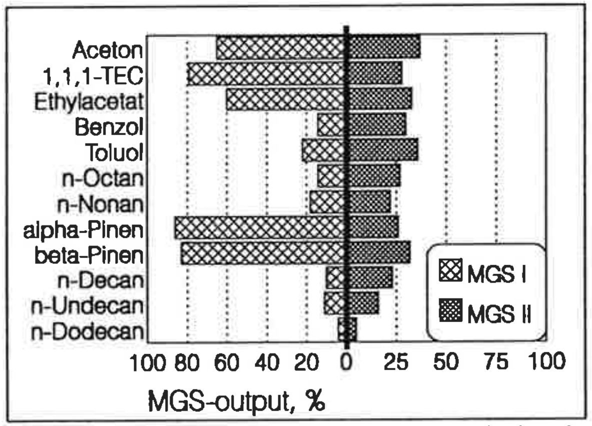

Fig. 3. MGS response to a 0.5 µl injection of single substances.

CONCLUSIONS

Pilot studies on metal oxide sensors from the view of experimental hygiene have shown

- It is still impossible to determine air quality by sensors of the present generation **in analogy** to IAQ perceived by man.

- Concentrations of single pollutants and mixtures of them with constant mixture ratio can be measured and controlled by MGS.

- Regulation of air quality in spaces with sporadic changing of some of the pollutants by air quality sensors may occur hyper/hypo-ventilation. But development and adaptation of non-selective sensors are a feasible way for a healthy environment indoors.

REFERENCES

1. Pettenkofer, M.v.: Über den Luftwechsel in Wohngebäuden, München, 1858.
2. Fanger, P.O., Lauridsen, J., Bluyssen, Ph., Clausen, G.: Air pollution sources in offices and assembly halls, quantified by the olf unit. Energy Build. 12(1988)S.7-19.
3. Pejtersen, J., Oie, L., Skar, S., Clausen, G., Fanger, P.O.: A simple method to determine the olf load in a building. Proc. of Indoor Air Quality Congress, July 1990, Toronto.
4. Raatschen, W. ed.: Demand Controlled Ventilating System. Swedish Council for Building Research, Stockholm, 1990.
5. VDMA-Einheitsblatt 24 772: Sensoren zur Messung der Raumluftqualität in Innenräumen. Verband Deutscher Maschinen- und Anlagenbauer, Frankfurt, 1990, 6.
6. Fanger, P.O.: Introduction of the olf and decipol units to quantify air pollution perceived by humans indoors and outdoors. Energy Build., 12(1988)S.1-6.
7. Bluyssen Ph, Fanger PO: Addition of olfs from different pollution sources. Proceedings Indoor Air '90, Toronto, July 1990.

INDOOR AIR QUALITY AND ENERGY CONSUMPTION WITH DEMAND CONTROLLED VENTILATION IN AN AUDITORIUM

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ABSTRACT

The ventilation system of an auditorium was regulated in response to continiously measured CO_2 concentrations in the room, or according to the time-table of the occupancy. The running time, the energy consumption and several climatic parameters as well as the CO_2 concentrations were measured under winter and summer conditions. Furthermore, the occupants' judgement of the indoor air quality was surveyed with a questionnaire. It was shown that during the monitored periods the ventilation controlled by measured CO_2 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 odour in the room would be eliminated, the indoor quality would still remain within an acceptable range.

INTRODUCTION

Over the last few years, various attempts to run Demand Controlled Ventilation (DCV) Systems have been conducted at international levels (1). However, only in a few of these trials have the possible energy savings of DCV systems been calculated or measured, compared to conventional systems recording **simultaneously** the users' judgement of the indoor climatic parameters and the indoor air quality. Feedback is therefore missing concerning the user acceptance of the possibly altered DCV system conditions. As our own investigations had shown (2) that user perception of indoor air quality correlates well with the CO_2 content of indoor air (correlation coefficient: 0.77), corresponding trials were run using a CO_2 controlled DCV system. The experimental set-up was as follows:

- Installation and operation of a CO_2 controlled DCV system in an auditorium.
- Measurement of the electrical, heating and cooling energy saved in comparison to the normal operating mode (time control) of the ventilation system.
- Measurement of the indoor air quality and of the most important indoor climatic parameters at different locations of the auditorium during both control conditions.
- Surveying of the room occupants regarding indoor air quality during both conditions.

