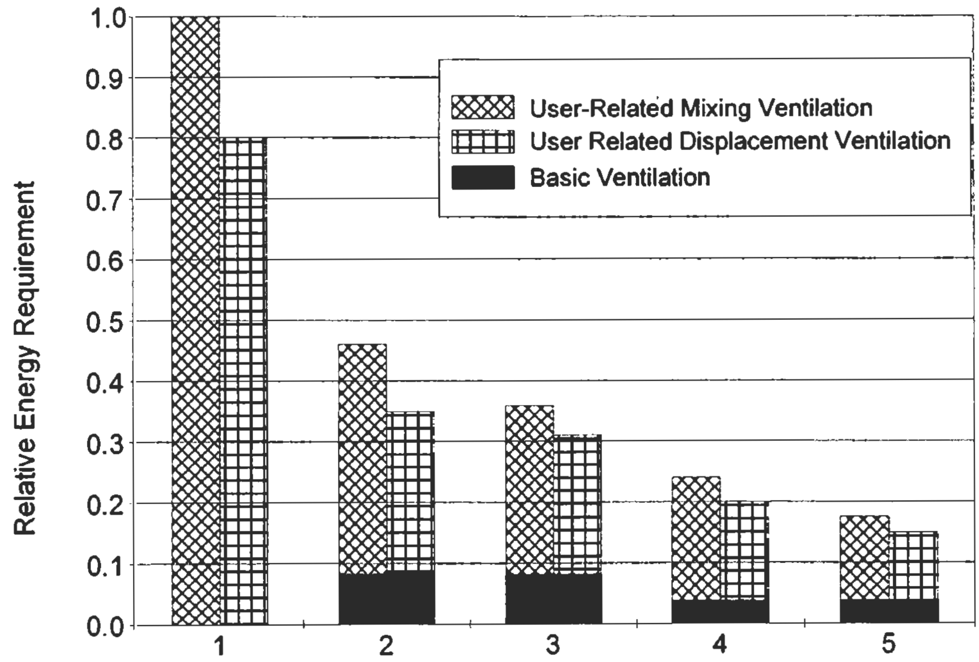


*Figure 6.1 Energy throughput as a function of design and mode of operation in a classroom for 30 pupils*

*Table 6.1 Relative effect of various ventilation strategies on the energy requirement for schools*

| Ventilation strategies in a classroom 200 $m^3$ in size, with 30 pupils, 10 l/p·s, basic flow 0.5 $h^{-1}$. The displacement ventilation results in a 20% reduction of the user-related requirement | | |
|---|---|---|
| No. | Strategy | Relative energy requirement |
| 1 | Full flow, 24 h | 1.0 |
| 2 | Full flow 10 h during day, basic flow 14 h | 0.47 |
| 3 | Presence-related control | 0.36 |
| 4 | As for case 2, but with 50% heat recovery | 0.24 |
| 5 | As for case 3, but with 50% heat recovery | 0.18 |

## 6.3 Day-care centres

The number of people and the level of activity in day-care centres vary widely. Generally, children spend longer periods of time indoors than children in a classroom.

Therefore, when providing ventilation for day-care centres, the following points generally apply as supplements to the requirements for ventilation in schools:

- Basic ventilation should be in operation when the day-care centre is not in use.
- Smoking shall be forbidden in all areas.
- Carbon dioxide sensors can be used for control purposes.
- Opening windows to air rooms should be a supplement to the ventilation system when the outdoor temperature permits or demands this.
- The air flow (in the form of heated supply air during the winter) must be supplied by means of a fan, at least in areas with a colder climate.

## 6.4 Assembly halls

Demand controlled ventilation is frequently a viable solution for all types of assembly hall. The basic ventilation and choice of materials for the building and equipment, along with presence-related ventilation, must be selected such that the first impression gained by a person entering the premises is that the air inside is fresh (i.e. free of odour).

Ventilation systems in a new or renovated assembly hall should be continuously operated for a period which is long enough to ensure that the usually high emission of pollutants found just after the premises have been completed does not cause discomfort. Once the initial emission of pollutants has subsided, demand controlled can be applied.

The control system must be able to control the air quality, air speed and room temperature. In the case of assembly halls, carbon dioxide sensors as controllers are the primary choice. Wherever possible, heat recovery should generally be implemented.

## 6.5 Offices

Control strategies for offices will depend on the structure and operation of the building. DCV may be applied to the entire office or to individual floors or rooms. Much will depend on the occupancy pattern. As a rule, demand controlled ventilation in offices of uniform occupancy is not profitable except for simplistic controls to switch the ventilation system on or off.

Demand controlled ventilation for meeting rooms, conference rooms and other transiently occupied areas can be profitable in approximately the same way as for large assembly halls. Control can be effected by means of carbon dioxide sensors or, possibly, presence sensors.

In small offices, basic ventilation for times outside office hours may be possible by operation of toilet extract fans.

# 7. Savings

An essential purpose of demand controlled ventilation is to reduce energy demand. In many cases, it is possible to show energy savings of 60% or more when compared with the continuous operation of a ventilation system. Before implementing a demand controlled system, however, a full benefit analysis should be undertaken. Savings are calculated by comparing the estimated energy demand based on DCV with that of a conventional system. Payback periods may then be evaluated, taking into account any additional cost, maintenance and operational requirements.

In case study examples, actual savings were found to vary from between 0-80% of those actually calculated. The zero level is usually a result of improper operation and maintenance. To investigate the feasibility of a DCV system in complex situations, it is important to undertake conventional simulation modelling in which system performance is analysed under typical (as opposed to extreme) climate conditions for the locality.

Estimated energy savings and payback periods for various building types and DCV systems are summarised in Table 8.1. This represents only basic guidance, however, and the designer must apply conditions and costs as they relate to the particular climate and country of the proposed building.

***Table 7.1 Potential savings with demand controlled ventilation***

| Type of building | Type of DCV system | Saving, % | Saving [1) ] ECUs/($m^2$ y) | Investment [1) ] ECUs/$m^2$ | Repayment time, years |
|---|---|---|---|---|---|
| **Residential buildings** | Manual or moisture sensor | 5 – 15 | 1 – 3 | 3 – 5 | 1 – 5 |
| **Offices** | | | | | |
| Sale 40% presence and 50% heat recovery | $CO_2$ | 20 – 30 | 1 – 2 | 10 – 20 | 5 – 10 |
| Admin. 90%, presence and 50% heat recovery | $CO_2$ | 3 – 5 | 0.3 | 10 – 20 | > 30 |
| **Schools** | | | | | |
| Heat exchange | $CO_2$ presence | 5 – 10 | 3 – 6 | 5 – 10 | 0.5 – 3.0 |
| No exchange | $CO_2$ presence | 20 – 40 | 15 – 25 | 20 – 60 | 1.5 – 2.5 |
| **Assembly halls** | $CO_2$ | 20 – 50 | 20 – 40 | 10 – 70 | 0.5 – 3.0 |
| **Day-care centres** | $CO_2$ | 20 – 30 | 3 – 5 | 5 - 10 | 0.5 – 3.0 |
| **Department stores** | VOC | 50 – 70 | 15 – 20 | <0.1 | < 0.1 |
| **Sports centres** | VOC | 40 – 60 | 20 – 30 | 5 –10 | 0.2 – 0.5 |

*1) 1 ECU = US$ 1.25*

# 8. Conclusions and Recommendations

Demand controlled ventilation is applicable when there is a transient and identifiable 'dominant' source of pollutant. To perform correctly, the building shell should be constructed to a high level of airtightness (i.e. typically < $5m^3/m^2.hr$ at 50 Pa) and the initial emission of pollutants arising from new construction or retrofit must be separately vented (e.g. by window opening or by continuous operation of the ventilation system).

Outside periods of occupancy, a basic rate of ventilation rate (e.g. 0.35 $l/s.m^2$) or pre-occupancy ventilation should be applied to prevent the build-up of pollutants emitted from furnishings and materials. During occupancy periods demand controlled ventilation systems may be appropriate. The minimum rate of ventilation should not fall below that required for 'basic' ventilation, while the maximum rate should be capable of satisfying the peak design pollutant load.

Realistically, the current primary demand controlled strategies:

- ***Humidity (principally for dwellings):*** Basic fibre type sensors have been shown to be unreliable hence systems based on electrical impedance characteristics should be considered. Sensors incorporated within vent openings themselves have been demonstrated to be effective.

- ***Metabolic carbon dioxide (principally for transiently and densely occupied buildings):*** This approach has been shown to be reliable but sensors must be regularly calibrated. Occupants must represent the only source of $CO_2$ generation. Each room within the building should be separately monitored.

