Document

D7:1983

A CO_2-controlled ventilation system

Pilot Study

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Swedish Council for Building Research

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This document refers to research grant 801037-0 from the Swedish Council for Building Research to Paul Petersson AB, Stockholm.

D7:1983

ISBN 91-540-3911-8
Swedish Council for Building Research, Stockholm, Sweden

Spångbergs Tryckerier AB, Stockholm 1983

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FOREWORD

At a meeting in Helsinki in October 1979, more extensive collaboration in the building and installation sector was recommended by the Department of Trade and Industry in Helsinki and the Swedish Council for Building Research in Stockholm.

Some month later, Vidar Westerholm, EKONO, Helsinki, proposed controlling ventilation by CO_2-content and studying function and profitability in a test building.

The special controlling eqipment necessary was provided by EKONO's filial branch in Seattle, U.S.A, and EKONO's new office-building in Otnäs, outside Helsinki, was selected as suitable premises.

The following persons have participated in the work- and consultative group from Helsinki:

Vidar Westerholm	EKONO
Antero Punttila	EKONO
Leena Kuusela	EKONO

And from Stockholm:

Bo Göstring	The Trade Association for the Swedish Mechanical and Electrical Engineering Industry
Thomas Lindvall	The National Institute of Environmental Medicine
Jan Sundell	The National Board of Occupational Safety and Health.
Leif Tegman	The National Board of Physical Planning and Building.

Nina Dawidowicz from the Swedish Council for Building Research has been the research secretary.

I should like to thank all participants for their extraordinarily good and stimulating co-operation, wich I consider has contributed towards very good research results.

Stockholm. July 1982

David Södergren

SUMMARY

Large savingsin the cost of construction and operation could be made if ventilation were adapted to the prevailing need. Ventilation of empty rooms is a frequent extravagance.

Amongst the most promising of present possibilities for indicating occupancy, and thus the ventilation need, is that of measuring the level of carbon dioxide.

The project includes a test with eqipment for CO_2-control of the outdoor air-flow in an office building.

At the same time as the air-flow througt the building is regulated, so that the fixed CO_2-level is maintained, the presence of other pollutants has been checked, futhermore, local concentrations of CO_2 have been registered. No disturbin concentrations have been discovered in any case.

The office employees have been asked their opinion of the indoor climate under normal circumstanses, and during CO_2-controlled air-flow. There has been no significant difference.

The test has shown that the method works satisfactoirly. Due to energy saving, the eqipment would pay for itselt within about a year, but this depends on the design of the current construction.

The need for development of components and systems has been analyzed. In the opinion of the ventilation branch, it is possible to introduce the principle with the selection of components available at present, provided that the control system is safe and reliable.

1 INTRODUCTION

Large energy savings and improved comfort could be reached if the ventilation system could be controlled, so that the air-flow was constantly adjusted to the existing need.
So far, variations in the air flow have mainly been controlled by timers, programmed according to anticipated requirements The temperature, or temperature regulation has often governed the quantity of outdoor air.
The first rule, in order that a requirement-adapted ventilation system can be developed, is that a method for measuring the air-quality must be found.

In the project, a carbon-dioxide measuring instrument has been installed in the office-building in question and the carbon dioxide level in the exhaust-air has controlled the quantity of outdoor air, so that the CO_2-level has been constant. The purpose of this has been to see how the equipment functions, and at the same time, to study other effects of air-flow regulation - for example, how the CO_2-level can vary locally, how other pollutants in the air can vary, how much energy can be saved, etc.

This project has been limited to the examination of conditions in an office building with a re-circulated air system, and where air is used for the heating system.

The building is in Helsinki, and is the base for a firm of consultants called EKONO. The larger part of the measuring work has been carried out by EKONO staff, and the project has thus become an example of valuable Research and Development co-operation between Finland and Sweden in the building sector.

Other work in the same field has been reported from Japan and the U.S.A, but there are few publications as yet. However, a preprint from the Engineering Research Institute, Iowa State University, U.S.A., can be mentioned here. It is compiled by James E Woods and others, and is titled "Subjective and objective Evaluation of a CO_2-controlled Variable Ventilation System".
The summary was written for the ASHRAE conference in Houston, Texas, January 1982, and describes how a CO_2-controlled ventilation system in a wing of a school-building works. The result indicates that notable energy savings can be made without subjective difficulties.

2 QUALITY DEMAND FOR INDOOR AIR

In the Royal Swedish Academy of Science's documents from 1757, Pehr Wargentin wrote the following concerning ventilation requirements:

"Those who know about nature have shown, in their unquestinable findings, that no animal can live, and no plant grow without air.Futhermore, they cannot thrive for long without a change of air, and that man also needs new and fresh air often is equally underiable, for just as fire cannot burn in a stifted room, but dies as soon as one removes those qualities which give it life, in the same way, a man cannot endure life long without a change of atmosphere".

The air quality inside a building depends on the presence of pollutants and the amount and quality of outdoor-air brought in. We spend more than 4/5 of our time indoors; for most of us, at home and in offices and similar buildings. Therefore from a general perspective, airquality in non-industrial buildings is of great importance.

The standard for hygiene in non-industrial places of work cannot be used directly to evaluate air quality. In comparison with industrial work-places, the group of people in question is different, (with respect to age, health etc), and the exposure time is often longer and more complex. In spite of a great need for a special air quality standard for non-industrial indoor-air, there are only a few such suggestions. New materials, new methods, changed subjective preferences and behavior are some of the factors that must be considered in this case.

Quality demand for indoor-air in non-industrial buildings is almost always expressed in terms of determined outdoor-air flow, and not in maximum concentrations of other materials or pollutants allowed. This simple demand philosophy, based on decades of practical experience, presumes that air pollution emission has not increased, that outdoor-air quality has not worsened and that those margins which the earlier applied outdoor-air flow have given have not decreased. Development has, in fact, progressed in a different way. Much new building material has come into being at the same time as effective control of products has not taken place, and energy costs have forced lower outdoor-air flow. In today's situation, a choice must be made: the security margins must either be increased through greater outdoor-air flow, product control etc., or through more effektive use of the low outdoor-air flow we have at present. CO_2-controlled ventilation could be one solution.

Among the pollutants inside buildings are odour from people and animals, tobacco smoke, combution products such as nitric oxide and carbon monoxide, fromaldehyde, hydrocarbon and particles. (Södergren et al. 1981). Ionizing radiation from radon and radon components is a problem in some buildings. Other problems are caused by dust mites and mould spores, which can cause allergic reaction. It is most probable that health risks are associated not only with individual pollutants, but more so with the joint reaction of different pollutants and other climatic factors.

