PROGRESS AND TRENDS IN AIR INFILTRATION RESEARCH

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Paper 2

ANNEX 18

DEMAND CONTROLLED VENTILATING SYSTEMS

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SYNOPSIS

The IEA Annex 18 Demand Controlled Ventilating Systems-(DCV-Systems) with 9 participants are just in the middle of the work. Reviews are indicating energy conservation possibilities in the range of 8 - 40 % in experiments and even more in theoretical studies. Most of the case studies will start this autumn with sensor tests, test room studies, and trials in occupied spaces. In the test rooms will be simulated the conditions in dwellings and offices with various ventilating systems. Almost 30 occupied buildings will be involved in tests in dwellings, offices, auditoria, and schools. The final report will be given in a source book planned to be printed at the end of 1991.

1. BACKGROUND

Many IEA countries have an increasing problem with the indoor air quality and studies are undertaken concerning outgasing from building material, human habits, odour, threshold limits etc. Such energy conservation measures as tightening of the building envelop and increased use of return air has in many cases been accused to be the main reasons of the indoor air quality problems. The experiences from all these indoor air quality studies may result in a demand for an increased outdoor air volume.

Variations in the number of occupants and their activities will lead to the possibility to control the supply and exhaust air volume according to the demand.

We are spending almost 90 % of our time indoors at home or at work. However the problem is to predict the number of people in a room, a dwelling, a building etc. These circumstances can lead to overventilation and unnecessary use of energy.

The problem is that there is always more or less uncertainty in the assumption of how many occupants there are or can be in a room. Each room or building then need a certain air flow to extract pollutant from outgasing of materials to an acceptable level. Before and after a space has been used it can also be necessary to run the ventilation system in order to remove the pollutant from the material and the occupants. If we can find ventilating systems which can be controlled to above mentioned conditions good enough sensors, the use of outdoor air will be more effective and also give a good possibility to save energy.

2. INTRODUCTION

In the IEA Annex 9 Minimum Ventilation Rates results are given to meet the requirement of air flow rates based on human needs. The discussion started on how to use the knowledge with the purpose to minimize the waste of energy.

When the basic needs were given it was obvious that the results could be used in a new Annex focusing on how to control the ventilation following the occupants' demand.

The objective of the Annex 18 is to develop guidelines for Demand Controlled Ventilating System (DCV systems) based on state of the art analyses and case studies for different users in different types of domestic, office, and school buildings.

The work in the Annex is divided into three Subtasks.

Subtask A: Review of existing technology

Subtask B: Case studies
1. Sensor tests
2. Trials in unoccupied test buildings.
3. Trials in occupied spaces.

Subtask C: Design and operation of DCV systems

Participants in the Annex are:

Canada	Lead Country Subtask B
Denmark	
Fed. Rep. of Germany	Lead Country Subtask A
Finland	
Italy	Lead Country Subtask B2
The Netherlands	
Norway	
Switzerland	
Sweden	Operating Agent and Lead Country Subtask B1 and C

Observers:

AIVC
Belgium

3. SUBTASK A - REVIEW OF EXISTING TECHNOLOGY

This subtask is now to be completed as a report with the title "Demand Controlled Ventilating System - State of the Art Review". The result is used in the work in the Annex by choice of sensors, making the case studies comparable, and focusing on questions not yet sufficiently answered in the already finished case studies.

The chapters in the report are the following subheadings 3.1 - 3.5.

3.1. Review of contaminant concentrations in occupied spaces.

The information about average and peak concentrations can be found but not easily if the measurements were carried out in projects with no connection to any research work. The participants have gathered information from both research projects and other reliable measurements often with the purpose to find a solution of an indoor air quality problem.

In table 1 is summarized data about carbon dioxide and in table 2 about hydrocarbons. Information about humidity is found in the results from Annex 14 - Condensation and mostly from measurements in dwellings. Not many studies are reported about humidity in countries with cold climate.

3.2. Review of international standards

The threshold values of indoor air pollutant are given for humidity, carbon dioxide, carbon monoxide, nitrogen dioxide, formaldehyde, and hydro carbons. These standards were reported at the 9th AIVC conference in Gent, 1988.