- ***Presence sensors (for transiently occupied buildings):*** These are inexpensive and can be used to operate a ventilation system while people are present in a space. If the detectors can be contrived to count the number of people entering and leaving a space, this approach could be used to modulate the actual rate of ventilation otherwise an additional $CO_2$ sensor may be needed.

- ***Other sensors (time controls, switches and smoke detectors):*** these all have potential applications and offer inexpensive solutions for specific situations. Simple methods should be considered at the design stage and selected in preference to more complex systems when possible.

- ***Oxidisable 'mixed gas' sensors:*** These are readily available and are inexpensive. The Annex 18 study recognised a potential for such sensors but concluded that further development was necessary to both the hardware and associated control software to enable some discrimination between the cocktail of gases that are detected.

The intention behind demand controlled ventilation is to provide good air quality with low energy consumption. The service life cost varies, depending on the type of building and the method of utilisation. Sensors are being developed at a rapid pace.

Therefore, it is essential that an investigation be carried out at the planning stage to find out what options are available.

Mediocre maintenance of the sensors and control system can lead to operating results which are poorer than anticipated.

Each building must be dealt with separately. Experience has shown that demand controlled ventilation can function well and reduce energy consumption, as well as providing good indoor air quality.

## 9. References

ASHRAE Standard 62, *Minimum Ventilation for Acceptable Indoor Air Quality*, Public Review Draft, 1996.

Dickson D., *Ventilation Technology in Large Non-Domestic Buildings*, Air Infiltration and Ventilation Centre, Draft Technical Note, 1997.

Liddament M.W., *A Guide to Energy Efficient Ventilation*, Air Infiltration and Ventilation Centre, 1996.

Månsson L.-G. and Svennberg S. A., *Behovsstyrd ventilation i bostäder och lokaler*, Swedish Council for Building Research, Stockholm, Sweden, ISBN: 91-540-5587-9, 1993.

# Appendix 1 - Contributors and Participating Countries

| Country | Name and organisation | Annex 18 National representative | Expert | Contributor to full-scale trials |
|---|---|---|---|---|
| Belgium | Peter Wouters, CSTC/WTCB | x | x | x |
| | P Jardinier, Aereco, France | | | x |
| | J Simonnot, Serva, France | | | x |
| Canada | Bob Davidge, Public Works | x | x | x |
| | Tom Hamlin, CMHC | | x | x |
| | Peter Moffatt, Sheltair Scientific Ltd. | | | x |
| Denmark | Peter Collet, Dansk Teknologisk Institut | x | | |
| | Geo Clausen, DTH | | x | |
| Finland | Marianna Luoma, VTT | x | x | |
| Germany | Willigert Raatschen, Dornier GmbH | x | x | x |
| Italy | Gian V Fracastoro, Politecnico di Torino | x | x | x |
| | Marco Masoero, Politecnico di Torino | | | x |
| Netherlands | J J M Cauberg, Cauberg–Huygen Ing BV | x | x | x |
| | Hans J Pfaff, TNO | | | x |
| Norway | Finn Drangsholt, NTH/SINTEF | x | x | x |
| Sweden | Lars-Göran Månsson, LGM Consult AB | Operating Agent | x | |
| | Sven A Svennberg, RAMAS/KTH | x | x | |
| | Hans Stymne, Byggforskningsinstitutet (SIB) | | x | x |
| | Mats Sandberg, Byggforskningsinstitutet (SIB) | | | x |
| | Magnus Mattsson, Byggforskningsinstitutet | | | x |
| | (SIB) | | x | x |
| | Leif Norell, ABB Fläkt | | x | x |
| | Per Fahlén, SP | | | x |
| | Helena Andersson, SP | | | x |
| | Svein H Ruud, SP | | x | x |
| | Ove Strindehag, ABB Fläkt/CTH | | | |
| Switzerland | | | x | |
| | Charles Filleux, Basler & Hofmann | x | x | x |
| | Marco Zamboni, Basler & Hofmann | | x | x |
| | Jürg Fehlmann, Federal Inst. of Tech. (ETH) | | | x |
| | Claude-Alain Roulet, LESO, Lausanne | | | |

## Appendix 2 - Publications of Annex 18

Work on ANNEX 18 has resulted in the following publications, all bearing the title ***Demand Controlled Ventilating Systems:***

1. **State of the Art Review**
   BFR D9:1990, ISBN 91-540-6169-X
   The progress report contains:
   - Pollution content in various types of building
   - Standards for indoor air quality
   - Function principles for sensors
   - Review of studies on demand controlled ventilation
   - Pollutant levels measured in occupied buildings

2. **Sensor Market Survey**
   BFR D2:1992, ISBN 91- 540-5417-6
   This market survey contains manufacturer data on 52 commercially-available sensors as specified below:
   - Moisture sensors (26)
   - Carbon dioxide sensors (7)
   - Sensors for oxidisable substances (“air quality sensors”) (7)
   - Presence sensors, etc. (12)

3. **Sensor tests**
   SP Report 1992:13
   ISBN 91-7848-331-X
   Sensor tests were carried out at SP in Borås, which comprised the testing of 15 types of sensor, four of each (a total of 60 sensors) as specified below:
   - Moisture sensors (8 types)
   - Carbon dioxide sensors (2 types)
   - Sensors for oxidisable substances(5 types)

4. **Case Studies**
   BFR D1:1993, ISBN 91-540-5511-3
   These case studies were carried out in laboratories in two instances and in the field for several projects as specified below:
   - Houses (10)
   - Flats (7)
   - Office blocks (6)
   - Assembly halls (2)
   - School (1)

   Tests have been carried out with both mixing ventilation and displacement ventilation.

5. **Source Book**
   BFR D2:1993, ISBN 91-540-5513-X
   The Source Book, which is summarised in the subsequent report, shows the utilisation of demand controlled ventilation, with its advantages and limitations.

They can be purchased from:
*ECBCS Bookshop, c/o AIVC, Unit 3a, Sovereign Court, University of Warwick Science Park, Sir William Lyons Rd, Coventry, CV4 7EZ, United Kingdom,*
*Tel: +44 (0)1203 692050, Fax: +44 (0)1203 416306, Email: bookshop@ecbcs.org*

# Appendix 3 - Bibliography of Other DCV-Related Publications

## A3.1 Dwellings

**#NO 4285 Demand controlled ventilation systems in three Finnish demonstration dwelling houses.**
AUTHOR Luoma M, Laine J, Kohonen R
BIBINF Netherlands, International CIB W67 Symposium, "Energy, Moisture and Climate in Buildings", 36 September 1990, Rotterdam, pII10, 2 figs, 6 refs. #DATE 00:00:1990 in English
ABSTRACT In this study the multifamily demonstration buildings with demand controlled ventilation systems are discussed. Furthermore, the heating systems together with demand controlled ventilation are looked at. Examples are given of the centralized supply and exhaust ventilation system, the centralized exhaust ventilation system and the apartment based ventilation system. All the systems are mechanical, natural ventilation is not discussed here. In cold climates natural ventilation, i.e. opening of the windows, can't meet the requirements on good indoor air quality and thermal comfort and leads to poor energy economy.
KEYWORDS demand controlled ventilation, residential building, testing house

**#NO 4853 Performance assessment of a humidity controlled ventilation system.**
AUTHOR Fantozzi C, Fracastoro G V, Masoero M
BIBINF UK, AIVC 11th Conference, "Ventilation System Performance", held 1821 September 1990, Belgirate, Italy, Proceedings published March 1990, Volume 2, pp 6380, 12 figs, 4 tabs, 3 refs. #DATE 00:03:1991 in English
ABSTRACT Demand controlled ventilation systems have recently become an interesting opportunity to achieve acceptable indoor air quality while minimizing energy consumption. Although they are usually designed for buildings showing relevant variations of occupancy (e g, office buildings, schools, etc), there are now examples of applications also in residential buildings. One example is the passive humidity controlled ventilation system recently developed in France. This type of installation has been tested in a five story apartment building located in Torino, Italy, during the winter 1989. Preliminary results, concerning air temperature and relative humidity data and system operation, are presented in this paper. Analysis of data shows that the system is capable of maintaining air humidity levels below the limit values in most situations, reacting effectively to changes in the occupancy patterns and activities. The energy savings compared to a conventional constant flow ventilation system have also been calculated.
KEYWORDS humidity, controlled ventilation

