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Demand Controlled Ventilation
– Full Scale Tests in a Conference Room

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Synopsis

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.

The room is also acting as a reference field test installation for a simultaneously ongoing testprogram for sensors for demand controlled ventilation. From measurements on sensors for humidity and volatile organic compounds, conclusions have also been drawn about how suitable these sensors are for the purpose of demand controlled ventilation.

A simple system with temperature controlled air flow rate can in many cases be sufficient to achieve a well functioning demand controlled ventilation.

Carbon dioxide control seems to work very well and the output of the sensors has a very distinct and good correlation with the number of persons present in the room. The measured background/outdoor level is quite stable and the sensors do not show any great sensitivity to changes in temperatur, humidity or any other contamination in the air.

The relative humidity sensors are quite accurate and seem to bee very suitable for humidity control , but as their output is only slightly increased even for a large number of persons present and as the background/outdoor level can vary substantially and rapidly, they do not seem suitable for this type of demand controlled ventilation.

The sensors for volatile organic compounds are quite sensitive to the presence of persons, tobacco smoke and other contaminants produced in the room, but they are also very sensitive to changes in temperature/humidity and to changes in the contamination level in the outdoor air. Different sensors also have quite different outputs for the same air. The sensors seem to have a potential for demand controlled ventilation, especially when the main load is something other than heat sources and human related production of carbon dioxide, but further development of sensors and/or control system software is needed.

List of Abbreviations

AQ	Air Quality
CO_2	Carbon Dioxide
DCV	Demand Controlled Ventilation
IEA	International Energy Agency
RH	Relative Humidity
HVAC	Heating, Ventilation and Air Conditioning
VOC	Volatile Organic Compounds

1 Background

Within the framework of IEA Annex 18 "Demand Controlled Ventilating Systems" a number of research projects are being operated at present. The aim is to investigate the possibility to reduce energy consumption while maintaining a good indoor AQ. One of these projects is a full scale test of a DCV-system in a conference room situated at The Swedish National Testing & Research Institute.

2 Project Description

The conference room has been in use for about eight years. All furniture and other inventories are of about the same age. The room has a mixed ventilation system designed for a maximum of about 20 persons. A new HVAC-system, separated from the rest of the building, has been installed. The system is equipped with devices for heating, cooling and heat recovery. It has been especially designed to give a larger than usual span between maximum and minimum air flow rate. To regulate the air flow rate, the system is equipped with sensors for both temperature and CO_2. It is normally temperature regulated, but when the CO_2 concentration exceeds 700 ppm the system is CO_2 controlled. Both sensors are installed on one of the walls, 1.7 m above the floor. To avoid that the temperature sensor is influenced by heat from the CO_2-sensor, the sensors are placed several meters apart from each other.

A proposed "Method for Evaluation of Demand Controlled Ventilation" has been used as a guideline throughout the project. The above given air flow rates have been checked and the output voltage signal from the air terminal devices calibrated. The room-average air-change efficiency (RAACE) has been measured by means of CO_2-decline at two different air flow rates. RH- and CO_2-sensors have also been calibrated in the beginning and the end of the project. The VOC-sensors have only been checked functionally. These sensors all give an output signal between 0 and 10 volts, which we in the following will refer to as an indicated AQ of 0–100%. The energy consumption of the lighting can vary from 160 to1200 W.

Area:	43 m²
Volume:	115m³
Air flow span:	170–1000 m³/h
RAACE:	46% (900 m³/h), 64% (300 m³/h)

(inlet temperature 5 °C below room temperature)

The room has also been acting as a reference field test installation for a simultaneously ongoing testprogram for DCV-sensors. CO_2-sensors, RH-sensors and VOC-sensors have therefore been installed in a chamber connected to the exhaust air duct. It was planned to control the system with some of these sensors as well, but due to problems in getting a stable baselevel to regulate against these plans had to be abandoned.

The main purpose has been to evaluate the ability of a DCV-system to maintain a good indoor AQ. Measurements have only been made on the temperature- and CO_2 controlled system, but from simultaneous measurements on sensors for RH and VOC, conclusions have also been drawn about how suitable these sensors are for the purpose of DCV.

The conference room is in rather limited use. Most of the time it is empty and when in use there are very seldom more than 10 persons present. Because of this the threshold level for CO_2–control is rarely exceeded. Instead of making long time measurements we have there–fore concentrated our measurements to 12 shorter periods of 6–12 hours. These periods have been chosen to cover different load conditions that are of interest. During the test periods the following parameters have been measured:

Air flow rate:	exhaust air
Temperatures:	inlet air, exhaust air, on one of the walls
RH:	exhaust air (9 sensors)
CO_2:	exhaust air (2 sensors), on one of the walls (1 sensor)
VOC:	exhaust air (6 sensors)

As most of the time the system is only temperature controlled, we have decided to include some results and conclusions from measurements on this as well.

A test is also conducted where the reaction of the sensors to tobacco smoke is studied. This is done at three different manually chosen air flow rates.