3.3. Sensors

The function principles of sensors are given for humidity, carbon dioxide, and mixed gases. The sensor market review reports complete devices distributed on:

Humidity	17
Carbon dioxide	6
Carbon monoxide	7
Air quality sensor	6

A detailed report on sensors and sensor market is given in the proceedings from the 9th AIVC conference.

3.4. Review of measured results and knowledge about DCV systems

The last 10 years case studies and experiences with regard to DCV systems have been reviewed.

Out of totally 32 reports was found that nearly all (29 reports) were discussing CO_2 sensors and CO_2 as the controlling pollutant. In some of the reports were also discussed humidity (5 reports) and mixed gases (7 reports) to be the controlling pollutants. Totally 23 reports are from real experiments with

DCV-systems and the other papers are reports on monitoring studies and theoretical analyses. Two examples of reviewed papers will be given.

The first example is a CO_2-controlled air conditioning system in a bank i Pasco, WA U.S.A. The objective was to save energy without sacrificing the indoor quality. In figure 1 is compared normal temperature control with CO_2-control. The experiment was run both during winter and summer conditions. Energy savings was reported to be 8 % and the pay-back time was 2 - 3 years.

The second example is an office in Otaniemi, Finland. Also here the objective was to save energy in an air conditioned building. Three different modes were studied and the energy savings were compared to normal designed control strategy.

A) CO_2 set point 700 ppm gives 40 % savings
B) CO_2 set point 650 ppm gives 10 % savings
C) Time-related control case with the air flow close to A) above gives 30 % savings

Figure 2 gives the air flow rates during a working day in the three studied modes.

3.5. Conclusions

Most of the studies were about application of DCV-systems in offices and public buildings and only 3 studies were about dwellings. The choice of building is probably depending on the expectation that public or office buildings easier can stand the investment and handle larger air flows per installed DCV-unit.

The sensors used in the reviewed projects were to control on CO_2, humidity, and odour.

The location of the sensors are generally chosen to be in two places. One is in the exhaust duct close to the return duct and controlling the mixing of return air and outdoor air. The other is to locate the sensor close to temperature control in the room. No detailed study has been carried out on the sensor location. But yet ventilation efficiency has been studied in some tests giving an idea if the location of the sensor in the room was a good choice according to the air distribution pattern.

Reported energy savings vary from between 8 % to 40 % in projects based on measurement and from 30 % to 60 % in theoretical studies. A general remark is that the percentage of the energy savings depend on many factors e.g. total energy consumption, air flow, climate, basic standard of the system.

The design of a DCV system will very much depend on climate, building type, occupancy pattern, and the general design of the ventilating system. Therefore, energy savings coming from the use of a DCV system should be reported in relation to a defined reference system, for which air quality levels are well known. Energy savings and air quality achieved can then be put in a calculus where investment is compared to energy savings and life cycle costs. If a method for comparing human performance as a function of air quality can be found, also that parameter can be included in the life cycle cost.

4. SUBTASK B - CASE STUDIES

Some of the case studies have already started but most of them will start during this autumn and winter. Here is given a short description of the various tests. See also in the Appendix and in the matrix giving the distribution of the work amongst the participants.

4.1. Sensor test

A fundamental prerequisite for demand controlled ventilation system is the possibility to find a measurable "indicator" of the air quality. Another prerequisite is the existence of commercially available sensors for the measurand which have acceptable sensitivity, accuracy, long term characteristics and price level.

15 sensors for the following types of indicators will be tested:

* water vapour (RH, WBT, DPT)	7 sensors
* carbon dioxide	3 sensors
* unoxidized gases (H_mC_n, CO, etc. also called mixed gase sensor)	5 sensors

The tests will consist of 2 main parts. In part 1 one specimen of each sensor type is extensively laboratory tested. In part 2 three specimens of each sensor type is exposed to normal indoor climate conditions (in an office building).

The laboratory test procedure will consist of 4 main parts including

* data sheet evaluation
* performance of new sensors
* cross-sensitivity
* environmental tests.

The field test procedure will consist of 4 main parts including

* performance of new sensors
* a building status control
* exposure to ambient conditions
* renewed performance control

The Federal Republic of Germany and Sweden (lead country) are the participants.

4.2. Trials in unoccupied test buildings

The main aims with the experiments in unoccupied test buildings are to study how different ventilating systems can be made controllable. Most of the trials will be concerning pollutants in dwellings and systems applicable there. In one trial is going to be studied simulated normal conditions an office.