MATERIALS AND METHODS

The trials were undertaken in an auditorium of the Swiss Federal Institute of Technology in Zurich. The auditorium has a surface area of 120 m², a volume of 440 m³, and a seating capacity of 80 persons. The room features two external walls, each with three sound proofing windows which cannot be opened. Radiators are located underneath all of the six windows. The floor slopes upwards from the front to the back by 0.66 m. The room is equipped with a two-stage air ventilation unit with heating, heat recovery and cooling capacity. Running on the first stage capacity, the external air supply is 1000 m^3h^{-1}, at second stage setting 1700 m^3h^{-1}. The incoming air is blown into the room through ventilation slots located at the front edge of the students' desks. The exhaust air is drawn out at the ceiling by exhaust air ducts.

During the trials the following parameters were continuously measured and mean values recorded at 5-minute intervals:

- **Energy:** Recording of operating times and the respective operational setting of the ventilation unit, recording of the power consumption of the ventilators, recording of the consumed heating or cooling energy and of the energy output of the radiators.
- **Room climate and air quality:** The CO_2 concentrations (Binos 100 NDIR) and the room temperatures (Pt-100) were continuously measured in the centre of the room as well as at the lectern. Additionally, the relative air humidity was recorded by means of a capacity measuring sensor in the centre of the room.
- By means of a specially designed questionnaire (2) the students' evaluation of the **perceived air quality** (olfactory perception, olfactory nuisance, acceptance) was recorded at the beginning and at the end of each hourly lecture.

During normal operation, the ventilation system of the auditorium is run by central control system according to the occupancy time-schedule. The heating or cooling of the incoming air is controlled by a temperature sensor. As mainly cooling energy is needed during summer and heating energy during winter, the trials were run in June (1990) and in January (1991). By means of simulation calculations with a dilution equation (2), the following CO_2 concentrations were determined for the activation and deactivation of the ventilation system:

1st stage on:	CO_2-concentration >	750 ppm
2nd stage on	CO_2-concentration >	1300 ppm
2nd stage off	CO_2-concentration <	1100 ppm
1st stage off:	CO_2-concentration <	600 ppm

The CO_2 concentration as measured at the centre of the room (with Binos 100 NDIR gas analyzer) was used to control the ventilation. In order to guarantee sufficient indoor air quality at the beginning of the lectures in the morning at 8:15, the ventilation unit was automatically put in the second stage operational mode on Monday through Saturday between 7:30 am and 8:00 am.

RESULTS

Occupancy, unit running time and energy consumption

The number of people present at each lecture multiplied by the duration of 45 minutes, was used as a measure for auditorium **occupancy**. A single person accounted for 45 person-minutes for each lecture. The calculation of the theoretically possible number of person-minutes was based on an occupancy of 81 persons for 9 lectures per day over five weekdays. This allowed a comparison between the theoretical maximum occupancy density

and the actual occupancy density during the trials. During the summer trials, the occupancy was only 8.5% of the theoretically possible occupancy density. In winter, the actual occupancy density was considerably higher, at 24% during the time controlled ventilation and at approximately 12% during the CO_2 controlled ventilation. The auditorium may be considered to have been underutilized.

The **running times** of the ventilation unit were reduced during the CO_2 control period by 67% (in winter) and up to 75% (in summer) compared with the time control period. Except from the half-hourly airing in the morning, the second stage operational mode was never used during the CO_2 control period. Table 1 summarizes the results of the **energy consumption** measurements. These were considerably lowered by the CO_2 control system. The high energy savings in summer are mainly the result of the reduction of running times which decreases the use of cooling energy. The energy savings were lower in winter because the outside temperatures were on average 5°C lower during the week of CO_2 control than during the week of time control.

Table 1. Energy consumption (MJ/week) of the ventilation unit in summer and in winter during time and CO_2 control of the ventilation unit, respectively.

	Electrical energy MJ/week	Heating / Cooling MJ/week	Total energy consumption MJ/week
SUMMER			
Time control	336	616	952
CO_2 control	44	158	202
Reduction	**87%**	**74%**	**79%**
WINTER			
Time control	343	1095	1438
CO_2 control	61	943	1004
Reduction	**82%**	**14%**	**30%**

Parameter studies using the simulation programme TRNSYS (3) have shown that achievable energy savings are particularly dependent on comfort requirements and occupancy density (3). Under normal circumstances using CO_2 control is used instead of time control, when energy savings in the order of 50% may be achieved.

Indoor air quality and room climate

Only the time frames during which the auditorium was occupied (occupancy time) were evaluated. Figure 1 shows a typical pattern of the measured CO_2 concentration during a day with CO_2 control of the ventilation unit.