**#NO 5287 Performance analysis of demand controlled ventilation system using relative humidity as sensing element.**
AUTHOR Parekh A, Riley M
BIBINF UK, AIVC 12th Conference, "Air Movement and Ventilation Control within Buildings", held 2427 September 1991, Ottawa, Canada, proceedings published September 1991, Volume 2, pp 227234. #DATE 00:09:1991 in English
ABSTRACT This paper evaluates the suitability of humidity controlled house ventilation system to determine (i) the effectiveness of relative humidity as a sensing element, and (ii) the operating and performance characteristics of such ventilation strategy. The ventilation system consists of continuously running "mechanical" air extractor units and "passive" air inlet units equipped with humidity sensors. The ventilation system was installed in two single story houses which were monitored during November 1989 to April 1990. Results showed that the changes in the relative humidity did not appear to track the levels of normal human activity accurately. The difference in air inflow through each passive air inlet due to changes in RH (2 to 10%) varied from 0. 8 L/s to a maximum of 1.7 L/s, which was found to be insufficient based on high CO2 levels (> 1200 ppm) in occupied rooms. The humidity controlled mechanical exhaust system was found satisfactory in maintaining the level of exhaust airflow with changes in RH. The air inflow and outflow analyses showed that the air leakage though the house envelope remained as a predominant form of fresh air supply to the house, thus defeating the purpose of demand controlled ventilation. The energy consumption of these two houses reduced by more than 8% by cutting down the fresh air provided to house during unoccupied periods. Relative humidity as an exclusive sensing element may not be sufficient enough to achieve required quality ventilation in houses.
KEYWORDS performance testing, demand controlled ventilation, humidity

**#NO 5289 A demonstration of low cost DCV technology on five Canadian houses.**
AUTHOR Moffatt P
BIBINF UK, AIVC 12th Conference, "Air Movement and Ventilation Control within Buildings", held 2427 September 1991, Ottawa, Canada, proceedings published September 1991,

Volume 2, pp 245256. #DATE 00:09:1991 in English
ABSTRACT Field investigations were undertaken on five houses to determine the potential for improved performance and lower costs through the use of a demand controlled ventilation (DCV) systems. All 5 houses were energy efficient, low toxicity construction, and where chosen to reflect a range of mechanical systems consistent with Canada's new ventilation standard (CSA F326). Three of the test houses were extensively monitored and, after 90 days of conventional operation, were converted to DCV using a wide variety of sensors and controls. A fourth house with a previously installed DCV system was submitted to a series of "activity scenarios" to evaluate the performance of a DCV system based on extractors and inlets that respond to indoor relative humidity. The fifth house was a new house, designed to demonstrate DCV technology, and to validate the insights obtained from the other 4 houses. Commissioning of the new DCV house showed the suitability of using low cost sensors for detecting VOCs, absolute humidity, air flow and activity levels. A low-cost but sophisticated computerized control and monitoring system was used to analyze the ventilation needs and to switch fan motor windings and speeds to create a range of "operating modes" for the ventilation system. A video monitor display with occupant control added a further measure of demand control. The result was a successful demonstration of how currently available and affordable sensors and controls can be used to improve the performance of typical ventilation systems.
KEYWORDS demand controlled ventilation, residential building, energy efficiency

### #NO 5989 A new ventilation strategy for humidity control in dwellings.

AUTHOR Nielsen J B
BIBINF UK, Air Infiltration and Ventilation Centre, 13th AIVC Conference, proceedings, held Hotel Plaza Concorde, Nice, France, 1518 September 1992. #DATE 15:09:1992 in English
ABSTRACT This report presents the results from the registration throughout a month of relative humidity, temperature and outdoor air exchange as well as the concentration of carbon dioxide in each room of an inhabited single family house, in which all rooms are ventilated by a mechanical balanced ventilation system with variable air volume. The outdoor air rate is controlled by the relative humidity, which is kept on a value adequate to reduce the living conditions for house dust mite and prevent condensation on the indoor surfaces of the building. Due to the demand controlled ventilation of each individual room a higher efficiency for reducing water vapors in the dwelling as a whole is likely to be achieved. The results show that it was possible in the context of Danish outdoor climate to maintain humidity conditions that is anticipated to reduce the number of house dust mites in all rooms of a dwelling during more than five months of the year. In all the months the mean daily mechanical ventilation rate is estimated to be 39% below the level recommended by the Nordic Committee on Building Regulations and in the Danish Building Code. At the same time indoor condensation was avoided on poorly insulated surfaces of the building. The concentration of carbon dioxide was below the level recommended in national ventilation standards.
KEYWORDS ventilation strategy, humidity, residential building, carbon dioxide, mechanical ventilation, ventilation rate

### #NO 6386 Final report. Demand controlled ventilation.

AUTHOR Sheltair Scientific Ltd
BIBINF Canada Mortgage and Housing Corporation, March 1991, 119pp + app. #DATE 00:03:1991 in English
ABSTRACT This research project was completed for the Research Division of Canada Mortgage and Housing Corporation, and is part of Canada's contribution to an international research effort on Demand Control Ventilation (DCV). The research took place between September 1989 and December 1990. The primary objective for the project was to determine if DCV can improve the way in which Canadian houses are ventilated, while lowering the operating or capital cost of ventilating systems. A further objective was to provide guidance for home builders and ventilation system designers on what DCV strategies might be most appropriate for near term applications. The project was completed in five separate phases, which included a literature survey, the preparation of a Primer for home builders and system designers, extensive field research on five houses, computer simulations, and economic analysis.
KEYWORDS demand controlled ventilation, residential building, ventilation system

### #NO 7943 Performance of humidity controlled house ventilation system in cold climates

AUTHOR Parekh A J, Riley M A
BIBINF USA, ASHRAE Transactions, Vol 100, Pt 2, 1994, (preprint), 9pp, 7 figs, 2 tabs, refs. #DATE 00:00:1994 in English
ABSTRACT This paper evaluates the applicability of a humidity controlled house ventilation system in cold climate. The ventilation system consists of continuously running mechanical air extractor units and passive air inlet units equipped with humidity sensors. The results of monitoring two such houses showed that changes in the relative humidity (RH) did not appear to track the levels of normal human activity accurately. The difference in airflow through each passive air inlet due to changes in relative humidity (2% to 10%) varied from 0.8 L/s

(1.7cfm) to a maximum of 1.7 L/s (3.5 cfm) which was found to be insufficient based on high carbon dioxide (CO2) levels (>1,200 ppm) in occupied rooms. The air inlets responded quickly to sudden large changes in occupancy by opening; however, the net change in fresh air inflow was insufficient. The humidity controlled mechanical exhaust system was found satisfactory in maintaining the level of exhaust flow with the changes in relative humidity. The air inflow and outflow analyses showed that air leakage through the house envelope remained the predominant form of fresh air supply at the house, thus defeating the purpose of demand controlled ventilation. The energy consumption of these two houses was reduced by more than 8% by cutting the fresh air provided to the house during unoccupied periods. the results of air quality monitoring (particularly CO2) in both houses, however raised questions about the suitability of humidity sensing as an exclusive demand control strategy for ventilation.

KEYWORDS humidity, controlled ventilation, cold climate

**#NO 7945 Evaluation of strategies for controlling humidity in residences in humid climates**

AUTHOR Trowbridge J T, Ball K S, Peterson J L, Hunn B D, Grasso M M

BIBINF USA, ASHRAE Transactions, Vol 100, Pt 2, 1994, (preprint),15pp, 12 figs, 2 tabs, refs.#DATE 00:00:1994 in English

ABSTRACT Maintaining relative humidity in the range of 30% to 60% in buildings results in many advantages, such as improved comfort and reduced health risks. However, for residences in humid environments it is difficult to maintain these conditions all year. Several passive strategies involving modifications of the moisture capacitance and transmittance of the building envelope, coupled with conventional air-conditioning equipment, are investigated to reduce interior humidity levels. A parametric study is conducted for a typical residence in Austin, Texas, using FSEC 3.0 a building simulation program. The conclusion is that none of the passive strategies provides a comprehensive year round solution to elevated indoor humidity conditions. However, the addition of a separate controlled vapor compression ventilation system ( controlled by a humidistat)for the conditioning of outside air can provide improved indoor air quality and may lower peak electric demand for residential air conditioning during the cooling season

**#NO 7981 Simple and reliable systems for demand controlled ventilation in apartments.**

AUTHOR Svennberg S

BIBINF UK, Air Infiltration and Ventilation Centre, 1994, "The Role of Ventilation", proceedings of 15th AIVC Conference, held Buxton, UK, 2730 September 1994, Volume 1, pp313320.