In general the countries with cold climate have equipped the test facilities with balanced ventilation systems and the countries with milder and more humid climate are testing natural and exhaust ventilating systems. The location of sensors, and supply and exhaust terminal devices will be studied with regard to the concentration of the measured pollutant from simulated occupants. Energy savings potential will be calculated based on the measured results.

Some of the factors to be studied are:

- Set point or acceptable level of chosen pollutant
- Source strength
- Distribution of sources in the room(s) or the system
- Character of source
- Air distribution pattern
- Choice of sensor type and control strategy
- Various time constants of the system

In the appendix is summarized the experiments in the five countries involved in test room studies. An example of a test room study is given in figure 3. The participating countries are Belgium, The Federal Republic of Germany, Finland, Italy (lead country), and Sweden.

4.3. Trials in occupied spaces

The main purpose with trials in occupied spaces is to study the energy conservation possibilities without sacrificing the indoor air quality.

Under real conditions DCV-systems will be evaluated. Different control strategies in different ventilation systems are applied in various buildings such as residentials, auditoria, offices, schools.

In a few months approximately 30 buildings are involved in tests in the participating countries. The plans are to measure in the following building types:

Residential		14 buildings
single family houses	11 bldgs	
blocks of flats	3 bldgs	
Offices		6 buildings
Auditoria		3 buildings
Schools, day nurseries		3 buildings

Details about the distribution of the work will be found in the appendix.

An example of a trial is illustrated in figure 4. The measurements and evaluation will cover:

- Regulating/controlling function
- Dynamic behaviour of the room and system
- Air quality
- Energy savings

The performance of the ventilation system will be checked in accordance to the Swedish guide "Inspection and performance checking of ventilation systems".

The participating countries are Belgium, Canada (lead country), ltaly, Norway, Sweden and Switzerland.

5. SUBTASK C - DESIGN AND OPERATION OF DCV-SYSTEMS

In the subtask will be summarized the knowledge concerning DCV-systems based on the experiments in subtask B and results from now already finished work. Conclusions and recommendations will be given in a source book which can be translated to national languages and then used as a hand book.

SUMMARY

The results from subtask A indicates a broad range of how much energy that is possible to save. Finished experiments in occupied spaces reports that between 8 % to 40 % of energy consumptions could be saved.

The first sensor tests will be carried out on 15 sensors exposed in laboratory and in ventilation systems in an office. Test room studies about air

distribution will give us better knowledge of optimal sensor location and if the ventilation systems can be made controllable.

In occupied rooms or houses of various use will be studied DCV-systems with different control strategy. Conclusions, recommendations and results from the trials will be given in a source book. The work is planned to be finish in June 1991 and a printed report late 1991.

References

1. Raatschen W. Market Analysis of sensors for the use in demand controlled ventilating systems 9th AIVC conference 1988.
2. Demand Controlled ventilating Systems - State of the art Review - working document IEA - Annex 18 Subtask A

Table 1. Measured CO_2 concentrations some examples

Ventilation System	Building use	Air exchange rate (h^{-1})	CO_2 Min	conc [ppm] Max	Mean	Comments
Natural	Day nurseries	0.5 - 1.5	1000	2500	1500	
	schools	0.5 - 4	1000	7500	3000	
	schools			5500	1500	
	dwellings		500	1900	1400	closed doors max 2800 ppm
	school			4500		
Exhaust	Day nurseries	1 - 8	600	1000	800	
	dwellings		800	1700	1400	closed doors max 3700 ppm
	school				900	
Supply Exhaust	day nurseries	2 - 9	400	800	600	
	auditorium		700[1]	1700[2]		
	dwellings		800	1600	1400	closed doors 1400-2900 ppm
	cinema				900	
	day nursery[4]	8	1300	1600		
	nursery[4]	4	1300	1600		
Supply Exhaust Return Air	school		600	1000		
	office		700	1200		humidified air
	office	3)		1000	700	
VAV System	school			2600	1000	
	auditorium				800	DCV-System

1) Air flow rate 2 l/s,person
2) Air flow rate 16 l/s,person
3) 0.1 ach/h during night
4) Two cases: a) supply and exhaust devices located at the ceiling
b) supply devices located at the floor and exhaust at the ceiling

Table 2. Volatile organic compounds (VOC) of which the main parts are hydrocarbons.