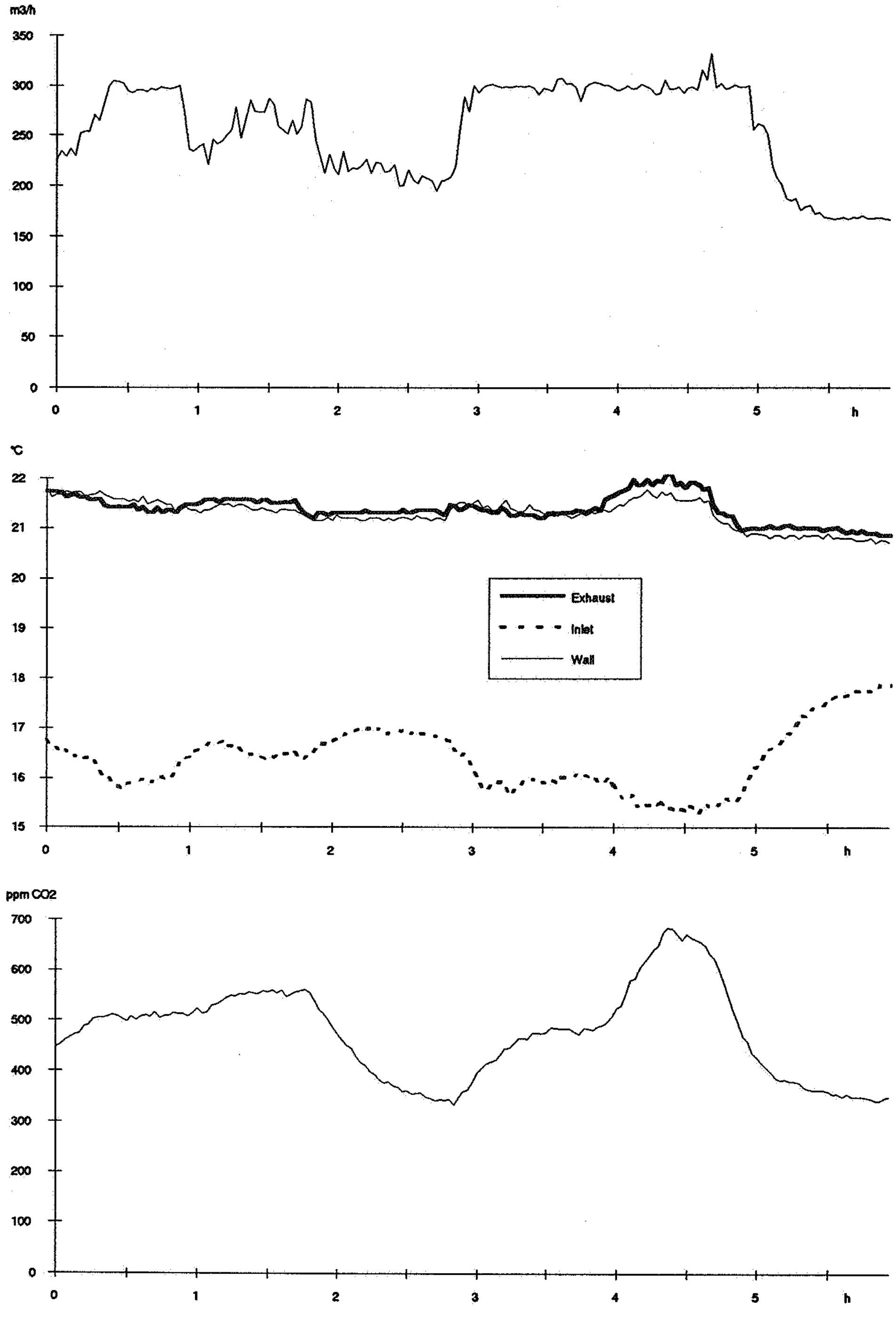
Calculations on energy savings are very much dependent on other system components than the DCV itself, what system you are comparing with and also how often the system is in use. Because of the very limited use of the actual system it has not been considered worthwhile to make any such calculations.

3 Full Scale Tests

3.1 Temperature Controlled Ventilation

Due to the heat produced by the human body itself and other heatsources that are activated when people are in the room, in this case mainly electric lighting, the system will react by in–creasing the air flow rate and decreasing the inlet air temperature. If the increase in air flow rate, due to the influence of the human body as a heat source, corresponds to the human need of fresh air, then a temperature controlled system vill theortically act just as a CO_2 controlled system. The problem is that the human beeing is very seldom the only heat source in a room and that these other heat sources can vary quite differently from the number of persons present. But if the main load is due to heat sources, then a simple temperature control is probably the best system and other more sofisticated systems are superfluous. We have in our case also noticed that the lighting is a heat source of the same magnitude as the heat from 10–15 persons. The lighting is therefore such a large heat source that it can force the system to increase the air flow rate all on its own.
Test No.7, that is shown in diagrams 1–3 below, is a good example of how the temperature control is working. During the test there was first a meeting with 4 persons going on for two hours, then a lunch break for one hour, then another meeting with 3 persons for one hour followed by a third meeting with 8 persons going on for half an hour. The lighting was

then turned off and the room was empty for the rest of the measurement periode. The lighting was also lowered after one hour of the first meeting and throughout the lunch break. Although the air flow rate never exceeded 350 m³/h the CO_2 concentration was always below 700 ppm and both the air quality and the thermal comfort were considered as good.