ABSTRACT The paper is presenting experience from a several year long time of operation in a group of apartment buildings in the Stockholm area, Sweden, having an extremely low energy usage, less that 110kWh/(m2.year), electricity supply to the building services included. The system solution used has a very low pressure drop in the exhaust ducts. Every exhaust point is connected to an individual duct leading to a fan chamber in the attic. The pressure in that chamber is kept constant. The attendant in a flat wanting a higher flow rate starts an individual booster fan situated at the top of his own duct. Supply air is furnished by valves installed in the external walls of the flat. Balancing is made in the fan chamber only. Thus nobody can arrange a higher base flow rate for an individual flat without having access to the fan chamber. The investment level is comparable to that of a traditional system. Duct dimensions are chosen so as to allow them to be built-in into the walls. The system, which was designed by Mr Henry Willman of HEWAB Engineering, Stockholm, is applicable for offices and the like with or without a mechanical air supply system.

KEYWORDS (demand controlled ventilation, apartment building, fan)

**#NO 7983 Improvement of domestic ventilation systems.**

AUTHOR Heikkinen J, Pallari ML

BIBINF UK, Air Infiltration and Ventilation Centre, 1994, "The Role of Ventilation", proceedings of 15th AIVC Conference, held Buxton, UK, 2730 September 1994, Volume 1, pp333342.

ABSTRACT The aim of the study was to identify methods for the renovation of ventilation systems in domestic buildings which are 38 stories high. Three typical buildings were selected and the problems in ventilation were examined. The designers made their proposals for repairs and the research team analyzed the solutions and made improvements. The special problems compared with new buildings included less airtight building envelopes and leakages in existing ventilation ducts. An analysis was performed, using a multizone airflow model, for the whole year and therefore the ventilation heat loss could be found in each case. As anticipated, the airflow rate of passive stack ventilation was too high in winter and too low in summer, but the system can be improved by means of controlled air inlets and outlets. A mechanical extraction system can be improved with demand controlled ventilation instead of time control. The installation of heat recovery system requires improved sealing of the building envelope to minimize cross ventilation. The proposed systems will be tested and followed up later in experimental buildings.

KEYWORDS (ventilation system, high rise building, building envelope, duct)

#NO 8621 Evaluation of strategies for controlling humidity in residences in humid climates.

AUTHOR Trowbridge J T, Ball K S, Peterson J L, Hunn B D, Grasso M M

BIBINF USA, ASHRAE Transactions, Vol 99, Part 2, 1993, pp 5973.

ABSTRACT Maintaining relative humidity in the range of 30% to 60% in buildings results in many advantages, such as improved comfort and reduced health risks. However, for residences in humid environments, it is difficult to maintain these conditions all year. Several passive strategies involving modifications of the moisture capacitance and transmittance of the building envelope, coupled with conventional air conditioning equipment, are investigated to reduce interior humidity levels. A parametric study is conducted for a typical residence in Austin, Texas, using FSEC 3.0, a building simulation program. The conclusion is that none of the passive strategies provides a comprehensive, year round solution to elevated indoor humidity conditions. However, the addition of a separately controlled vapour compression ventilation system (controlled by a humidistat) for the conditioning of outside air can provide improved indoor air quality and may lower peak electric demand for residential air conditioning during the cooling season.

KEYWORDS humidity, humid climate, cooling

#NO 8879 Comparison of ventilation systems performances related to energy consumption and indoor air quality

AUTHOR Villenave J G, Riberon J, Millet R R

BIBINF Canada, proceedings Indoor Air Quality, Ventilation and Energy Conservation in Buildings , Second International Conference, held May 912, 1995, Montreal, edited by Fariborz Haghighat, Volume 2, pp710717.

ABSTRACT In France the ventilation of residential buildings have to continuously supply fresh air to the habitable rooms and to exhaust stale air from the service rooms with the possibility of reducing the ventilation rate during under occupancy and reversing the normal one when necessary. The regulation stipulates requirements both in terms of results for the energy consumption and in terms of means for the indoor air quality: the thermal regulation requires to include the energy loss due to ventilation in the total energy loss of the building and the ventilation regulation requires a minimal value of the extract flow in the service rooms. The C.S.T.B. has developed a methodology to assess the efficiency of the different ventilation systems in use, by comparison with a conventional mechanical exhaust ventilation system. both indoor air quality and heat losses, evaluated by using a computer code, are compared to the reference system. The computer code SIREN ( Simulation du RE Nouvellement d air ) is used to calculate the air flow rate throughout the entire heating season (about seven months) in a dwelling equipped with the purposed ventilation systems: reference ventilation system, passive stack ventilation, demand controlled ventilation system. This paper presents the compared results of the different ventilation systems bands shows the balance between energy consumption and indoor air quality depends greatly on the type of ventilation system.

KEYWORDS ventilation system, energy consumption, indoor air quality

#NO 9068 Improvement of a mechanical ventilation system regarding the utilization of outdoor air.

AUTHOR Carlsson T, Blomsterberg A

BIBINF UK, Air Infiltration and Ventilation Centre, 16th AIVC Conference Implementing the results of ventilation research , held Palm Springs, USA, 18 22 September, 1995, Proceedings Volume 2, pp 315326.

ABSTRACT Nowadays it is rather common with demand controlled ventilation in public buildings and offices. The purpose of demand controlled ventilation is to adapt the ventilation to the varying needs of the occupations. In dwellings it is rather unusual with demand controlled system. The main reason for that is the high investment cost for the system. The outdoor air used for ventilation in dwellings is therefore not effectively used. For example in a mechanical exhaust ventilation system 50% of outdoor air is leaving the house without being used for people. In a multi zone computer program simulations based on tracer gas measurements were done for two modern typical houses. We did calculation for outdoor air floe for the whole and for a single room, during a heating season. Two different ventilation systems were simulated. The air flows between rooms and between the inside and outside were calculated. We found that we could utilize the outdoor air better if the systems were reconstructed. The reconstructed system contains the same amount of air inlets and outlets, but all outdoor air is supplied to the bedrooms. Further calculations show us the ratio between the interzonal air flow created by the fan(s) and interzonal sir flow created by differences in temperature was 1 to 10. The paper presents the results from calculations of air flows for two different ventilation systems. Further on the paper discusses how a system should be constructed to utilize the outdoor air in an optimal way.

KEYWORDS mechanical ventilation, outdoor air, demand controlled ventilation

**#NO 9084 A new ventilation strategy for humidity control in dwellings a demonstration project.**

AUTHOR Nielsen J B, Ambrose I

BIBINF UK, Air Infiltration and Ventilation Centre, 16th AIVC Conference Implementing the results of ventilation research , held Palm Springs, USA, 18 22 September, 1995, Proceedings Volume 2, pp 493506.

ABSTRACT A demand controlled ventilation system with humidity as the control parameter was tested in an experimental demonstration project in 16 apartments. In the same housing complex 16 identical apartments with a constant exhaust airflow rate were included in the test as a reference group. The purpose of the study was to investigate whether satisfactory physical health conditions could be reached in the humidity controller in apartments, while at the same time reducing the use of energy for heating. In the apartments with humidity controlled ventilation the air supply was regulated so that the humidity in the indoor air in all rooms was kept at a level which was below the limit for growth of house dust mites and just sufficient to prevent condensation on all indoor surfaces of the building. The airflow could increase up to a maximum to the requirements as stated in the Nordic Committee on Building Regulations and in the Danish Building Code. The airflow in the reference apartments was at a constant level, according to the requirements. In the humidity controlled apartments the total outdoor air change, the mechanical exhaust airflow rate, and the energy consumption for heating were significantly reduced compared to the reference apartments, at mean temperatures per day below 9 degrees C and at the same time the humidity criteria were met. In addition to the technical study, a resident indoor climate satisfaction study was carried out in the housing complex. The main purpose of this study was to gain knowledge of the residents appraisals of the indoor climate.

KEYWORDS ventilation strategy, humidity, residential building

**#NO 9852 Practical experiences with IR controlled supply terminals in dwellings and offices.**

AUTHOR Ducarme D, Wouters P, Jardinier M, Jardinier L

BIBINF UK, Air Infiltration and Ventilation Centre (AIVC), 1996, proceedings of 17th AIVC Conference, "Optimum Ventilation and Air Flow Control in Buildings", Volume 1, held 1720 September 1996, Gothenburg, Sweden, pp 243252.