In relation to energy, the relative importance of ventilation has increased as a result of the fact that today's buildings are air-tight and well insulated CO_2-controlled ventilation is one way of overcoming ventilation losses and thereby keeping energy consumption low - without worsening air quality. CO_2-controlled ventilation does, however, depend on the fact that several critical aspects are carefully considered, of which some are biological. (Berglund, Johansson, Lindvall 1982). Firstly the control variables that are used must be biologically based. Besides pollutants from occupants and those from building materials, activity and outdoor-air must be observed. Secondly, placing of sensors that monitorthe control variables must be carried out so that an acceptable air quality is guaranteed for all occupied parts of the building.

Taken that generation of pollutants from the building, inventories and processes is low, the odour criterion becomes the determining factor for the ventilation requirement. Already 100 years ago, Max von Pettenkoffer showed the connection between bodyodour, CO_2-concentration and the number of occupants in a room. He suggested 1500 ppm CO_2 as an upper limit for acceptable air quality. He considered that over that limit the odour intensity became discomforting.

Yaglou, (et al, 1936) illustrated a somewhat more complicated connection between odour and people, outdoor-air flow and room volume per person. The connections illustrated are still, generally speaking, the controlling factor for the ventilation demand given in building regulations in many parts of the world. (See fig 3:3).

It has recently been maintained that the connection between odour from people and outdoor-air flow does not depend at all on room volume per person. (Cain et al 1981; Madsen 1982). Cain et al. suggested an outdoor-air flow of 4 l/s p. for acceptable air quality, taking body odour into consideration. This air flow gives, in balance, a CO_2-level that generally agrees with von Pettenkoffer's suggestion, i e 1500 ppm, provided that the occupants are resting, Berglund and Lindvall (1978) suggested however, a lower limit, i e 700 ppm. It was shown that odour from occupants dominated the other odours in the building if this limit was raised.

Apart from being used as an indicator of body odour, CO_2 can have unhealthy effects if in large concentrations. The upper limit for places of work in Sweden is 5000 ppm at present for non-industrial indoor miliev, ASHRAE (1981) have a limit of 2500 ppm in their new ventilation standards. This corresponds in balance to a metabolism of approx. 120 W, an outdoor-air requirement of approx 2,5 l/s p. In contrast to this, NKB (The Nordic Committee for Building Regulations 1982) has given, in its guidelines for building regulations concering air quality, a demand on the lowest outdoor-air flow as 4 l/s p. The NKB guidelines have begun with a suggested activity level for occupants in the building, the hygienic limit for CO_2 at work, and a security factor, (3 for offices and 5 for houses). According to NKB's work group, this flow can be seen as a definite minimum limit which is only recommended because of the great need to save energy at present.

It seems suitable that in CO_2-controlled ventilation systems the limit should not be set higher than the CO_2 levels normally kept in connectionally ventilated buildings.In Scandinavia, typical CO_2 levels in office buildings are a maximum of 800 ppm. (Berlund, Johansson and Lindvall 1982. Seppinen 1981). In the current investigation and desired value of 700 ppm has been chosen.

In an office studied by Berglund, Johansson and Lindvall (1982), CO_2 concentration varied with the rate of occupancy, as expected, but other pollutants followed a different pattern for example, with changes in the amount of recirculation-air, the levels of CO_2 and C_9 alkanes increased with heightened recirculation-air level, while NO_x decreased, and the pattern for other organic combinations and CO lay in-between. The investigation shows that other pollutants than CO_2 must be observed while using a CO_2-controlled ventilation system.

3 TESTS WITH REQUIREMENT-CONTROLLED VENTILATION

3.1 Test Building

The measurements have been taken in the newest part of EKONO's office-building, in a suburb of Helsinki. The building has been in use since the end of 1979. The office has a gross area of 4 700 m^2, and a total volume of 14 800 m^3. A microprocessor computer system controls heating and ventilation, and enables several different tests to be carried out.

3.1.1 The Heating and Ventilation System

The ventilation system operates normally between 08.00 and 17.00 hours with full fan-speed, and then at half fan-speed until 20.00 hours. The ventilation system is used to distribute warmth throug the building. There are no radiators, and the fan starts to operate in the morning, according to a fixed programme that calculates the commencement of pre-heating. The building has up to 180 occupants, and the air supply rate is calculated at 7,3 m^3/s, wich corresponds to 2,5 changes of the total air volume per hour. The ventilation air flow for an office occupied by one person is 32 l/s, and for two persons 48 l/s. The air is supplied to the office via hollow slabs, and is sucked out through an exhaust air window, as shown in fig 3:1.

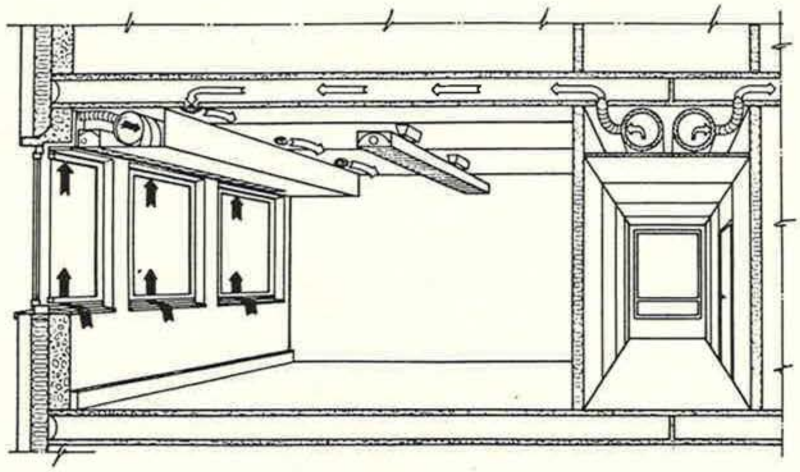

Fig 3:1 Cross-section of a typical office.

The office employees have a flexible working day, beginning between 07.00 and 09.00, and finishing between 15.00 and 17.00. Lunch break is half an hour, between 11.00 and 13.00. The canteen is situated in a nearby building.
The air leakage in the building has been calculated by using the tracer gas technique (N_2O). Using 100% recirculation air, it was found that the ventilation system's infiltration level was 0.15 air change/h during the winter. When the fans were turned off, the level decreased to an average of 0.1 air change/h.