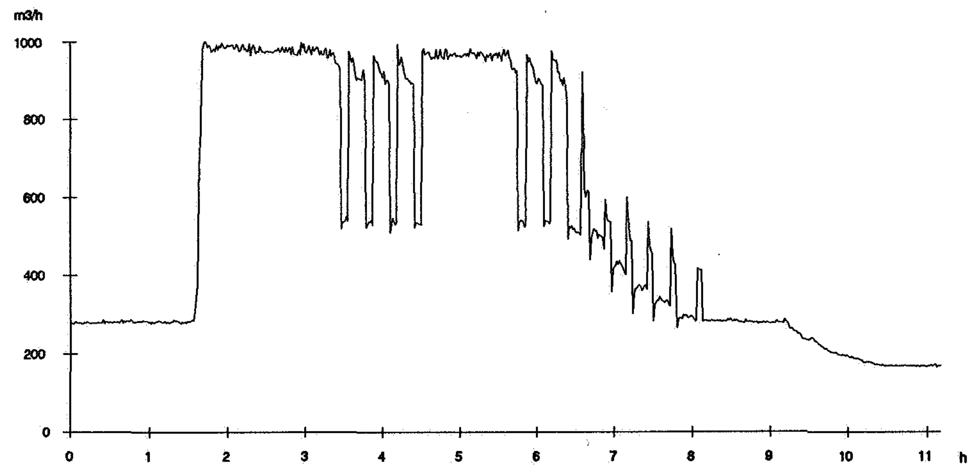


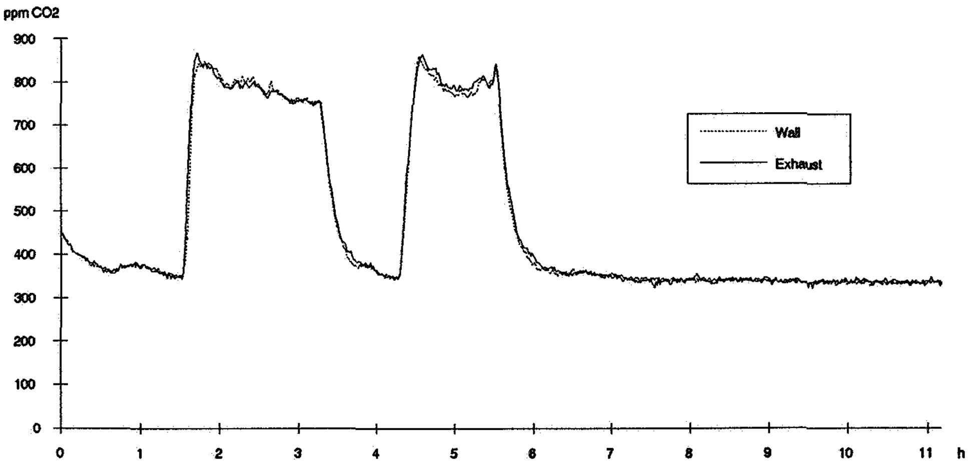
Diagrams 1–3; Air flow rate, temperatures and CO_2 concentration (test No.7).

The test presented above is for a low heat load condition. At medium loads we have had some problems with instability. Changes between half and full speed of the fans can then occur up to 6 times per hour, resulting in unpleasent sound and pressure shocks.In the next test that is presented (No.11) this is exemplified by the system behaviour during the lunch break and for two hours after the last meeting.

3.2 Temperature- and CO_2 Controlled Ventilation

Test No.11, that is shown in the diagams 4–5 below, is a good example of how this system is working . When the measurment starts the room is empty, but people have been in the room for a very short while about half an hour before. This can bee seen on the CO_2 concentration which is a little bit higher than the background level (335 ppm according to the sensor) and slowly declining. After a little bit more than one hour and a half 24 persons enter the room attending a meeting for nearly two hours. Then there is a lunch break for one hour and a half, followed by a second meeting with the same people, going on for slightly more than one hour. The room is then left empty for the rest of the day. Lighting is on during the first 9 hours of measurement. The AQ and thermalcomfort are also this time considered as good.





Diagrams 4–5; Air flow rate and CO_2 concentration (test No.11).

In diagram 5 above one can clearly see when people are entering and leaving the room. One can also see that there is no great difference between the sensor placed in the exhaust air duct and the one that is placed on one of the walls. This difference (exhaust conc. minus wall conc.) is more clearly shown in diagram 6 below.