ABSTRACT Ventilation is necessary to provide a good indoor air quality to occupants in office buildings but is however a major energy consumer. In that manner, ventilation in itself can contribute to much more than 50% of the energy consumption for heating in well insulated office buildings. Likewise, the general trend in standards to augment ventilation requirements would still increase its energy costs. Thus, it seems obvious that an intelligent control of ventilation in office building allows to obtain substantial reductions of energy consumption. To a certain extent this is also true for dwellings even if in general ventilation represents a smaller contribution to the energy consumption for heating than in office buildings. In this connection, it should be noted that the increasing requirements regarding insulation of dwellings has for effect to augment this proportion. Demand controlled ventilation in dwellings appears therefore also as an interesting way to achieve energy consumption reduction.

KEYWORDS air conditioning, demand controlled ventilation, office building, insulation

**#NO 10026 Field demonstration of a prototype residential ventilation controller.**

AUTHOR Kesselring J P

BIBINF Indoor Air '96, proceedings of the 7th International Conference on Indoor Air Quality and Climate, held July 2126, 1996, Nagoya, Japan, Volume 1, pp 847852.

ABSTRACT Nonuse of residential mechanical ventilation equipment is due in part to the lack of user-friendly ventilation control systems. A prototype residential ventilation controller was developed and field-tested to determine its acceptability to homeowners. The prototype controller incorporated an adjustable duty cycle to control ventilation rate, programmable time of day scheduling, countdown timer override/purge to adjust CO" level, manual override with adjustable ventilation rate, and maximum limit CO2 based override. Controllers were installed at 16 field test sites and data on CO2 concentration and ventilation fan use were taken over a fourmonth period. Homeowners reported a significant improvement indoor air quality and judged the prototype controller easy to use. Data analysis showed the average CO2 concentration was reduced by 7%.

KEYWORDS mechanical ventilation, carbon dioxide, demand control

## A3.2 Sensors

**#NO 4958 IAQ management by demand controlled ventilation.**

AUTHOR Raatschen W

BIBINF Proceedings of a Workshop held Lausanne, Switzerland, 2728 May 1991, Brussels Luxembourg, ECSCEECEAEC, Publication No. EUR 137766 EN of the Commission of the European Communities, Scientific and Technical Communication Unit, Directorate General Telecommunications, Information Industries and Innovation, Luxembourg, pp 181190. #DATE 00:05:1991 in English

ABSTRACT Research results of the last 2 years clearly showed, that the pollution load in a room originates from a variety of sources. Main sources of concern are emissions from building material, emissions from filters, emissions from dirty ducts, and emissions from occupants according to their activity level. It depends on the building itself, whether the occupancy load dominates the pollutant level or not. Demand Controlled Ventilation offers the possibility to control the airflow rate according to the pollution level in a room. The abundance of indoor air pollution gases leads to a classification of control strategies into 3 groups: humidity, carbon dioxide, and volatile organic compounds. In addition to an effective extraction of the contaminant the detection with a reliable IAQ sensor is of fundamental interest. This paper focuses on the requirements to IAQ sensors, compares this with their current performance and highlights new areas of research.
KEYWORDS demand controlled ventilation, occupancy effects, humidity, carbon dioxide, organic compound

**#NO 5285 Demand controlled ventilation evaluation of commercially available sensors.**
AUTHOR Fahlen P, Ruud S, Andersson H
BIBINF UK, AIVC 12th Conference, "Air Movement and Ventilation Control within Buildings", held 2427 September 1991, Ottawa, Canada, proceedings published September 1991, Volume 2, pp 201216. #DATE 00:09:1991 in English
ABSTRACT A test programme has been designed to evaluate the performance characteristics of sensors for the automatic control of ventilation rates. The test programme consists of two main parts, one being the evaluation of sensor performance in laboratory tests and the other referring to long term characteristics of sensors in actual buildings. Included in the present evaluation are eight different types of humidity sensors, two carbon dioxide sensors and five mixed gas sensors.
KEYWORDS demand controlled ventilation, sensor, testing

**#NO 6674 Occupancy sensors for ventilation control.**
AUTHOR Anon
BIBINF USA, Energy Design Update, January 1993, pp 1415, 3 figs. #DATE 00:01:1993 in English
ABSTRACT Describes the advantages and disadvantages of a demand controlled ventilating system which uses occupancy sensors. Very few of the major ventilation equipment manufacturers sell occupancy sensing controllers for its systems. The general opinion is that the concept of ventilation control by occupancy sensors has merit, particularly for spot loads such as bathrooms, workshops, or kitchens, but that it is probably not a good idea for control of whole house ventilation systems.
KEYWORDS sensor, occupant behaviour, demand controlled ventilation

**#NO 6969 Mixed gas sensors strategies in nonspecific control of IAQ.**
AUTHOR Bischof W, Witthauer J
BIBINF Finland, Helsinki, Proceedings of 'Indoor Air '93', The 6th International Conference on Indoor Air Quality and Climate, July 48, 1993, Volume 5, "Ventilation", pp 3944. #DATE 00:07:1993 in English
ABSTRACT While outdoors some known pollutants may be present in higher concentrations a wide spectrum of mainly unknown contaminants is typical for indoor air. The knowledge about combined and long term effects of volatile organic compounds and respirable suspended particles with high adsorptive load on gases and vapors on human health is still fragmentary. But the first step to healthy indoor air is to minimize emissions from sources as building materials, interior (furniture, equipments), HVAC systems, and only secondly by demand controlled ventilating (DVC) systems. DCV systems have to be controlled by sensors. While classical CO2 and humidity sensors detect above all human emissions mixed gas sensors (MGS) are responsible for a large scale of pollutants. Up to now knowledge about mixed gas sensors is very limited. Experimental studies with metal oxide sensors showed problems in stability, drift and reproducibility. An air mixture (nDcan, Toluol, 1,1,1Trichlorethan, oPinen, Ethylacetat) was used as standard pollutant. Concentrations were controlled by gas chromatography. High influence of humidity and nonsystematic differences in sensitivity between the single compounds are the main dilemma for the practical use of MGS. For constant mixture ratio the normal case in most of indoor environments our experiments showed a good correlation with air quality, but simultaneous compensation of air humidity is essential.
KEYWORDS sensor, indoor air quality, pollutant, organic compound, particle, humidity

**#NO 8748 Air quality sensors for demand controlled ventilation**
AUTHOR Alpers R, Zaragoza J.
BIBINF UK, Heating, Piping, Air Conditioning, July 1994, pp 8991, refs.
ABSTRACT Gives a comparison of carbon dioxide sensors and mixed gas sensors for measuring indoor air quality in demand based ventilation applications. Discusses the causes of air contamination, controlling pollutants, time versus demand based, mixed gas and CO2 sensors.

**#NO 9448 CO2 and air quality sensors: understanding the difference for demand controlled ventilation.**

AUTHOR Schell M

BIBINF Paper from: USA, University of Tulsa, 8th Conference on Indoor Air Pollution, proceedings, held September 2527, 1995.

ABSTRACT As the indoor air quality industry has grown, there have been a number of new technologies that have burst upon the marketplace. One of these technologies often called Air Quality or Volatile Organic Compound Sensors (VOC) sensors have generated great interest as a possible approach to control air quality in all types of buildings. This section provides an overview of CO2 and air quality sensors and outlines the best application for both types of technology. While both sensor technologies can be useful in indoor air quality control they are not interchangeable. Each has its own application.

KEYWORDS carbon dioxide, sensor, demand controlled ventilation

## A3.3 Auditoria, Conference Rooms, Schools, Restaurants

**#NO 5213 Demand controlled ventilation by room CO2 concentration: a comparison of simulated energy savings in an auditorium space.**

AUTHOR Warren B F, Harper N C

BIBINF UK, Energy and Buildings, No 17, 1991, pp 8796, 10 figs, 2 tabs, 17 refs. #DATE 00:00:1991 in English

ABSTRACT The investigation models the energy savings which can be made if the ventilation rates supplied to an auditorium located in a U. K. urban environment are controlled in response to CO2 concentration. Ventilation profiles based on CO2 concentration levels, generated from a step by step integration preprocessor, are supplied to a dynamic thermal simulation computer program which models a space with fluctuating occupancy levels. The simulations suggest that heating energy savings of as much as 50% may be achieved where auditoria currently using 100% fresh air ventilation systems are retrofitted to incorporate CO2 controlled ventilation.

KEYWORDS demand controlled ventilation, carbon dioxide, auditorium

**#NO 5284 Demand controlled ventilation: full scale tests in a conference room.**

AUTHOR Fahlen P, Andersson H

BIBINF UK, AIVC 12th Conference, "Air Movement and Ventilation Control within Buildings", held 2427 September 1991, Ottawa, Canada, proceedings published September 1991, Volume 2, pp 187200. #DATE 00:09:1991 in English

ABSTRACT A conference room has been converted to temperature and carbon dioxide controlled ventilation. A number of tests have been conducted with the system in different load conditions. The variables that have been measured are air flow rate, temperature and carbon dioxide concentration. The activity in the room during the measurements has also been well recorded. The main purpose has been to evaluate the ability of a demand controlled ventilation system to maintain a good indoor air quality.