Reference	VOC-concentration [ug/m^3]
1. Mølhave, Møller	
Dwellings, new houses	6200
Dwellings, old houses	400
2. Johansson et al.	
Day nurseries	290 - 500
3. Berglund et al.	
New day nursery	300
4. De Bortoli et al. Dwellings, offices	range 200 - 10000 mean 3000
5. Lebret et al. Dwellings	no smoker mean 210 smoker mean 350
6. Mølhave, Lundqvist Dwellings, unoccupied	range 30 - 5500 mean 4600
7. Krause et al. Dwellings	range 70 -2700 mean 400
8. Hawtorne et al.	
Dwellings	mean 240

Normal concentration is below 1000 ug/m^3

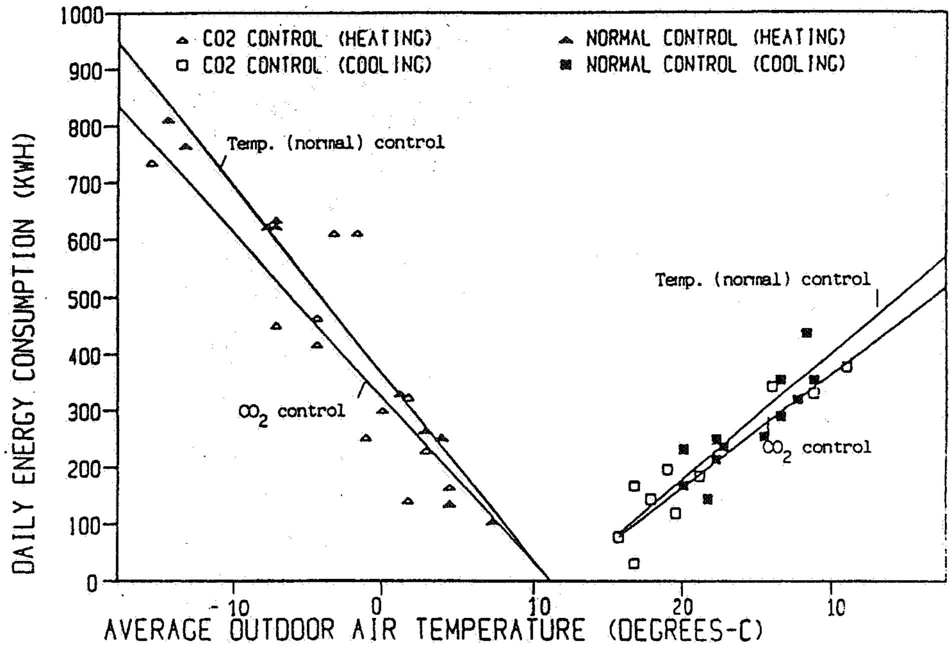

Figure 1. Energy consumption in a bank, Pasco, WA, U.S.A. CO_2 control mode compared to temperature (normal) control mode. Energy savings 8 %. Ref. Gabel S.D; Janssen J.E. et al. Carbon Dioxide based ventilation Control System Demonstration DOE BPA. April 1986. AIVC # 2333