3.2 Indoor-air quality measurements

3.2.1 Ventilation control system

Three different ventilation control systems have been studied in this investigation, (fig 3:2).

1. Constant outdoor air-flow
2. CO_2-based ventilation control system.
3. Timer system

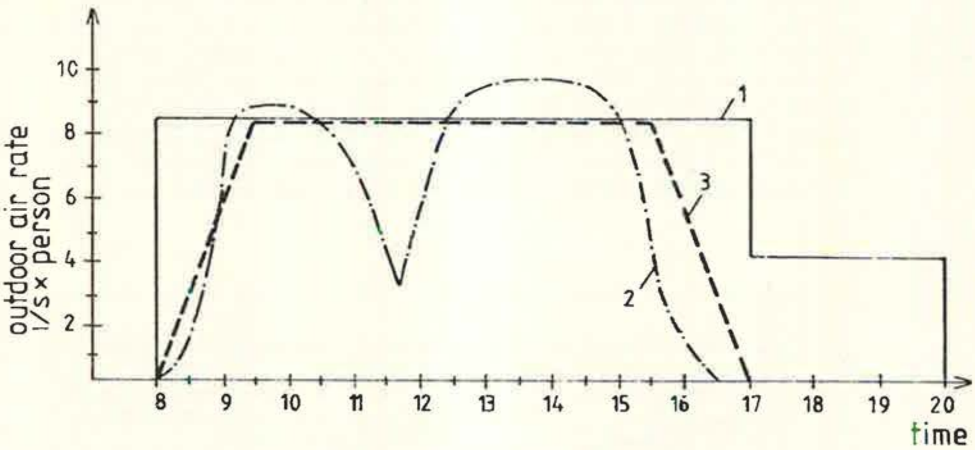

Fig 3:2 Outdoor air-flow with three different ventilation control systems.

In the first case, the outdoor air rate was set so that it corresponded with the minimum outdoor air flow recommended by the National Building Code of Finland, (fig 3:3) i.e. 4,5 l/s per person in a room with two occupants. The supply air-flow was quite high because of the warm-air heating system - 421 l/s, of which 80% of the total flow is recirculation air.

A CO_2 analyzer was connected to the main return-air duct in control system 2, (fig 3:4).

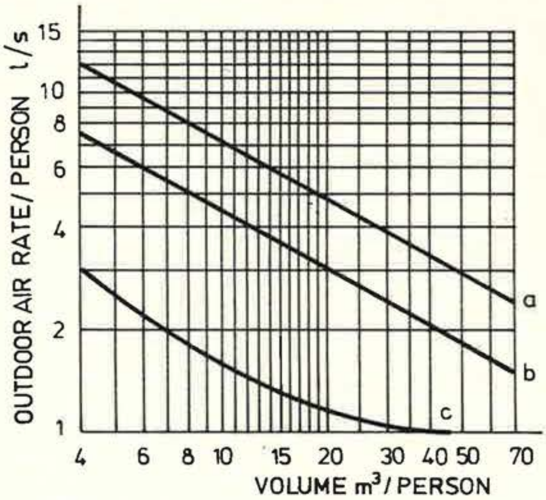

Fig 3:3 Outdoor air-flow per person according to the National Building Code for Finland and Sweden.

a = Room where smoking is allowed
b = Room where no smoking is allowed
c = Additional air rate for room without windows

The CO_2 analyzer was connected to damper motors via a computer for regulation of recirculation air-flow. The computer regulated the recirculation air-flow so that the CO_2 level, (eg. 700 ppm) was maintained in the return air.
In control system 3, when the outdoor air damper was regulated by a timing function, the level of carbon dioxide concentration varied similarly to the concentration when the damper opening was fixed. The damper was opened at 07.45 and closed at 15.30. The damper takes 1,5 hours to move from fully open to fully closed.

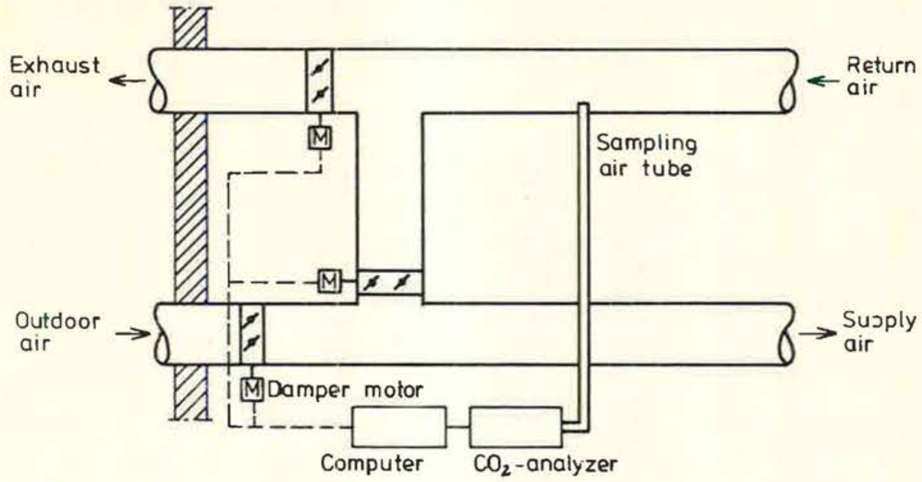

Fig 3:4 The Principle of a CO_2-controlled Ventilation System.

3.2.2 Methods for measuring indoor-air quality

There is a selection of parameters that indicate indoor-air quality to choose from. The primary objective was to study how the concentration of generated CO_2 varied with different ventilation control systems.

The carbon-dioxide concentration was measured in the main return-air duct with a non-dispersive infrared instrument, ANDROS 302. The concentration was measured in the same way in the offices, in several different areas in the room. Radon concentration was also measured in the return-air duct and the offices. Employees were interviewed during the first and second ventilation control systems. The interview can be found in Appendix I. Interviews were held between 14.00 and 15.00 hours, when the indoor-air quality was considered worst.

3.3 Results

3.3.1 Fluctuation of CO_2 in recirculated air

Figures 3:5, 3:6 and 3:7 illustrate how the carbon dioxide concentration changed daily in the three ventilation control systems. The carbon-dioxide concentration was measured in several points in the return-air duct, after the fan, and was found to be the same. This shows that the concentration does not vary in any part of the duct's cross-section. The concentration of CO_2 in the out-door-air was 350 ppm.