KEYWORDS demand controlled ventilation, carbon dioxide, air flow, temperature

**#NO 5984 Demand controlled ventilation: a case study.**

AUTHOR Fleury B

BIBINF UK, Air Infiltration and Ventilation Centre, 13th AIVC Conference, proceedings, held Hotel Plaza Concorde, Nice, France, 1518 September 1992. #DATE 15:09:1992 in English

ABSTRACT Good indoor air quality in buildings becomes such a major concern that new design recommendations emerge in many countries (USA, Nordic Countries,...). Improvement of the interior environment should not beat the expense of higher energy consumption. Heat recovery systems are one appropriate answer to this challenge. However, additional energy savings could be achieved by applying demand controlled ventilation when the internal loads vary significantly. A CO2 controlled ventilation system has been installed in a conference room with high variable occupancy in mid 91. In this paper, we present the survey of 6 months of use, the limits and the benefits of such a system. We focus on the practical aspects to offer the optimum air quality and to integrate the occupants and building owner's requirements.

KEYWORDS demand controlled ventilation, indoor air quality, building design, carbon dioxide

**#NO 5290 Demand controlled ventilation in a school.**

AUTHOR Norell L

BIBINF UK, AIVC 12th Conference, "Air Movement and Ventilation Control within Buildings", held 2427 September 1991, Ottawa, Canada, proceedings published September 1991, Volume 2, pp 257274. #DATE 00:09:1991 in English

ABSTRACT The performance of a system for demand controlled ventilation was investigated for a period of 1.5 years. Presence sensors of the passive infrared type are used to control the ventilation rate in each classroom. The signal from the presence sensors was recorded, as well as the CO2 concentration in the classrooms. One of the classrooms was equipped with displacement ventilation. A comparison was made between displacement and mixing ventilation to investigate the CO2 concentration in the stay zone. A

significantly lower CO2 concentration was measured in the case of displacement ventilation.
KEYWORDS demand controlled ventilation, school

**#NO 5604 Long term experience with demand controlled ventilation systems.**
AUTHOR Strindehag O, Norell L
BIBINF USA, Ashrae, "IAQ 91 Healthy Buildings", proceedings of a conference held September 48, 1991, Washington, DC, pp 108110, 4 figs, refs. #DATE 00:09:1991 in English
ABSTRACT The performance of three demand controlled ventilation systems has been studied for a period of 1.5 to 3 years. The ventilation systems are installed in an auditorium, a conference room, and a school. In both the auditorium and the conference room, carbon dioxide sensors are used for air quality control, whereas presence sensors of the passive infrared type are used to control ventilation rates in the school. The results of numerous measurements of carbon dioxide concentrations and airflows of the buildings under different outdoor conditions and occupant loads are reported here. The reliability of the control systems is also discussed.
KEYWORDS demand controlled ventilation, auditorium, school, carbon dioxide, sensor

**#NO 6391 The applicability of demand controlled ventilating systems for assembly halls.**
AUTHOR Drangsholt F
BIBINF Norway, University of Trondheim, Norwegian Inst of Technology, Thesis, May 1992, 150pp. #DATE 00:05:1992 in English
ABSTRACT The thesis is devoted to a study of the Applicability of Demand Controlled Ventilation Systems for Assembly Halls. The main part of the study is concerned with full scale trials with Demand Controlled Ventilation (DCV) in the auditorium EL5 at the Norwegian Institute of Technology. This auditorium is ventilated by displacement and has a seating capacity of 300 students. Results from full scale trials in an auditorium ventilated by dilution are also referred to. The latter study was carried out by the author in 1984.
KEYWORDS demand controlled ventilation, auditorium, displacement ventilation

**#NO 6970 Indoor air quality and energy consumption with demand controlled ventilation in an auditorium.**
AUTHOR Fehlmann J, Wanner HU, Zamboni M
BIBINF Finland, Helsinki, Proceedings of 'Indoor Air '93', The 6th International Conference on Indoor Air Quality and Climate, July 48, 1993, Volume 5, "Ventilation", pp 4550. #DATE 00:07:1993 in English
ABSTRACT The ventilation system of an auditorium was regulated in response to continuously measured CO2 concentrations in the room, or according to the timetable of the occupancy. The running time, the energy consumption and several climatic parameters as well as the CO2 concentrations were measured under winter and summer conditions. Furthermore, the occupants' judgment of the indoor air quality was surveyed with a questionnaire. It was shown that during the monitored periods the ventilation controlled by measured CO2 concentrations consumes 80% less energy during summer and 30% less during winter than the ventilation operating on a fixed time schedule. If all the avoidable sources of odor in the room would be eliminated, the indoor quality would still remain within an acceptable range.
KEYWORDS energy consumption, demand controlled ventilation, auditorium, carbon dioxide

**NO 6977 Mixed gas or CO2, sensors as a reference variable for demand controlled ventilation.**
AUTHOR Meter S
BIBINF Finland, Helsinki, Proceedings of 'Indoor Air '93', The 6th International Conference on Indoor Air Quality and Climate, July 48, 1993, Volume 5, "Ventilation", pp 8590. #DATE 00:07:1993 in English
ABSTRACT The purpose of the investigation was to gather information about the currently available types of sensor with regard to their suitability for providing a reference variable for demand based ventilation, and to be able to estimate the associated energy saving potential. To this end, the air quality was measured continuously for a week in each of the following areas at the University of Zurich: the staff restaurant, a lecture hall for 300 people, and a large sports hall. The sensors used to measure indoor air quality were mixed gas sensors (1) and CO2 sensors. In order to evaluate the effect of temporarily switching off the ventilation system, the plant was operated manually at times. It was found that, compared with conventional time switch control, significant energy savings can be made by operating the plant on the basis of air quality demand, and that this does not significantly affect the comfort of users of the spaces, CO2, released by respiration, serves as an indicator for the presence of people. Mixed gas sensors respond to oxidisable gases and vapours. In addition to body odours, therefore, these sensors also measure the majority of other variables which affect air quality. In a subsequent phase, the ventilation systems in the staff restaurant and sports hall will be operated on a demand basis, using mixed gas sensors for the reference variable so that the actual energy savings achievable can be quantified.
KEYWORDS carbon dioxide, sensor, demand controlled ventilation, large building, energy saving

**#NO 7020 Demand Controlled Ventilation in an Auditorium.**

AUTHOR Svennberg B A, Mansson LG

BIBINF UK, Air Infiltration and Ventilation Centre, 14th AIVC Conference, "Energy Impact of Ventilation and Air Infiltration", held Copenhagen, Denmark, 2123 September 1993, proceedings, 10pp. #DATE 21:09:1993 in English

ABSTRACT In conjunction with IEA Annex 18, DCV systems, a test on an auditorium in a school in Tyreso south of Stockholm has been carried out. The auditorium has 450 seats on a slightly sloped floor and a ventilation system with low impulse air supply devices placed at the lower (front) part of the auditorium. The system is intended to act as a displacement ventilation system during operation with heat load from people. The flow rate is governed by a CO2 sensor in the exhaust air device. In non-operational state, and if heating is necessary, the system operated with recirculation of air. The system is provided with a cyclic heat exchanger for heat recovery from the exhaust air. The air flow rate is kept at a low level during non-operational times. On increasing load from persons the CO2 sensor causes a change from recirculation to ventilation with 100% outdoor air. If the CO2 concentration rises, the air flow rate is increased by changing the speed of the fans. When occupied the auditorium ventilation system gives an increased air flow rate that should be proportional to the increase of CO2 content in the room air. In most cases however the system flow rate rises to the maximum level. It thus acts as a two level governing system. The reason for this is the difficulty in finding a proportional band and delay times for system speed changes so that the outdoor airsupply will not be too low for keeping the CO2 level down as high people load. The CO2 concentration has been monitored at the exhaust air device, which is situated at the back wall of the auditorium. Concentration levels are well in coincidence with theoretically calculated values. Temperature gradients have been measured by using sensors placed at four different levels. The contents of volatile pollutants in the room air have been measured with a new hand carried device. Moistening the floor and the seats was found to rapidly increase VOC's.

KEYWORDS demand controlled ventilation, auditorium

**#NO 8329 Analysis of IAQ in a university auditorium**

AUTHOR Borchiellini Romano, Fracastoro Gian Vincenzo, Perino Marco.