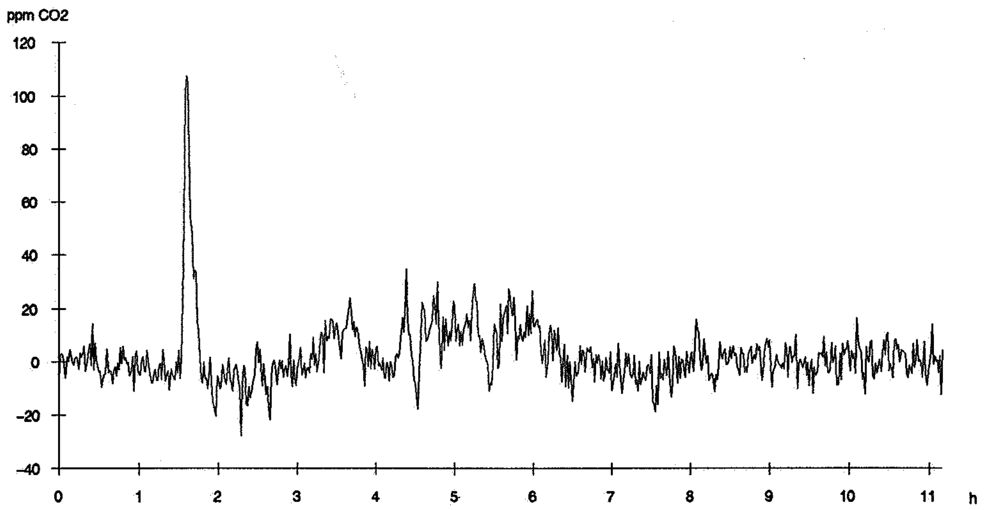


Diagram 6; Difference between CO_2–sensors in two different positions (test No.11).

This diagram shows that the difference between the two sensors most of the time is less than ±20 ppm. It is only during the beginning of the first meeting that the difference for a short while is a little bit more than 100 ppm. This particular sequence is more clearly seen in diagram 7 below. From this diagram one can see that the wall–mounted sensor has a delay of about 2 minutes.

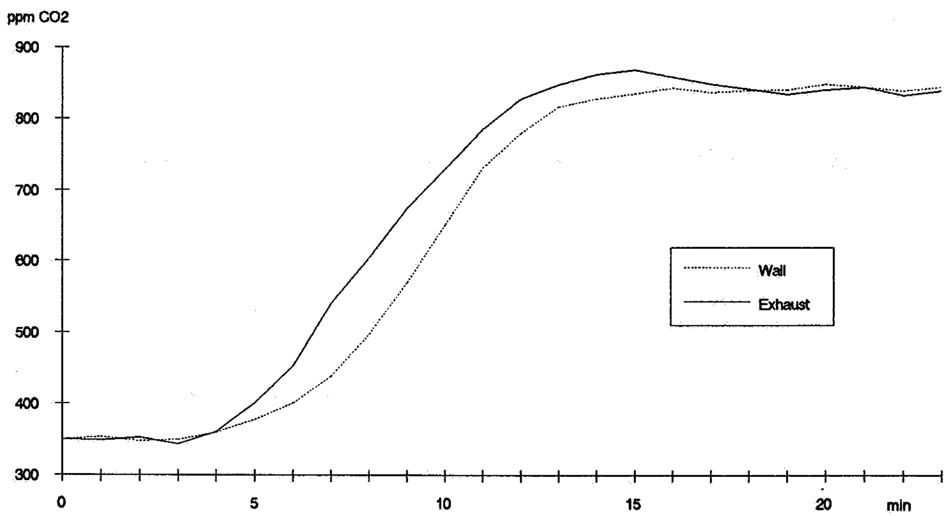


Diagram 7; Step–up for CO_2 –sensors in two different positions (test No.11).

In diagram 8 below the response curve of the flow rate is given together with the CO_2 concentration in the exhaust air. The result must be considered as very good. Especially as the system is controlled by the delayed sensor on the wall. A test with a simulated heatsource (1200 W lighting + 1200 W heat fan) does not give the same quick response at all.

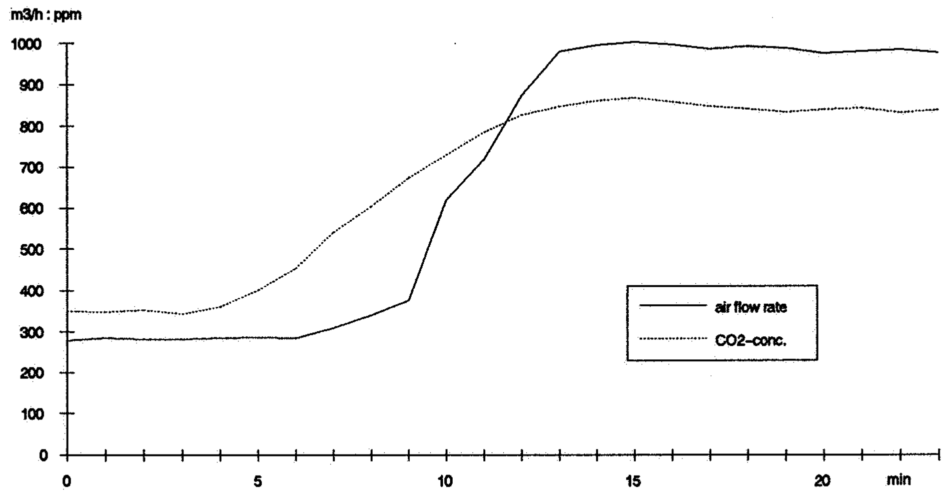


Diagram 8; Air flow rate and CO_2 conc., 24 persons enter the room (test No.11).

In diagram 9 below the measured background/outdoor CO_2 concentration during two different tests are shown. To what extent this variation is due to variations of the real concentration or variations in the sensor itself we do not know. The difference is in any case so small, compared with the response due to human presence, that it almost can be neglected.