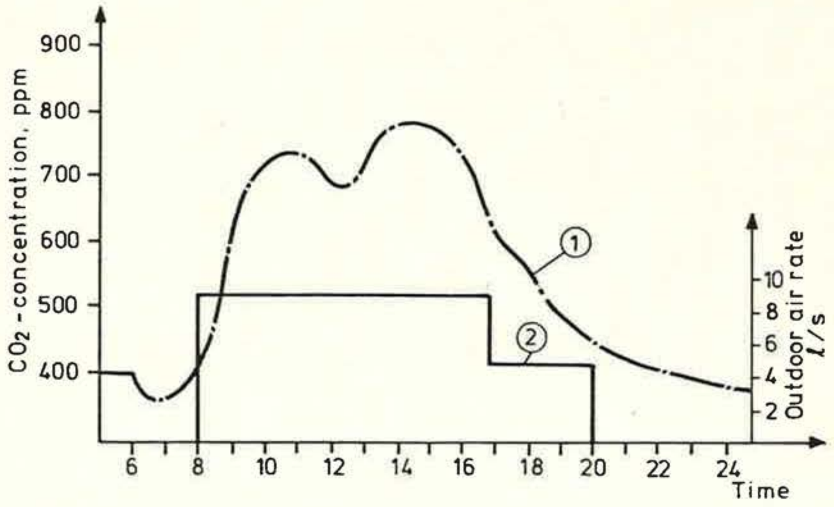

Fig 3:5 CO_2-concentration over a 24-hour period, (1) and outdoor-air flow, (2) in control system 1.

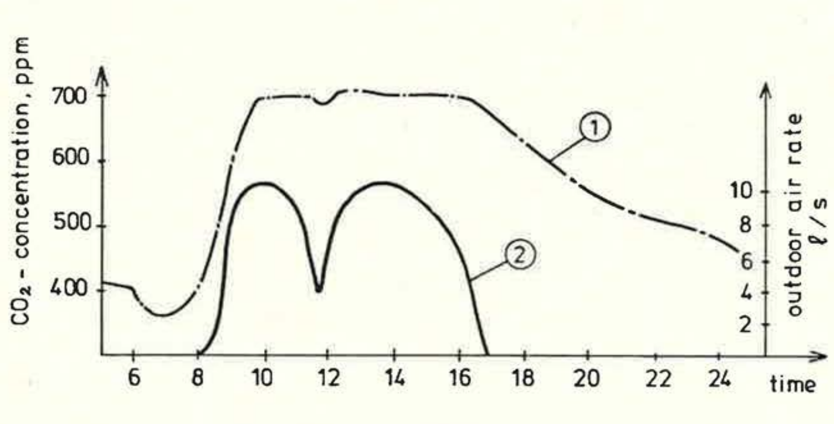

Fig 3:6 CO_2-concentration in the main recirculation air duct, (1) and outdoor air, (2) when the flow was controlled by a CO_2 analyzer. (System 2).

Fig 3:7 CO_2-concentration in the main recirculation air duct, (1) and outdoor air flow (2) when the flow was regulated by a timing function damper, adjusted to the requirements registered in System 2. (System 3).

The concentration in the return-air duct rose to 750-850 ppm when control system 1 was applied.

The concentration was highest at 15.00 hours. The changes in carbon dioxide concentration correspond closely to the degree to which the office is occupied. The employees arrive at the office between 07.00 and 09.00 hours. The canteen is open between 11.00 and 13.00 hours, (Lunchbreak is 30 minutes.) The employees normally leave the office between 15.00 and 17.00 hours.

In control system 2, the CO_2-concentration in the recirculation air was approximately 700 ppm. The amount of outdoor air varied between 1,5 and 2,3 m^3/s. By changing the desired value for CO_2-concentration by 50 ppm, the average value of outdoor air flow was changed by 10%.

When the outdoor air flow was regulated according to a set timing function, the carbon dioxide concentration corresponded fairly well to the conditions registered in control strategy 2.

3.3.2 Local variations of CO_2-concentration in an office

Local variations of CO_2-concentration were measured in a typical office, with an area of 18 m^2, normally occupied by two persons. Measurements were taken at five points, on three different levels, (fig 3:8) at 14.00 hours, when the CO_2-concentration in the return air duct of the building was 830 ppm. (Control strategy 1).

According to these measurements, the concentration was highest just under the ceiling, near a window, (fig 3:9). The concentration in supply air was 580 ppm, and 880 ppm in the return air.

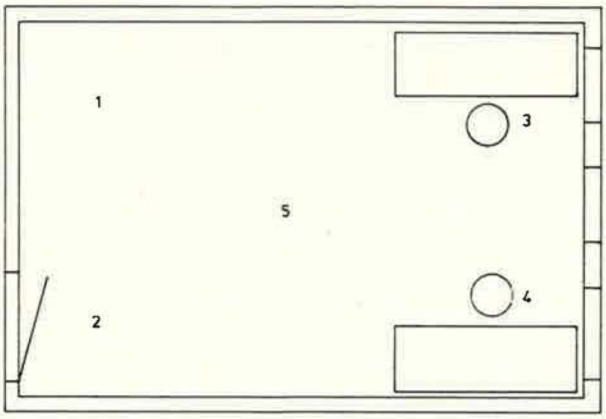

Fig 3:8 CO_2-concentration in an office was measured in five places in the room, at three levels above the floor in each place.