BIBINF Poland, Silesian Technical University, 1994, proceedings of Roomvent '94: Air Distribution in Rooms, Fourth International Conference, held Krakow, Poland, June 1517, 1994, Volume 2, pp 4762.

ABSTRACT The behaviour of the ventilation system installed in one of the large auditoria at the Polytechnic of Torino has been thoroughly investigated. The auditorium has a capacity of approximately 400 seats, and has been recently equipped with a Demand Controlled Ventilation System operating with constant total flow rate and variable air recirculation ratios. A number of measurements of IAQ and ventilation indices in different conditions of occupancy load and recirculation ratios have been performed. Simulations were also performed using a finite volumes CFD code, with steady state 2D and 3D models of the auditorium in nominal conditions. The experimental apparatus yielded the simultaneous measurement of CO2, H2O and tracer gases SF6 and N2O concentrations in up to six different locations within the auditorium. Results show that, in spite of the fact that CO concentration levels seldom exceed 1000 ppm, there is a tendency to accumulate at the upper part of the occupied area of the auditorium, and the coefficient of air change performance is rather low (about 50%).

KEYWORDS auditorium, university, indoor air quality, demand controlled ventilation, tracer gas

**#NO 8613 Customer benefits of demand based ventilation in a restaurant**

AUTHOR Meier S

BIBINF Sweden, Proceedings of the 4th International Symposium on Ventilation for Contaminant Control, Ventilation '94, held in Stockholm, September 59, 1994, Arbetsmiljoinstitutet, 1994:18, Part 1, pp 527532.

ABSTRACT In a restaurant with a "demand based" ventilation system, the air quality in the dining area is continually monitored by an air quality sensor and the fan stages are switched automatically on the bases of the sensor signal. Since the greatest irritation in restaurants is tobacco smoke, the air quality sensors used are of the "mixed gas" type. The study which has been in progress since December 1993 shows the following: By comparison with manual fan control, energy savings of over 25% can be achieved with a ventilation system controlled on the basis of air quality demand. There is a high correlation between the air quality measured with mixed gas sensors and the odour load in the room (people, smoking, ventilation rate). According to the restaurant manager, there has been a significant reduction in complaints by guests since the demand based ventilation system has been in operation. Not only were there fewer complaints about air quality while people were smoking, but also fewer problems with the air supply system (draft). The experience gained in the course of this investigation indicates that the outside air flow rate of 36 m3/h per person specified in many countries is not sufficient to produce a continuously acceptable level of air quality for the nonsmokers present.

KEYWORDS demand controlled ventilation, commercial building, indoor air quality, sensor, tobacco smoke, odour

**#NO 8747 Demand controlled ventilation in restaurants : mixed gas or CO2 sensors as a reference variable?**
AUTHOR Meier S.
BIBINF Switzerland, Staefa Control System, 6 pp, 3 figs, 8 refs.
ABSTRACT The purpose of the investigation was to gather information about the currently available types of sensor with regard to their suitability for providing a reference variable for demand based ventilation, and to be able to estimate the associated energy saving potential. To this end, the air quality was measured continuously for a week in each of the following areas at the University of Zurich: the staff restaurant, a lecture hall for 300 people, and a large sports hall. The sensors used to measure indoor air quality were mixed gas sensors [1] and CO2 sensors. In order to evaluate the effect of temporarily switching off the ventilation system, the plant was operated manually at times. It was found that, compared with conventional timeswitch control, significant energy savings can be made by operating the plant on the basis of air quality demand, and that this does not significantly affect the comfort of users of the spaces. CO2, released by respiration, serves as an indicator for the presence of people. Mixed gas sensors respond to oxidisable gases and vapours. In addition to body odours, therefore, these sensors also measure the majority of other variables which affect air quality. In a subsequent phase, the ventilation systems in the staff restaurant and sports hall will be operated on a demand basis, using mixed gas sensors for the reference variable, so that the actual energy savings achievable can be quantified.
KEYWORDS demand controlled ventilation, restaurant, carbon dioxide, sensor

## A3.4 Offices and Commercial Buildings

**#NO 5251 Demand controlled ventilation systems in office buildings.**
AUTHOR Davidge B, Vaculik F
BIBINF UK, AIVC 12th Conference, "Air Movement and Ventilation Control within Buildings", held 2427 September 1991, Ottawa, Canada, proceedings published September 1991, Volume 1, pp 157172. #DATE 00:09:1991 in English
ABSTRACT This paper illustrates the principles of demand controlled ventilation systems (DCV) as applied to office buildings. 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.
KEYWORDS demand controlled ventilation, office building, occupant reaction

**#NO 5967 METOP Energy efficient office building.**
AUTHOR Laine J, Saari M
BIBINF UK, Air Infiltration and Ventilation Centre, 13th AIVC Conference, proceedings, held Hotel Plaza Concorde, Nice, France, 1518 September 1992. #DATE 15:09:1992 in English
ABSTRACT A prototype of a low cost, low energy office building was built using a new Finnish component system building technology. Thanks to the energy efficient windows, the thermal insulation of the building envelope and the demand controlled variable outdoor air flow HVAC system with heat recovery and energy storing structures, the need for heating and cooling energy has been reduced to such a level that a low energy office can be cooled with outdoor air and with the aid of a heat recovery device. The building is kept warm with the support of its own operations almost throughout the year. It is possible to arrange a good individual indoor climate in this way almost without any purchased heating or cooling energy. There is need for heating only during the coldest but short periods in the night and during the weekends. Even during the summer heat periods, cooling energy produced by refrigerators operating on CFC is not needed.
KEYWORDS energy efficiency, office building, heat recovery, outdoor air, cooling

**#NO 6255 Carbon dioxide concentrations and minimum air change rates in a highrise office building.**
AUTHOR Reardon J T
BIBINF Indoor air quality, ventilation and energy conservation, 5th International Jacques Cartier Conference, Montreal, Canada, October 79, 1992, publisher: Center for Building Studies, Concordia University, Montreal, Canada, pp 334341. #DATE 00:10:1992 in English/French
ABSTRACT The carbon dioxide concentration patterns in a large highrise office building in Ottawa were examined experimentally using an automated data acquisition system. Daily CO2 concentration profiles throughout the building and air change rates, using SF6 as a tracer gas, were measured at minimum outdoor air supply rates during much of a heating season. Of particular interest was how well mixed the indoor air was and how well the CO2 concentrations measured in the central ventilation system's return air plenum represented the average

CO2 concentration behaviour in the building as a whole. CO2 concentration profiles were also measured on individual floorspaces in the building to determine the range of variability in the concentration behaviour. The measurement results are presented and discussed in the context of demand controlled ventilation.
KEYWORDS carbon dioxide, air change rate, high rise building, office building, demand controlled ventilation

**#NO 6857 IAQ and energy management by demand controlled ventilation.**
AUTHOR Haghighat F, Donnini G
BIBINF Environmental Technology, Vol.13, 1992, pp351359, 9figs, 13refs. #DATE 00:00:1992 in English
ABSTRACT As an alternative to conventional ventilation systems which modulate the outdoor dampers with respect to the air temperature, demand controlled ventilation systems allow ventilation air to be controlled based on a measure of indoor air quality. The concentration of carbon dioxide can be used as a surrogate measure of indoor air quality in occupied buildings. The energy savings possible using this technique makes buildings with variable occupancy schedules attractive applications. This paper compares the energy consumption and the indoor environment created by two different types of ventilation control systems in two floors of an office building.
KEYWORDS demand controlled ventilation, indoor air quality, carbon dioxide, office building

**#NO 6976 Evaluating demand control strategies for VAV supplementary bypass systems.**
AUTHOR Meckler M
BIBINF Finland, Helsinki, Proceedings of 'Indoor Air '93', The 6th International Conference on Indoor Air Quality and Climate, July 48, 1993, Volume 5, "Ventilation", pp 7984. #DATE 00:07:1993 in English
ABSTRACT This paper briefly summarizes the results of the carbon dioxide (CO2) demand control ventilation (DCV) strategy, and introduces a proprietary DCV system. This system already equipped with indoor air quality (IAQ) sensors directly measures the concentration of volatile organic compounds (VOCs) in a an occupied space and accordingly modulates supply air rates to provide acceptable IAQ, comfort and cost effectiveness (especially for variable airvolume (VAV) systems).
KEYWORDS demand controlled ventilation, indoor air quality, organic compound, cost effectiveness