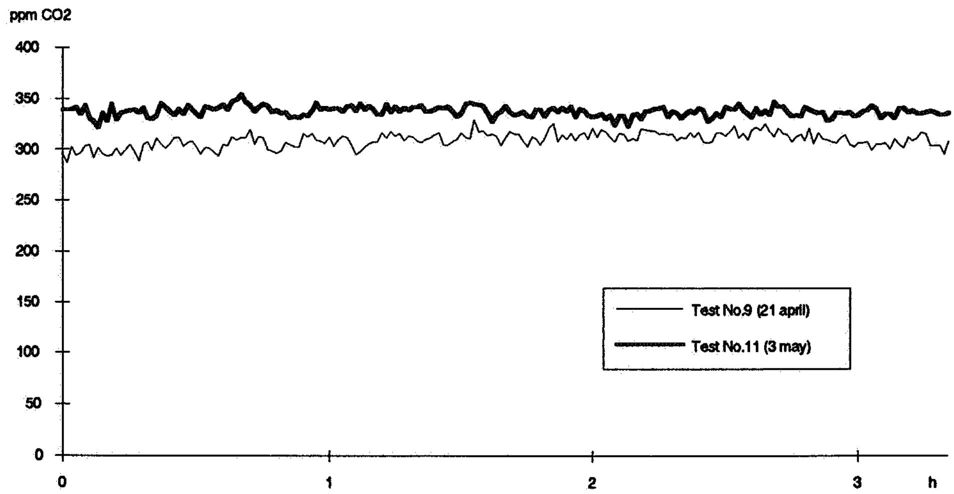


Diagram 9; Measured outdoor background CO_2 conc. during two different tests.

Note: We have in this context noticed some problems with one of the CO_2 sensor types. It has to be connected to the supply voltage for several days before the output signal reaches a long term stability. If the supply voltage exceeds the nominal voltage by more than 10% (not unusual), then it can cease to function. We therefore had to install a power resistor to keep the supply voltage down.

3.2 Humidity–sensor Measurements

Most of the RH–sensors have in the parallel laboratory testing project proven to be quite accurate. In our measurements all factory calibrated sensors but one are within a span of ± 5%RH. After our own calibration and curve fitting the results are even better. We have therefore chosen to present only curves for one sensor, but for three different tests. The results are given in diagram 10 below.

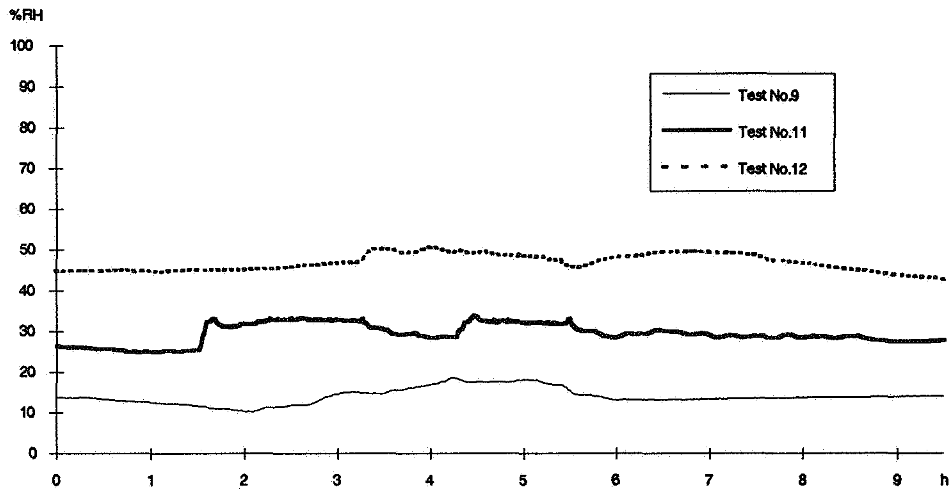


Diagram 10; Relative humidity during three different tests.

One can here clearly see the effect of human related humidificatin during test No.11. Calculations on the results indicates that about one third of the human energy consumption (30–40 W) goes into humidification of the air. During this test we have only very little variation in the background/outdoor RH level.

In test No. 9 the room is empty during the whole test. The variation in the background level is in this case of the same magnitude as was the effect of as many as 24 persons i test No.11.

Test No.12 is similar to test No.11, but the number of persons is now only 13–14 and due to simultaneous changes in the background level it is now impossible to distinguish when the meetings took place.

If one compares the different curves one can also see how much the background level can vary over a longer period of time.

If one wants to regulate the air flow rate with RH–sensors according to the number of persons present, then the RH and temperature must probably be measured both in the inlet and the exhaust air. The sensors will also have to be extremely sensitive and accurate. Finally some software must calculate the amount of humidity produced and regulate the air flow rate accordingly. One problem is that the humidification per person can vary quite much.

Another disadvantage with RH controlled DCV is that it does not react to smoke or any other source of contamination in the room.