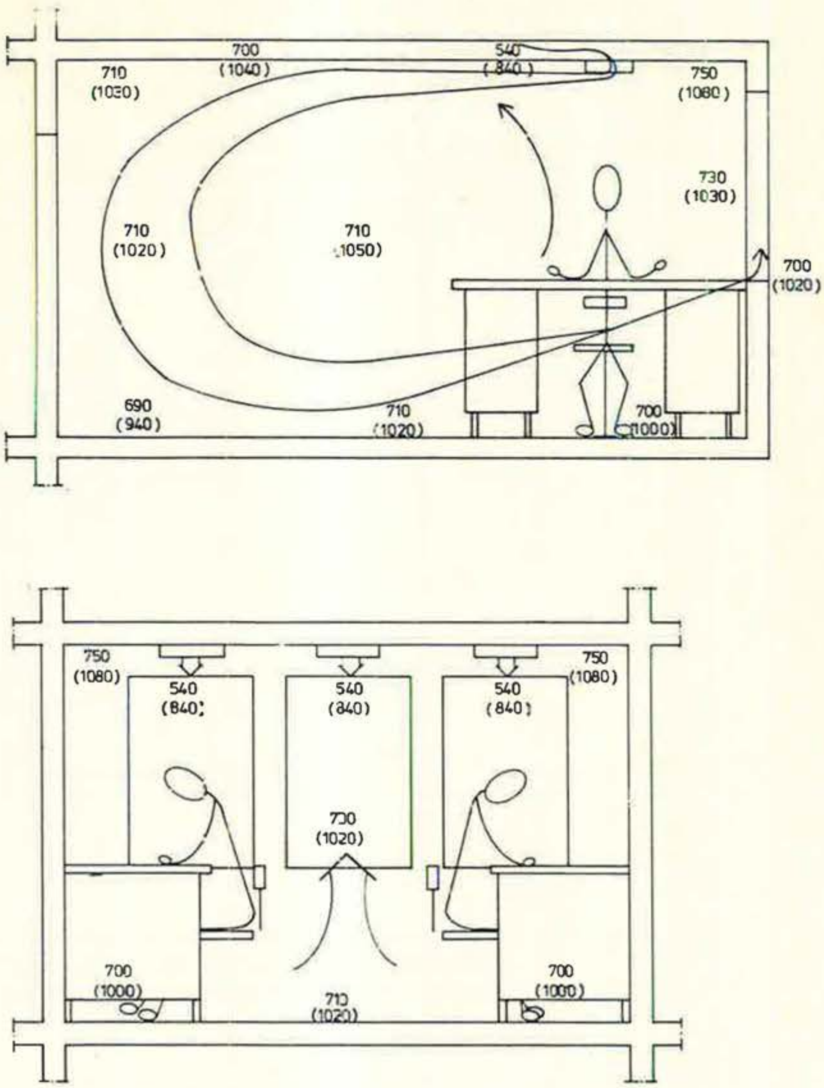

Fig 3:9 Local variations of CO_2-concentration in a typical office for two occupants.

3.3.3 Comparisons of variation in CO_2 level in different rooms

At 14.00 hours the CO_2-concentration in different rooms varied from 670 ppm to 1020 ppm. The concentration was measured near the extractor by a return-air window. The concentration was approximately 670 ppm in the corridors. The highest concentration, (1020 ppm) was measured in an office for two occupants, in which three persons had incidentally worked for the whole day.

3.3.4 Radon

The radon concentration in the main recirculation air duct varied during the day, as shown by curve 1 on the graph in fig 3:10. The concentration begins to rise as soon as the outdoor-air damper and fans are switched off at 20.000 hours, and falls when the fans are switched on at 05.30.

The daytime level was 10-15 Bq/m^3, and the night-time level was 60-120 Bq/m^3. Fig 3:10 also illustrates how the radon concentration varies in the return-air duct over a 24-hour period, when the fans are on full, and 100% recirculation all night, (curve 2 on the graph).

The maximum concentration was considerably lower in this case, which could be due to leakage in through dampers and openings in the building. Otherwise, the level in different parts of the building was equalized.

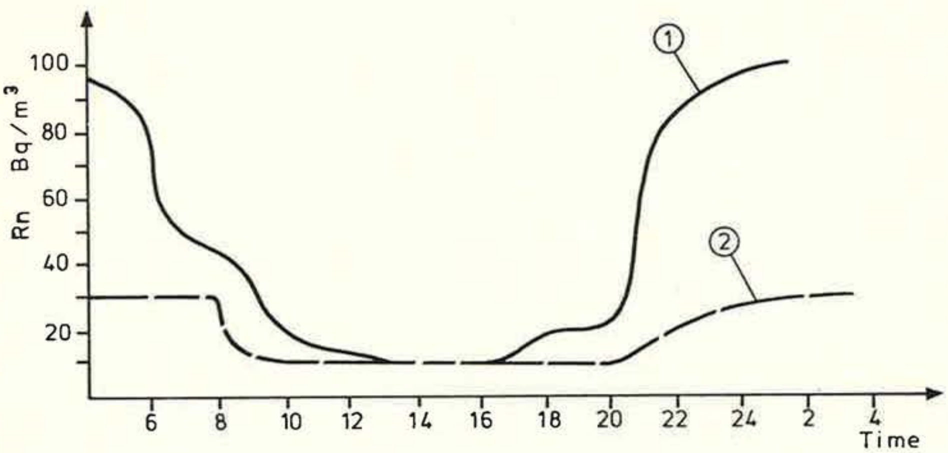

Fig 3:10 Radon concentration over a 24-hour period in the main recirculation air duct. 1. Normal operation. 2. Full fan speed with 100% recirculation air for the whole night.

3.3.5 Aerosols

Aerosols could be equally good indicators of indoor-air quality as carbon dioxide, (fig 3:11). However, the concentration of aerosols is greatly affected by the number of smokers, wich is not the case to the same extent with CO_2 level.

Furthermore special peaks in aerosol concentration arise when employees arrive at work, and when they leave. This is probably due to movement of dust particles in the air when there is movement in the building.

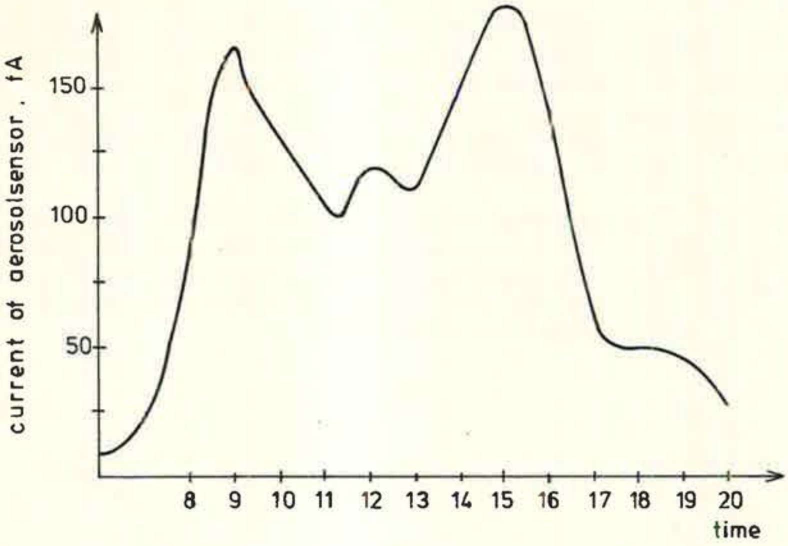

Fig 3:11 Concentration of aerosols in the return-air duct.