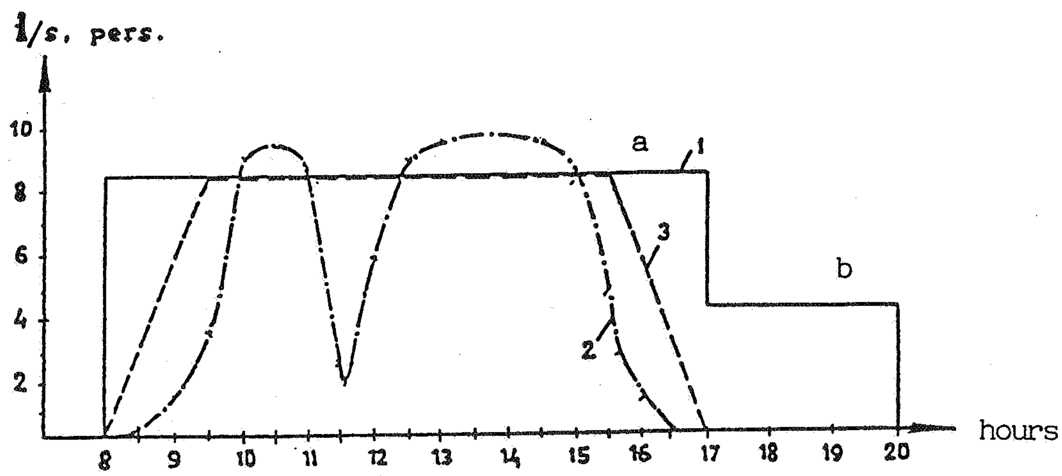

Figure 2. Office in Otaniemi, Finland. Outdoor air flow rates during a working day. Control modes:
1 Constant flow a) working hours b) evening c) during night - only return air.
2 CO_2 control. 3 Time control.
Ref. Södergren, D; Punttila, A.
A CO_2-controlled ventilation system. Swedish Council for Building Research D7:1983.
AIVC # 1218

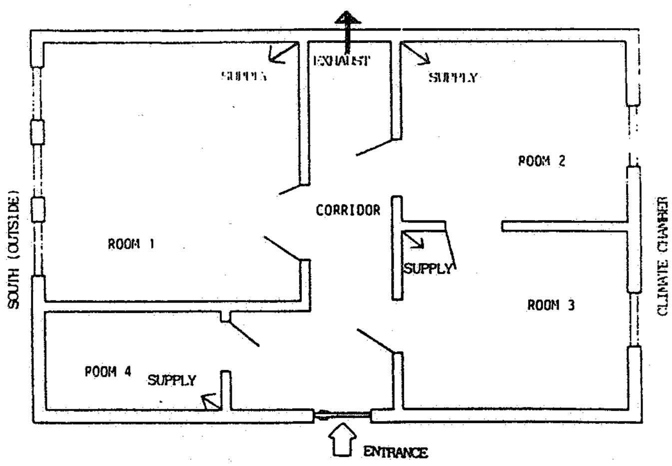

Figure 3. Test rooms at the Swedish National Institute for Building Research. An office space is simulated. Various tests will be run with people and also simulated by heat and CO_2. The number of simulated occupants in each room will vary from 0 - 2.

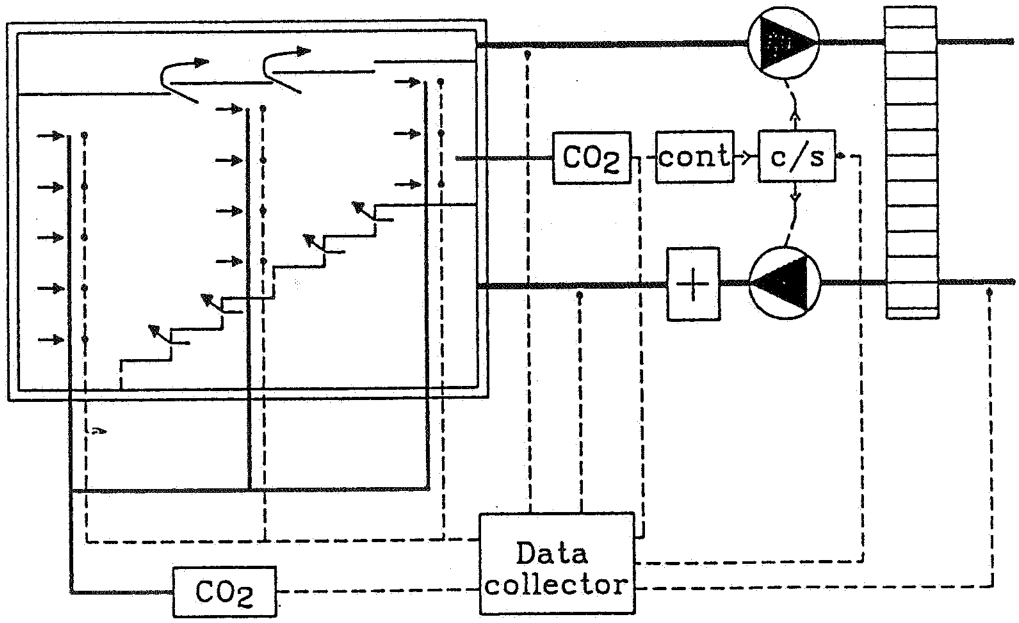

Figure 4. An auditorium in Trondheim, Norway, equiped with temperature and CO_2-controlled air flow. Sketch of the ventilation system, the controller unit, and the data acquisition system. Displacement ventilation with air inlets under the seats and outlets in the ceiling. CO_2 set point 900 ppm.