3.3 VOC-sensor Measurements

A rather representative set of VOC-sensor curves are shown in diagram 11 below. They are also taken from test No.11 and one can clearly see the response to human presence. Sensors 4 and 16 represent more or less the behaviour of all but one VOC-sensor. That is, they have the same kind of response but at different levels and with different sensitivities. Sensor 3 behaves a little bit differently. It seems to react negatively to something that is produced in the room and is therefore going down to a lower level when the air flow rate is decreased. It can also bee of interest to notice that all sensors indicate lower AQ after lunch.

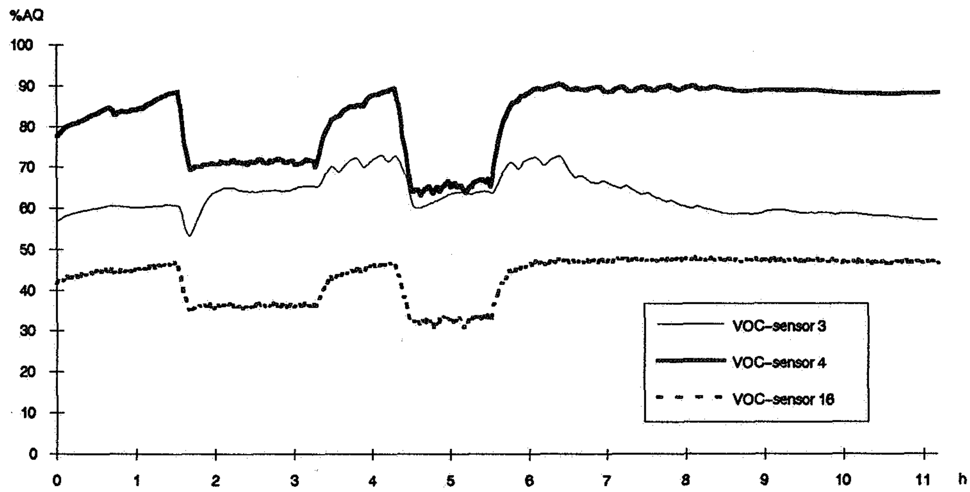


Diagram 11; The response of VOC-sensors to to human "load" (test No.11).

In diagram 12 below one can see that the sensors are sensitive to changes in temperature and RH. During the first two hours the temperature is increased, then for three hours everything but the RH (and possibly the outdoor AQ) is constant. One can also see that an overall decrease in RH results in an increased sensor-indicated AQ. For sensor 4 a RH below 20% makes it constantly indicate 100%AQ. Compare with diagrams 10-11.

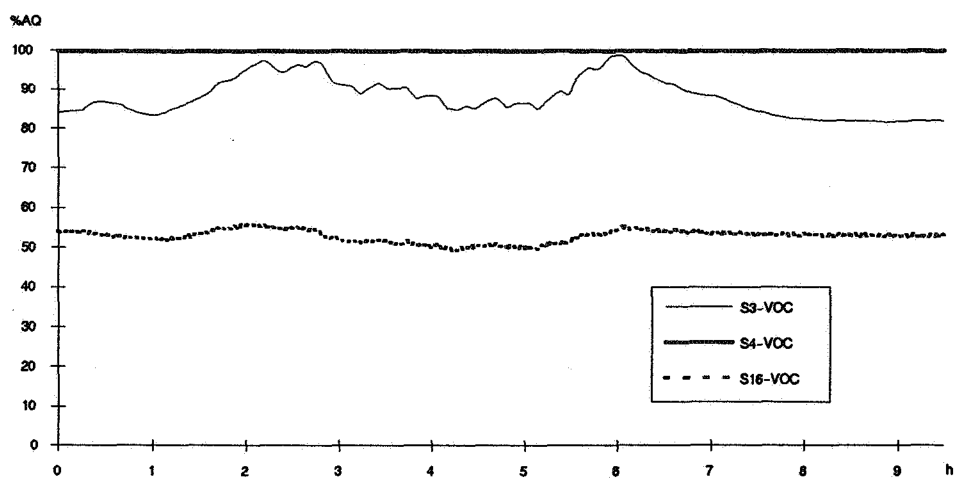


Diagram 12; The sensitivity of VOC-sensors to temperature and humidity (test No.9).

In diagram 13 below all other parameters (temperature, CO_2 concentration and RH) are held constant. This means that the variations of the VOC–sensors must be due to variations in the outdoor air. And if we look at the time when a decrease in AQ has occured, it correlates very well to people finishing their jobs in the afternoon. The decrease is therefore probably caused by contamination from cars that just have started up. There is a parking lot just outside the building and also a road with busy traffic at 16 pm and 17 pm. Sensor 3 is, unlike the other VOC–sensors, not sensitive to those outdoor variations. During functional tests with outdoor air, we have had atmospheric inversion and all sensors including sensor 3 were negatively affected (sensor3: 38%AQ, sensor4: 63%AQ, sensor 16: 26%AQ).