3.3.6 Results of the subjective analysis

Fig 3:12 illustrates employees' opinion about temperature, ventilation and air-quality when control system 1, (timing function) and system 2, (CO_2-controlled) were employed.

No significant difference of opinion about comfort using either of the systems can be found in the results.

Of the 180 employees interviewed, 99 were subjected to control system 1, and 88 to control system 2. The questionaire appears in Appendix I.

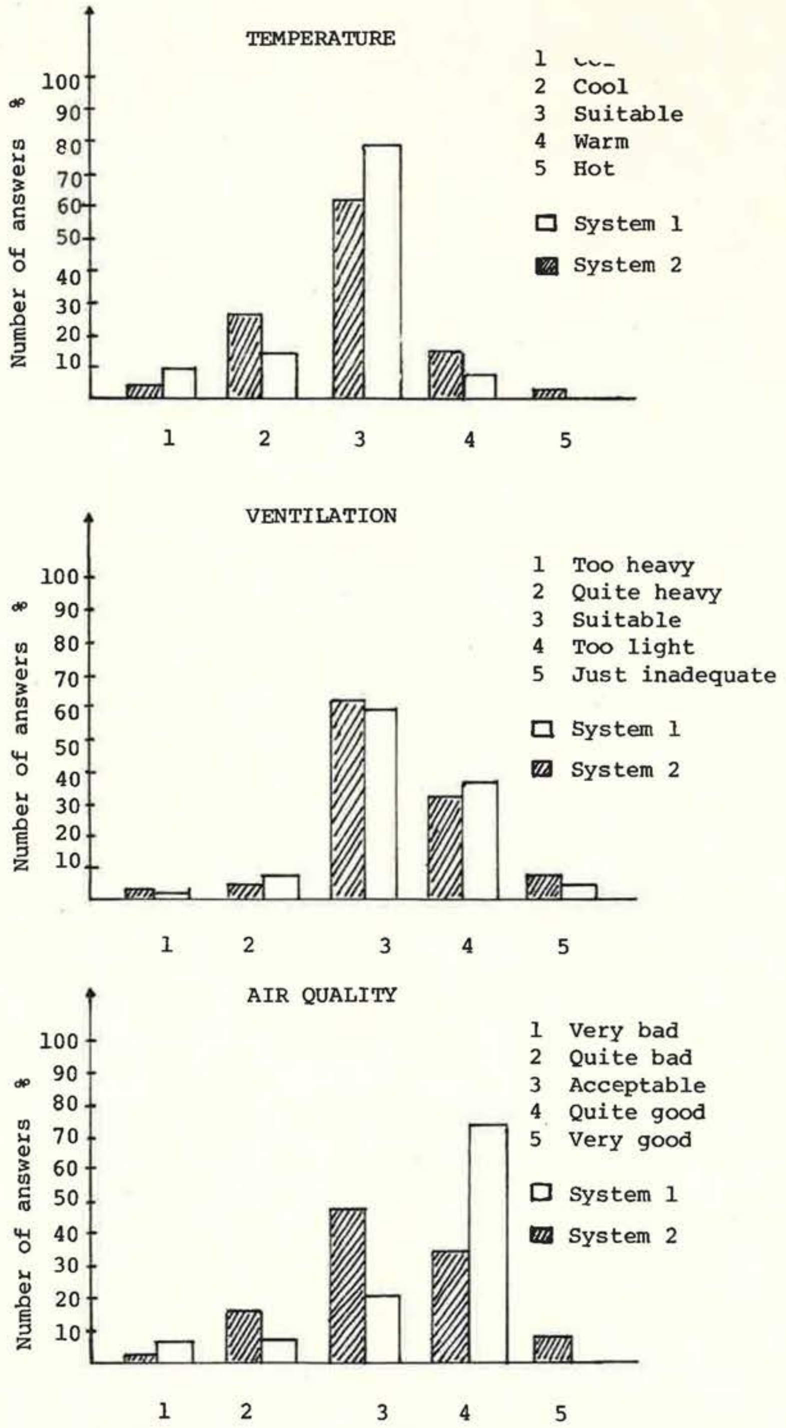

Fig 3:12 Results of interviews.

4 AIR-QUALITY CONTROL WITH A GASCHROMATOGRAPHE

At the same time as CO_2-content measurements were taken in the building, a gaschromatographic analysis of the indoor-air was carried out over several days. The intention was to study the connection between CO_2 content and the presence of other air pollutants.

The result can be summarized by an extract from a diagram, (fig 4:1).

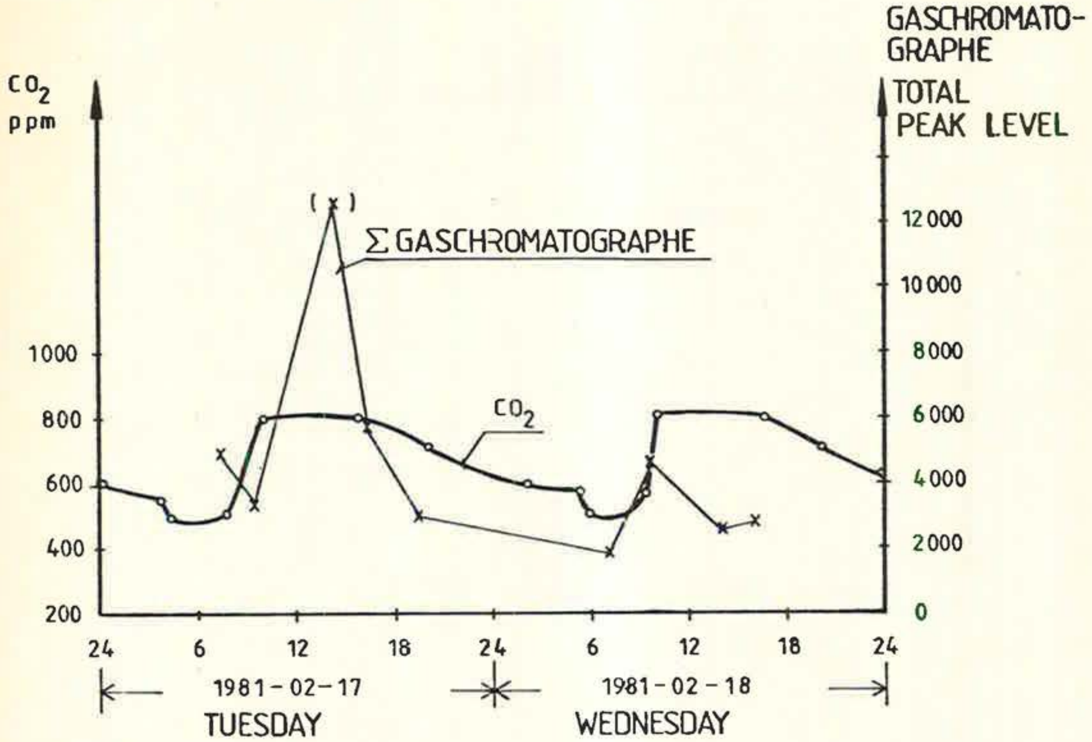

Fig 4:1 Concentration of other gases in relation to CO_2.