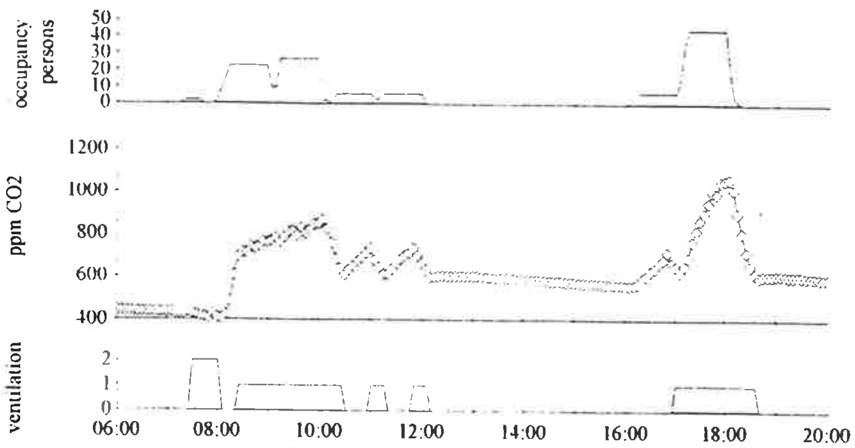

Figure 1. Pattern of the measured CO_2 concentration, occupancy in number of persons and the operational mode of the ventilation unit during a day with CO_2 control.

Table 2 gives an overview of the CO_2 concentrations measured during the winter and summer trials at the measuring points in the centre of the room and at the lectern. The values represent the arithmetic means of the calculated median values for each lecture period (45 minutes) and also the arithmetic means of the maximum and minimum CO_2 concentrations for each lecture period.

Table 2. Measured CO_2 concentrations in the centre of the room and at the lectern during time and CO_2 control of the ventilation unit in summer and winter.

Unit: ppm CO_2	SUMMER centre control time	SUMMER centre control CO_2	SUMMER lectern control time	SUMMER lectern control CO_2	WINTER centre control time	WINTER centre control CO_2	WINTER lectern control time	WINTER lectern control CO_2
Number of lecters	24	25	24	25	34	28	34	28
Average of medians 1)	461	637	456	636	559	676	571	708
Minimum mean concentration	402	547	404	557	456	573	455	568
Maximum mean concentration	507	710	493	714	665	754	674	775

1) Average of mean values of all measured lectures

Only very minimal differences in CO_2 concentration were measured between the measuring location at the centre of the room and that at the lectern. From this it can be concluded that in small to medium sized auditoriums, equipped with an effective mixed ventilation, the CO_2 sensor for the control of the ventilation system may be placed either in the centre of the room or at the lectern. Furthermore, Table 2 shows that only small differences in the measured CO_2 concentrations occurred between the use of the CO_2 controlled unit and the time controlled unit. The maximum concentration was never above 1300 ppm when the CO_2 control system was used without the second stage setting. As there was a higher occupancy density in winter, the measured CO_2 concentrations were generally higher.

The mean indoor air temperatures in the occupied zone during summer were rather low, at 19.6°C, during the time control period. During the CO_2 control period, the mean indoor temperature was 23°C. During the winter trials the mean indoor temperature was 20.2°C during both control periods. Relative air humidity was between 50% and 60% in summer. As the incoming air was not humidified in winter, the corresponding values for the relative air humidity were between 23% and 27%.

The room user survey

The results of the room user survey regarding the perceived indoor air quality can be seen in Table 3. A total of 1260 questionnaires were evaluated. The given values are the mean values of the results from the corresponding surveys at the beginning and at the end of the lecture periods.

Table 3. Results of the room user survey regarding the perceived air quality as a percentage of returned questionnaires.

Unit: %		SUMMER control time	SUMMER control CO_2	WINTER control time	WINTER control CO_2
Question: Do you perceive any smell?					
No		62,9	40,2	68,3	56,7
A smell is perceptible	from only just to clearly	36,5	50,7	31,5	41,4
	from strong to unbearably strong	0,6	9,1	0,2	1,9
Question: Are you bothered by the smell?					
I am	not bothered	69,8	41,2	60,1	56,8
	marginally to moderately bothered	28,7	49,6	39,3	41,4
	strong to unbearably bothered	1,5	9,2	0,6	1,8
Question: Do you find the smell in the room or the indoor air quality acceptable?					
acceptable		98,3	85,4	97,9	94,4
not acceptable		1,7	14,6	2,1	5,6

During the trials with CO_2 control, more persons perceived smell, more persons were strongly bothered and correspondingly more persons classified the air quality unacceptable than during the time controlled period of ventilation. The differences were greater in summer than in winter. An explanation for the high percentage dissatisfied in summer was quickly found. Every morning and at midday the blackboards of the auditorium were wiped with a cleaning agent which contained perfume. During the period of CO_2 control the ventilation system was only switched on occasionally, and therefore the perfume smells could not be eliminated as efficiently as during the period of time control. In the course of the day this lead to an accumulation and a mixing of the perfume smell with body odours.