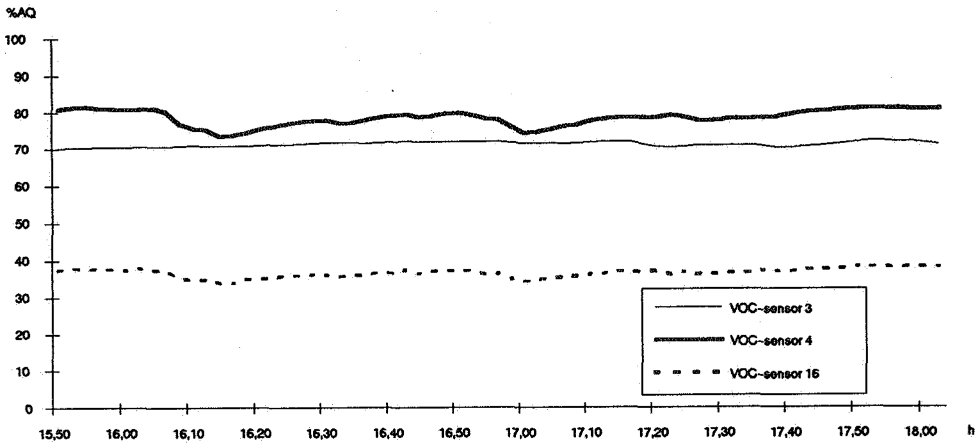


Diagram 13; Sensitivity of VOC–sensors to changes in the outdoor AQ (test No.2).

Sensor 16 was also equipped with a software that changes the output in three different steps. This can then be used to regulate the speed of the ventilation fans. Monitoring the outputs and recalculating them into three air flow rate steps in the range of 250 to 1000 m³/h gives for test No.11 the result given in diagram 14 below. This indcates that there is room for improvements on the software. (See top of page 5 for explaination of the curve for the real air flow).

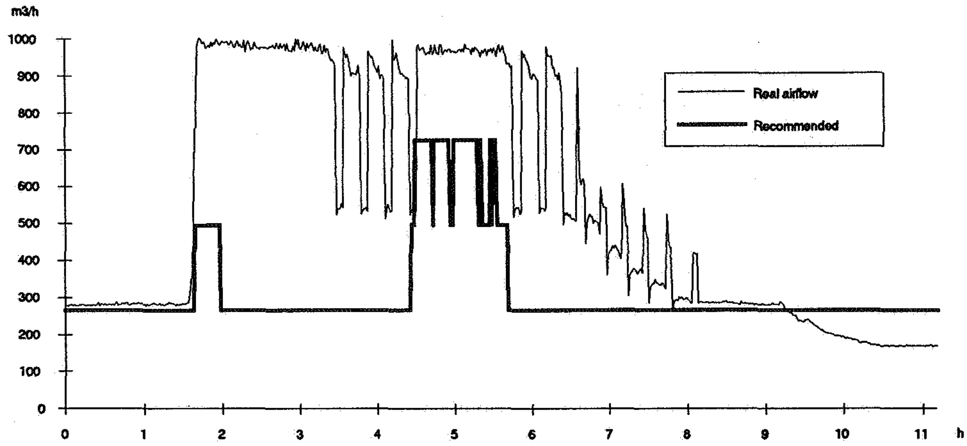


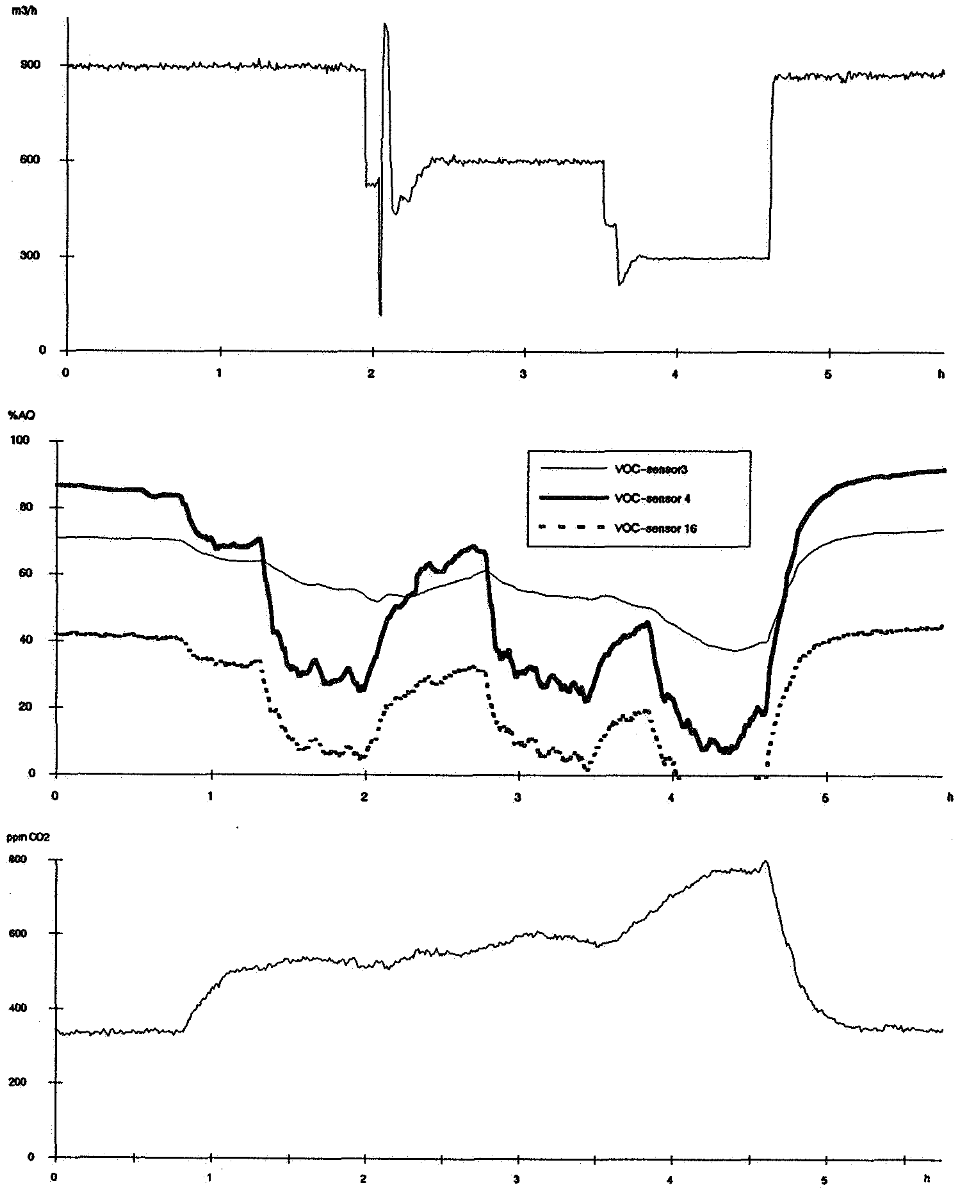
Diagram 14; Real air flow rate compared to that recommended by VOC–sensor 16 (test No.11).