SUBTASK B - CASE STUDIES

Short description of the tests.

Belgium:

B 2 Unoccupied test houses

In flats will be used DCV systems with humidity and CO_2 sensors and also manual controlled systems. Different locations of the supply and exhaust devices will be studied. One school will be equipped with manual, humidity, and CO_2 controlled natural ventilation.

B 3 Occupied buildings

1. One school with CO_2 controlled system.

2. 2 blocks of flats with natural ventilation have been selected. 10 flats in each block are equipped with humidity and manual controlled systems. During 5 weeks each season measurement will be carried out in bathroom, kitchen, livingroom and in the extract air.

3. Single family houses with natural and exhaust air ventilation will be controlled by CO_2 and humidity sensors also manual and time controlled.

Canada:

B 3 Occupied buildings

1. In the R-2000 program run by Energy Mines and Resources development of single family houses are going on to find energy efficient homes with good indoor air quality. Experiments are ongoing measuring in balanced ventilated houses with humidity control.

2. In an office building a CO_2-sensor is located in the return air shaft. The building is divided in two zones one with CO_2-sensor controlling half of the building and the other half normal temperature controlled.

3. In meeting-rooms the ventilation system will be controlled by CO_2 and humidity sensors and compared to manual and temperature controlled ventilation.

4. Canada Mortgage & Housing Corporation (CMHC) have selected 5 houses. One house will be equipped with a system that can change the supply air according to the number of persons in the house. One house is equipped with humidity control in exhaust and supply devices. One

that will be designed this winter. Two houses will be used more or less as references and equipped with balanced ventilation system and heat recovery, one with and one without reciculating air.

Denmark:

B 3 Occupied buildings
In two existing day nurseries will be installed ventilation system with supply and exhaust air. Humidity and CO_2 sensors will be used to control the air flow.

Federal Republic of Germany:

B 2 Unoccupied test houses

The main objective is energy conservation but also to attain good indoor air quality. Different habits in dwellings are simulated and the pollutant levels are studied while using different ventilating systems and using different control strategies. Ongoing measurement.

Finland:

B 2 Unoccupied test houses

In a standard single family house is installed a supply and exhaust ventilation systems. The research work is in three steps

a) Loading profile, simulation and calculations.

b) Testing the systems when simulating control by the occupants.

c) Interaction ventilation and heating.

Italy:

B 3 Occupied buildings

In a new block of flats with exhaust ventilation is installed humidity controlled supply air grilles in bedrooms and living rooms. The main objective is to avoid moisture damaging the structure.

Netherlands:

B 3 Occupied buildings

1. Tests have been carried out in humidity controlled houses.

2. The objective is to find a cheap and practical system to be used in dwellings. It could be a balanced ventilation system with heat recovery and controlled by a sensor.

The plans are to install DCV system with CO_2, humidity, and odour sensors. Energy consumption will be checked. Humidity set point will be changed according to outdoor temperature. Sensors will be located in the exhaust air duct and in the living room. The systems will be evaluated during 6 weeks with each location of the sensors.

Norway:

B 3 Occupied buildings

Measurements have started in a lecture hall at the University in Trondheim. CO_2 sensor is located in the hall with the set point at 900 ppm.

The system is alternate run with a week with thermal control and a week with CO_2-control. Tests have been done with the same number of students in the hall. Supply air devices are located under the seats and exhaust devices are located in the ceiling and no return air. Measure: CO_2, temperature, relative humidity, air velocity.

Sweden:

B 1 Long term tests of sensors

Sensors for humidity, CO_2 and mixed gases will be tested in laboratory and in field.

B 2 Unoccupied test rooms

A test unit of 4 unoccupied office rooms will be used. A balanced supply and exhaust ventilation system is installed. Air will be supplied in the rooms and exhausted in the corridor. The test unit will be simulated to be occupied. Air movement and the distribution of the pollutants will be studied for the cases of:

- different locations of the controlling sensor

- different locations of supply-air devices.

B 3 Occupied buildings

1. Tests will be carried out in a meeting room with max. capacity of 25 persons. Different sensors will be used when controlling the supply air flow.