During the corresponding trials in winter the blackboards were only wiped with sponge and water. The result was that in winter during CO_2 controlled ventilation only 5.6% of the room occupants found the smell or the indoor air quality to be unacceptable. For time control period the percentage was 2.1%. Therefore, the "deterioration" of the indoor air quality using CO_2 control can be considered insignificant.

DISCUSSION

The following conclusions can be drawn from the trials with a CO_2 controlled ventilation system for an auditorium:

1. Measuring the CO_2 concentration of indoor air is well suited for the regulation of a demand controlled ventilation system of an auditorium.
2. The use of demand control saves a considerable amount of energy. The auditorium that was investigated, however, featured only a low occupancy density. For an auditorium with a higher occupancy density the energy savings may be around 50%(3).
3. The use of a CO_2 controlled ventilation system may lead to a slightly higher mean CO_2 content in the room. In our case it resulted, after elimination of internal room odour sources, only in a marginal deterioration of indoor air quality. **The demand controlled operation of the ventilation system did not therefore lead to a considerable reduction of the indoor air quality.**
4. When operating a demand controlled ventilation system all internal sources of odour (cleaning agents, emissions from building materials and furniture) must be avoided.
5. In small to medium size auditoriums, with an effective mixed ventilation, the location of the CO_2 sensor for the DCV control plays a subordinate role.

ACKNOWLEDGEMENTS

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REFERENCES

1. International Energy Agency, Annex 18, demand controlled ventilating systems, state-of-the-art review, 1989.
2. Fehlmann J, Bedarfsgeregelte Lüftung in Räumen verschiedener Nutzung und Belegung, Dissertation ETH Nr. 9680, 1992.
3. Basler & Hofmann AG, Zürich, Bedarfsabhängige Lüftung in einem Hörsaal, 1992.

ENERGY SAVING IN BUILDINGS BY DEMAND CONTROLLED VENTILATION SYSTEM

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ABSTRACT

There are two techniques to evaluate the impact of demand-controlled ventilation procedure on the energy performance of buildings: 1) field measurements, or 2) computer simulation. This paper, first presents the results of field measurements carried out in a commercial building in Montreal. Then, the computer model of a large office building in Montreal, which was developed using the MICRO-DOE2 program, is used along with the Functional values feature to simulate the demand-controlled ventilation systems. The use of MICRO-DOE2 for simulation is a new approach, since normally this ventilation procedure cannot be analyzed by the energy analysis programs. Different scenarios for this type of ventilation control are evaluated, and then the impact on the energy-efficiency of the entire building is assessed.

INTRODUCTION

Buildings are ventilated with outdoor air to replace the oxygen consumed and to dilute air contaminants created by occupants and their activities. This imposes significant costs to condition that air. So far, the tendency has been to reduce outside air intake to a minimum in order to reduce the costs of conditioning the air. The ventilation reduction has been linked to Sick Building Syndrome.

ASHRAE Standard 62-1989 recommends two methods for maintaining acceptable indoor air quality: ventilation rate procedure and indoor air quality procedure. In ventilation rate procedure, it is assumed that the acceptable indoor air quality is achieved when the building is ventilated at the prescribed ventilation rate that is based on the design occupancy level. So far this procedure is used by designers and engineers in design and operation of the mechanical systems, and by software developers in modelling the thermal performance of buildings. TARP, BLAST and DOE uses ventilation rate procedure to calculate the energy required for ventilation. The inherent drawback of this procedure is when occupancy density falls below the design level, the building will be over ventilated.

Indoor air quality procedure, where the ventilation rate is controlled to maintain the concentration level within the standards, is called Demand Controlled Ventilation (DCV). DCV seems to offer means of improving the quality of indoor air in high demand zone by increasing ventilation rates, and saving energy by reducing ventilation rates where the demands are not needed. It has been suggested that carbon dioxide concentration can be used