There is no apparent connection between CO_2 and other gases. The abnormally high level of other gas pollutants at 14.00 hours on the first day can, however, be due to incidental gases - from a copying machine, for example. Apart from this peak in the curve, a certain likeness can be seen in the curves. It is emphasized that the CO_2-curve ought generally to be proportional to the number of occupants in the building, whereas the curve for the G.C. analysis also contains emissions from building material.

In a supplementary study, an identification of occuring substances has been made. On the whole, the same substances are found in room air in Sweden and Denmark. Some new substances have, nevertheless, been observed, of which dichlorobenzene was one. An isomer of this substance is found in solvents.

5 ENERGY SAVING

The energy requirements for heating of outdoor-air depend on the amount in question. This has, during control system 2, (CO_2-controlled) been calculated and compared with the amount of outdoor-air when the flow is constant during operating time, (Control system 1). For most of the year, the outdoor-air flow is naturally determined by the temperature. This occurs when the internal heating in the building is enough to heat the outdoor-air. However, when the outdoor temperature is lower, the hygiene demand becomes the determining factor for the air-flow, and the requirement-adapted CO_2-control provides an annual saving of about 40% in this case. This occurs when the desired value for CO_2-concentration is set at 700 ppm. If the value is lowered to 650 ppm, the saving decreases to 10%. The saving increases correspondingly if the value is raised to more than 700 ppm.

In control system 3, where the outdoor-air flow is controlled by timing function dampers, which are similar to the curves for CO_2-controlled dampers set at 700 ppm, a saving of 30% can be made.

6 COMPONENT AND SYSTEM DEVELOPMENT

A control system based on measuring the CO_2-concentration is most valuable in buildings where the occupants themselves are the main cause of pollutants. When planning such a system, it is advantageous if the building is divided up into zones with equal numbers of occupants.

Rooms used seldom, or at limited times should, in principle, be treated as separate control zones. In office buildings, for example, ventilation in conference rooms should be separated from that of the rest of the building.

If such a division is possible, it is desirable that the analyzer equipment has a central unit for all the zones, i.e. the analyzer should have such an effective air-pump that pipes for testing can lead to different parts of the building. A 30-minute sampling cycle should be satisfactory in most cases, as the CO_2-concentration seldom varies so quickly.

There are several different types of CO_2-analyzers in existence. That they are operatively reliable, and, for example, easily calibrated with outdoor-air is of great importance. They must be designed to withstand dusty conditions, but at the same time, consideration must be taken as to whether they can be placed in a separate cupboard or room. Their accurancy should be approximately ± 10 ppm over a range of 300-2500 ppm. The air pump should be so reliable that the only maintenance required is changing the pump filter.

The regulators funcion most effectively with slow changes in CO_2-concentration if they are microprocessor-based PID, in which the derivation time is 30-40 minutes. The derivation time for a standard controller is only 1-10 minutes, which causes undesirable fluctuations in the outdoor-air flow.

In order that the above described principle can be put into more general practice, it is necessary that the CO_2 analyzer becomes less expensive. A greater demand should result in development of new and cheaper components. A tight-fittning fan with a simple and cheap control device is an example of an inportant component.

Viewpoints concering developments of components for CO_2-controlled ventilation systems have been made available by Bo Göstring, The Swedish Manufacturers of air handling equipment in the mechanical, electrical and electronic engineering Industry.

7 DISCUSSION

The study that has been carried out has illustrated that a control system based on constant CO_2-concentration in the indoor-air is viable. However, more experimental work must be carried out in order to determine a suitable CO_2-concentration level, as energy saving is strongly dependent on this. Attention should be given to choosing where, and in how many places measurements are to be made.

Interviews with employees provided no air in determining the outdoor-air requirement and ventilation effectivity. Most employees were satisfied with the prevailing quality of the indoor-air, regardless of which control system was being used.

Aerosol concentration could perhaps be used as a reference substance for controlling the outdoor-air flow, but this demands more work with measuring instruments, and a more reliable method of determining a suitable desired value for CO -concentration.

Calibration of the CO_2 analyzers, (2 different ones) that were used during the test posed no great problems. A slow variation in the actual value in relation to the adjusted desired value was found in one of the analyzers, but an annual control should be sufficient, and is the present recommendation.

No dangerously high concentrations of other pollutants have been discovered, either from measurements or interviews. If the radon concentration is considered to be high during the morning, steps can be taken to air the building before employees arrive.

The principle of CO_2-controlled ventilation is of greatest value in buildings where the degree of occupancy varies greatly and irregularly, eg. schools, department-stores, banks, post-offices, conference-rooms, theatres, cinemas and restaurants.

The pilot study that has been carried out has illustrated the function of the principle under good supervision of equipment. Before a general application of the method can begin, further development projects must certainly be carried out, in which profitability can be studied, a factor that can be jeopardized due to supervision requirements and uncertainty in planning and performance.

APPENDIX I QUESTIONAIRE FOR SUBJECTIVE REGULATION

1. Floor ....
2. Facade a. east b. west
3. Sex a. man b. woman
4. What is the temperature like in your room today?
   1. Cold
   2. Cool
   3. Pleasant
   4. Warm
   5. Hot
5. Does the temperature change in your room during the day?
   1. Not at all
   2. Very little
   3. A little
   4. Quite a lot
   5. A great deal
6. What is the ventilation like in your room?
   1. To strong
   2. Strong
   3. Just right
   4. Insufficient
   5. Totally inadequate
7. What is the air-quality like at this moment?
   1. Very bad
   2. Quite bad
   3. Acceptable
   4. Quite good
   5. Excellent
8. Does the air-quality vary during the day?
   1. Not at all
   2. A little
   3. Very slightly
   4. Quite a lot
   5. A great deal

If it varies, why?