   The number of persons in the meeting-room can easily be controlled and the duration of the meetings.

2. In an office building tests will be done in a meeting-room for 15 persons and two open areas with a great variety in the number of persons.

   A VAV-system was installed from the beginning in the

2 year old building . The system controlled by CO_2-sensor will be compared to the original controlled by temperature.

3. A school which today has an exhaust air system will be equipped with a new supply and exhaust air system. The classrooms are nearly always used in the same way and with the same number of occupants present.

Occupied classroom: air flow rate	250 l/s
Unoccupied classroom: air flow rate	28 l/s

This will give 9 - 7,5 l/s, p and a calculated CO_2 level of 1000 ppm with 30 pupils and 900 ppm with 25 pupils. The supply principles will be "mixing" in 5 classrooms and "displacement" in 1 classroom. In 5 classrooms the air flow rate is controlled by an acoustic presence sensor and in 1 classroom controlled by a CO_2-sensor with the set point at 900 ppm.

4. In an office under construction a DCV system will be installed in the VAV-system. The building will be completed in Oct. 1989. Total area is 4500 m^2 and 185 office rooms. Measurements on volatile organic compounds, particles, CO_2, and humidity will indicate what pollutant that can be the controlling one. The measurement will also indicate when it is possible to control on activities coupled to the occupants and not on emission from building material.

Switzerland:

B 3 Occupied buildings

Two auditoria (70 persons in each) will be used at ETH in Zürich. The ventilation systems will be controlled by temperature in both systems. In one of the auditoria the indoor air is controlled by a CO_2-sensor. The supply, exhaust, and return air system is designed to give constant air flow with 750 ppm as a set point.

Table DISTRIBUTION OF THE WORK

Various test in unoccupied houses (B2) and occupied houses (B3) the controlstrategies, and the various ventilation systems.

Control Strategy	Building category: Residential – Single – unocc B2				Single – occ B3				Flats – unocc B2		Flats – occ B3		Auditoria Theatres – occ B3				Offices – meet rooms – occ B3	Offices – whole bldg – occ B3		Offices – small rooms – uno B2	Schools – unocc B2	Schools – occ B2	
	Na	E	SE	SEE	Na	E	SE	SEE	SE	SEE	Na	E	E	SE	SER	VAV	VAV	SE	VAV	VAV	Na	E	SE
Manual	D B	D B	SF		B	B	NL	CAN	SF		B	I					CAN				B		
Time Control	D	D			B	B									CH	N		CAN					
Presence	D	D																					S
Temperature (reference)															CH	N	S CAN		CAN	S			
Humidity	D B	D B			B	B	NL	CAN			B	I					CAN				B		DK1)
Pollution CO_2	D B	D B			B	B									CH	N	CAN S		CAN	S	B	B	S DK1)
Odour	D	D					NL										S						
C_mH_n																	S						
others								CAN									S						

1) Pressure diff B = Belgium, CAN = Canada, CH = Switzerland, D = Fed. Rep of Germany, I = Italy, N = Norway, NL = Netherlands, S = Sweden, SF = Finland.
Na = Natural vent., E = Exhaust vent, SE = Supply and exhaust, SEE = Supply and exhaust and extra exhaust fan, SER = Supply exhaust and return
VAV = Variable air volume

DK = Denmark 1) Day nursery

Discussion

Paper 2

Willem de Gids (TNO, Netherlands)

Was the booster fan also controlled by a sensor, and if so what type of sensor was used?

Lars Goran Mansson (LGM Consult AB, Sweden)

In ongoing projects in Canada single family houses have supply and exhaust ventilation systems. When needed the air flow is increased by a booster fan which is controlled by a humidity sensor.

Mike Holmes (Ove Arup, London UK)

Your example to demonstrate the potential savings due to the use of a CO_2 detector used working day and night-time ventilation rates of 8 and 4.2 l/s/person. The CO_2 detector model which showed savings of 40% was without any nighttime ventilation. Surely the same result would be achieved without using a detector and turning the system off at night?

Lars Goran Mansson (LGM Consult AB, Sweden)

The control mode 1, see Figure 1, shows the normal designed control of a constant air flow system in the Nordic countries. With the time clocked control mode giving an air flow more like the CO_2 control mode indicates that the potential saving is more like it is in the other example, Figure 1.