**#NO 9594 Demand based ventilation: indoor comfort at lower cost.**
AUTHOR Meier S
BIBINF Healthy Buildings 95, edited by M Maroni, proceedings of a conference held Milan, Italy, 1014 September 1995, pp 17431750, 7 figs, 1 ref.
ABSTRACT The distribution and conditioning of the air are significant cost factors in the operation of ventilation and air conditioning systems. Plant operating hours are normally kept under control by the use of time switches or by manual operation. In most cases, However, these methods by no means exploit the full potential for a reduction in operating hours. Compared with conventional methods of control, a far more significant reduction in operating costs can be achieved by basing air renewal on actual (measured) demand. The additional capital investment can be recouped within 1 to 5 years, the payback period depending primarily on the air flow rate. At an air flow rate of 2000 m3/h, the payback period is approximately 5 years, and falls, with increasing air flow rates, to as little as under a year. In automatic mode, the air quality control system switches the fan stages on and off or, in the case of VAV systems, adjusts the fan speed or damper position. Demand based ventilation systems are not just restricted to new systems; cost-effective conversion kits are available for existing systems. In a converted system, manual and/or timeswitch control are replaced by an air quality control system. Other analogue or digital controls (such as temperature) remain unaffected. On the basis of empirical values, preset as parameters in the controller, demand based ventilation systems can be started automatically at the touch of a button.
KEYWORDS demand controlled ventilation, human comfort

**#NO 9653 Energy and IAQ impacts of CO2 based demand controlled ventilation.**
AUTHOR Carpenter S C
BIBINF USA, Ashrae Transactions, Vol 102, Pt 2, 1996 [preprint], 6 figs, 4 tabs, refs.
ABSTRACT This study examines the effectiveness of using carbon dioxide based, demand controlled ventilation (DCV) to provide adequate indoor air quality with minimum energy use. A detailed building energy analysis program (ENERPASS) was combined with a contaminant level prediction program (CONTAM87) to perform the analysis. The combined program was used to evaluate the annual heating and cooling energy consumption and carbon dioxide and formaldehyde concentrations. The assessment was made on a midsize commercial building designed to comply with ASHRAE Standard 90.1. Three separate heating, ventilating, and airconditioning (HVAC) systems were studied: single zone (ie. multiple roof top units), multizone, and variable air volume (VAV). The simulations were made for five ventilation control strategies: fixed ventilation; building return air controlled to 1,000 ppm and 800 ppm; floor return air controlled to 1,000 ppm; and each zone controlled to 1,000 ppm.

KEYWORDS indoor air quality, carbon dioxide, controlled ventilation, demand controlled ventilation

**#NO 10315 The use of infrared controlled air terminals in an office building.**
AUTHOR Francis J, Edwards R E
BIBINF UK, CIBSE, 1996, proceedings of CIBSE/ASHRAE Joint National Conference Part Two, held Harrogate, 29 September 1 October 1996, Volume 2, pp 311320.
ABSTRACT Demand controlled ventilation (DCV) allows close control of air quality whilst minimising ventilation heat losses. It is thus a powerful design option and may be preferred to conventional systems where temporal variations in occupant density are unpredictable. CO2 monitors are expensive, which restricts their use in feedback control to large open plan offices and auditoriums. Presence Controlled Ventilation (PCV) is a low cost form of DCV in which on/off switching of fans or air terminals is controlled by infra red detectors. PCV has successfully been used to ventilate modular offices, hotel rooms and toilet areas. However, most office buildings are neither constructed on a large open plan format nor fall into the category of modular buildings. A building with mixed modular and small open plan offices was partially fitted with PCV air terminals to assess their suitability in such office suites. The whole office suite was serviced by a single air handling unit for combined supply and extract. Indoor air quality and ventilation heat loss was measured for the building as a whole and for the branch fitted with PCV. Some drawbacks of the installed system were identified which significantly affected the payback period of the installation.
KEYWORDS office building, demand controlled ventilation, sensor

## A3.5 General

**#NO 5773 Demand controlled ventilation.**
La ventilation asservie a la demande.
AUTHOR Norell L, Van den Bossche JP, Fleury B
BIBINF France, CVC Chauffage, Ventilation, Conditionnement, No 2, 1992, pp 3940, I fig. #DATE 00:00:1992 in French
ABSTRACT Carbon dioxide controlled ventilation requires the flowrate according to final CO2 inside concentration, the flowrate control technique varying in accordance with the architecture and building application. This system which has today proved effective, as it is demonstrated by two quoted examples preserves the health and comfort of occupants whilst respecting the French regulation.
KEYWORDS demand controlled ventilation, ventilation system, carbon dioxide, human comfort, building regulations

**#NO 7012 Theoretical basis for assessment of air quality and heat losses for domestic ventilation systems in France.**
AUTHOR Villenave J G, Millet JR, Riberon J
BIBINF UK, Air Infiltration and Ventilation Centre, 14th AIVC Conference, "Energy Impact of Ventilation and Air Infiltration", held Copenhagen, Denmark, 2123 September 1993, proceedings, pp6170. #DATE 21:09:1993 in English
ABSTRACT Ventilation of buildings is necessary, both to insure adequate indoor air quality and to protect the building itself against condensation and mould growth. On the other hand, ventilation rates must not lead to excessive energy consumption. French regulation doesn't appreciate directly the indoor air quality but fixes requirements for the value of exhaust stale air in service rooms; furthermore heat losses related to cross ventilation due to wind effects are also taken into account. For assessment of Demand Control Ventilation systems both air quality and heat losses have to be compared to a mechanical exhaust only system. In this paper, we describe the methodology and the CSTB computer models, and how they have been used to design the French rules related to the energy demand of ventilation systems and the air quality level obtained with DCV systems by reference to a conventional mechanical ventilation system.
KEYWORDS heat loss, residential building, ventilation system, wind effects

**#NO 7631 Advanced HVACsystems in energy efficient experimental buildings.**
AUTHOR Laine J, Saari M
BIBINF Finland, FINVAC, 1994, proceedings of the Cold Climate HVAC '94 Conference, held March 1518, 1994, Rovaniemi, Finland, Edited by J Sateri and E Kainlauri, pp 313322.#DATE 00:03:1994 in English
ABSTRACT Energy efficient experimental residential and office building utilizing advanced HVAC systems were designed and built in Finland according to the concepts of the Technical Research Centre of Finland (VTT). The buildings were built with Finnish companies using the new Finnish component system building technology, developed in different studies and in the development projects of different companies. The main objectives of these experimental buildings are to improve the indoor air quality and energy economy and at the same time improve the quality of the construction process and reduce the costs. The advanced HVAC systems are simple demand controlled variable air volume ventilation heating systems. Radiator heating system is not needed. The need for heating and cooling energy have been minimized with the high insulation technology windows, the good thermal insulation and air tightness of the building envelope, the individually controlled ventilation and room temperature, heat recovery and energy storing structures. In addition, the building structures are used as an installation space for the heating, piping,

ventilation and electrical systems. The heating energy consumption of the experimental buildings have been reduced at lest 30 60% compared to the average consumption in Finnish buildings. The new systems and prototype components functioned well and the indoor climate and the air quality were good. The descriptions of the two different experimental buildings and results of their follow-up studies carried out in 1990 1993 are considered.
KEYWORDS Energy efficiency, indoor air quality.
KEYWORDS carbon dioxide, sensor, demand controlled ventilation

**#NO 10083 On demand ventilation control: a new approach to demand controlled ventilation.**

AUTHOR Federspiel C C
BIBINF Indoor Air '96, proceedings of the 7th International Conference on Indoor Air Quality and Climate, held July 2126, 1996, Nagoya, Japan, Volume 3, pp 935940.
ABSTRACT In this paper a new strategy for controlling ventilation systems is described. The strategy provides fresh air at a flow rate proportional to an estimate of the rate at which occupants generate carbon dioxide. Thus, the ventilation rate is nearly proportional to the occupant density even under transient conditions. Properties of the new strategy are described, and the performance is compared to a concentration regulating strategy ion a simulation. The new strategy is shown to respond faster to a change in the occupant density and to keep the concentration at or below a threshold.
KEYWORDS controlled ventilation, demand control

## The International Energy Agency (IEA) Energy Conservation in Buildings and Community Systems Programme (ECBCS)

The International Energy Agency (IEA) was established as an autonomous body within the Organisation for Economic Co-operation and Development (OECD) in 1974, with the purpose of strengthening co-operation in the vital area of energy policy. As one element of this programme, member countries take part in various energy research, development and demonstration activities. The Energy Conservation in Buildings and Community Systems Programme has sponsored various research annexes associated with energy prediction, monitoring and energy efficiency measures in both new and existing buildings. The results have provided much valuable information about the state of the art of building analysis and have led to further IEA sponsored research.