VOC–sensors will probably have to be installed both in the inlet and the outlet air. Each pair (or more) of sensors will also have to be either nearly identical in behaviour or calibrated in such a way that some software can take care of the differences.

3.4 Smoke Test

A has been conducted with tobacco smoke. The temperature and RH were nearly constant during the whole test (20–21°C and 35–37%). The air flow rate was manually controlled to three different levels. The air flow rate, VOC-sensor output and CO_2 concentration during the test is shown in diagram 15–17 below. The test can be divided into 10 periods with different load conditions according to the following table.

period	1	2	3	4	5	6	7	8	9	10
start (hour.minute)	0.00	0.50	1.00	1.20	1.55	2.40	2.50	3.35	3.55	4.35
duration (minutes)	50	10	20	35	45	10	45	20	40	60
number of persons	0	0–7	7	7	6–7	7	5–7	6–7	7	0
number of cigarettes	0	0	0	12	0	0	10	0	8	0



Diagrams 15–17; Air flow rate, VOC-sensor response and CO_2 conc. (test No.4)

One can clearly see the decrease in indicated AQ during the smoking periods. The AQ was considered as very poor during periode 7 and especially during periode 9.

Calculations on the response of the VOC–sensors give the result that the presence of one human beeing corresponds to smoking in the range of 0.2 to 1.0 cigarettes per hour.

It is also of interest to notice that the CO_2–sensor during the same period of time gave no significant indication about how poor the AQ really was. If the CO_2 control had been turned on it would only have been activated during period 9 and the increase in air flow rate to decrease the CO_2 concentration to 700 ppm would only result in a slight and insufficient increase of the AQ.

4 Conclusions

The sudied system seems to have a very good ability to maintain a good indoor AQ. The main problem with the system has been instability at medium heat loads.

The usefulness of DCV are very dependent on what kind of system it is installed in and how the system is used. Furthermore the kind of DCV–system that is the best depends on what the main load is.

If the main load may be of different types at different times, then a combination of different control variables can be necessary.

A simple system with temperature controlled air flow rate can in many cases be sufficient to achieve a well functioning DCV. If the main load is due to heat sources, then a simple temperature control is probably the best system and other more sofisticated systems superfluous.

The lighting and other heatsources are often of such a magnitude that they can not be neglected, especially if the air flow rate is temperature controlled.

The output of a CO_2–sensors has a very distinct and good correlation with the number of persons present in the room. The measured background/outdoor level is quite stable and the sensors does not show any great sensitivity to changes in temperatur, humidity or any other contamination in the air. The latter can be both good and bad. Insensitivity to tobacco smoke is, as we have seen, not a good desired characteristic in DCV–systems where smoking may occur..

The RH sensors are quite accurate and seem to bee very suiteable for humidity control, but as their output is only slightly increased even for a large number of persons present and as the background/outdoor level can vary substantially and rapidly they do not seem to be suitable for the kind of DCV that we have studed. The requirements on sensitivity and accuracy will probably be too extreme, making sensors to expensive.

The sensors for VOC are quite sensitive to the presence of persons, tobacco smoke and other contaminants produced in the room, but they are also very sensitive to changes in temperature/humidity and to changes in the contamination level in the outdoor air. Different sensors also have quite different outputs for the same air. The sensors seem to have a potential for demand controlled ventilation, especially when the main load is something other than heat sources and human related production of carbon dioxide, but further development of sensors and/or control system software is needed.

Except for simple temperature control, CO_2–sensor controlled systems seem to be the only on the market today that have been developed enough to be recommended.

Having a well functioning mixed ventilation system, it does not seem to matter much whether the sensor is placed in the exhaust air or on one of the walls.

Acknowledgements

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Note: A more detailed report from the measurements will be published later this year.