How many cigarettes do you smoke during a working day?

APPENDIX II

SWEDISH MANUFACTURERS OF AIR HANDLING EQUIPMENT IN THE SWEDISH TRADE

PROMEMORIA
1982-04-14 BG/KE

Association for Mechanical and electrical engineering

Bo Göstring

CO_2-controlled ventilation systems, components and installation

Components

Those components that, in construction and/or function, can be affected by their installation in a CO_2-controlled system are principally control system and dampers.

Control system

Those demands made upon the control system's components and function, (sensor, CO_2 analyzer, microcomputer), must be investigated further, since it concerns a new, commercially untested application.

The control system, (especially the gas analyzer), is, at present substantially more costly than the conventional system.

A new market for these products could certainly lead to development of function-adapted, operatively reliable and cheaper products.

If some form of scanning could be put into practice, so that a CO_2 analyzer could be used as a sensor in several points, this would bring about a more flexible system.

As an alternative to sensors in the junction canal, sensors could be placed in the exhaust-air duct from a few of the "critical" rooms, i.e. conference rooms and other rooms with temporarily high occupancy.

This system could be used in cases where separate units are used in certain rooms.

Dampers

One condition for exact and stable regulation is that chosen dampers must have a suitable, (ideally linear) regulatory system. Possibilities should exist for developing dampers with better

	qualities in this aspect than those on today's market. In the case of function of dampers, it is easier to control air-flows according to CO_2-level than demand a set recirculation-air level.
Installation	Technically, there is no appreciable difference as far as installation is concerned, between requirement-controlled and conventional systems, apart from the control system, wich should not cause any installation problems. The demand for good air tightness must be regarded both in assembly and use (Air tightness class B). Responsibility for a new and untested control system is a legal problem for the contractor when installation has been carried out.
Adjustment	Special care must be taken over adjustment of the air-flows. Adjustment of the control system should be carried out by a specialist in this field.
Operation	Even during operation, care and maintenance of the control system must be precise, eg. during the regular calibration of the CO_2-analyzer.
Economy	CO_2-controlled ventilation is generally considered to be an economically advantageous alternative. An estimate of profitability must, however, be made with special regard to the following factors, and others: Type and construction of building Choice of system and components Operational maintenance Profitability criteria, (costs of energy, repayment period). It can be concluded that, from the ventilation branch's viewpoint, it should be possible for CO_2-controlled ventilation systems to be introduced with the present availability of products and technical knowledge of installation, provided that the control system i reliable.

REFERENCES

Gustavsson, I, 1977, Återluft, Recirculation Air, Technical Notes no. 106, (The Institute for Heating and Ventilation.) Stockholm.

Yaglou, C P, Rilley, E C, Coggings, D J, January 1936, Ventilation Requirements, Heating, Piping and Air Conditioning, p 65-76.

Kerka, W, Humphreys, C, April 1956, Temperature and Humidity Effect on Odor Perception, Heating, Piping and Air Conditioning, p 129-136.

Budnitz, R J, Berk, J V, Holowell, C D, Nazaroff, W W, Nero, A V, Rosenfeld, A H, 1979, Human Disease from Radon Exposures, The Impact of Energy Conservation in Residential Buildings, Energy and Buildings 2.

Åtgärder mot radon i bostäder, Measures against Radon in Housing, 1979, National Board of Physical Planning and Building Newsletter 5, p 172...183.

Swedjemark, G A, 1979, Problemet med radon och radondöttrar inomhus VVS3, The Problem of Radon and Radon Components in Indoor Air, p 51-52.

Klauss, A K, Tull, R H, Roots, L M, Pfaffin, J R, 1970, History of the Changing Concepts in Ventilation Requirements, ASHRAE Journal 12, p 51-55.

Turiel, I, Hollowell, C D, Thursten, B E, 1979, Automatic Variable Ventilation Control Systems Based on Air Quality Detection, Energy Conservation in the Built Environments 3, p 247...256.

Jennings, B H, Armstrong, J A, 1936, Ventilation Theory and Practice, ASHRAE Transaction part 2, p 423...429.

Liptak, B, July 1979, Savings through CO_2 based Ventilation, ASHRAE Journal, p 38...41.

Kusuda, T, 1976, Control of Ventilation to Conserve Energy While Maintaining Acceptable Indoor Air Quality, ASHRAE Transaction I, p 1169...1176.

Pettenkoffer and Flugge 1881, 1968, cited by M S Gorosomov, The Indoor Atmosphere and Air Circulation, World Health Organization, Pupblic Health Paper No 33, Geneva.

Hayman, E, 1978, Bidrag till kännedom om luftens beskaffenhet i skolor, A Contribution Concering Air Quality in Schools. Technical Notes from The Institute for Heating and Ventilation, KTH, p 47.

Hunt, C M, 1979, Ventilation Measurements in the Norris Cotton federal Office Building in Manchester, ASHRAE Transactions Part I, p 828...839.

Woods, J E, Winakor, G, Maldonado E A B, Kipps, S, 1981, January 1982, Subjective and Objective Evaluation of a CO_2 Controlled Variable Ventilation System, (Iowa State University) Preprint for presentation at the ASHRAE Semi-annual meeting in Texas.

Fanger, P O, 1982, Menniske og Indeklimat - Ny Viden, Nye Muligheder, föredragsresuméer, Man and Indoor Climate - New Perspectives, New Possibilities, Lecture Résumés, XII Nordic HEVAC Congress, Copenhagen.

Berg-Munch, B, 1982, Ventilationsbehov og Kropslugt, Nye Data för acceptabel luftkvalitet, föredragsresuméer, Ventilation Requirements and Body Odour, New Data for Acceptable Air Quality, Lecture Résumés, XII Nordic Congress, Copenhagen.

Berglund, B, Johansson, I, Lindvall, T, 1981, Underlag för Ventilationsnormer, Etapp II, Foundations for Ventilation Standards, Stage 2, Swedish Council for Building Research, Stockholm.

Löfgren, I, 1981-1984, Hälsoskydd i byggnader, Health Protection in Buildings, Research and Development, Stockholm.

Södergren, D, et al, 1981, Ventilation, Underlag för programplan 1981-1984, Stockholm.

Berglund, B, Johansson, J, Lindvall, T, 1982, The influence of ventilation on indoor/outdoor air contaminants in an office building, The National Institute of Environmental Medicine, Stockholm.