CONCLUSIONS

The use of CO_2 DCV strategy can provide reasonable readings for full- or part-occupancies. To avoid either the falsely low or falsely high readings, instrumentation should be checked and calibrated periodically, be at or near return air grilles, and operations be at lease six ft away from instrumentation during calibration.

The reduction of supply air flow rate can adversely affect IAQ in buildings having VAV systems. Use of a supplemental high-efficiency filter assembly in the bypass loop can provide a means for offsetting reduced air supply rates without sacrificing IAQ. The temperature of each zone is carefully monitored and controlled to the level that is most comfortable to the occupants. Cleaner air is supplied to the occupied zone whenever the supply air flow rate is reduced during the VAV-mode of the system, and the VOC control can be achieved within 30% of the supply air flow rate, independent of the space temperature and humidity.

REFERENCES

1. Meckler, M. 1992. "Evaluating IAQ compliance in buildings utilizing carbon dioxide level monitoring." Proceedings of IAQ '92: Environments for People. ASHRAE, Atlanta, GA.
2. Meckler, M. 1993. "Carbon Dioxide Prediction Model for VAV System Part-Load Evaluation." Heating/Piping/Air Conditioning, Jan.
3. ASHRAE 1989. ASHRAE Standard 62-1989: Ventilation for Acceptable Indoor Air Quality. ASHRAE, Atlanta, GA.
4. Yu, H.H.S. 1992. "Analysis of indoor air quality with VAV-bypass supplemental air cleaning. Proceedings of First Annual Indoor Air Quality Exposition, Tampa, FL, April 29 - May 3.
5. Liu, R.T. 1990. "Removal of volatile organic compounds in IAQ concentrations with short carbon bed depths." Fifth International Conference on Indoor Air Quality and Climate, Toronto, Canada, Aug.
6. Yu, H.H.S. 1991. "Supplemental air filtration and indoor air quality, Pt. 1." FARR Company Laboratory Report #1409-2 Add. #13 (Feb. 25).
7. Liu, R.T.; Raber, R.R.; and Yu, H.H.S. 1991. "Filtration and indoor air quality." FARR Company Laboratory Report #1409-6, Rev. B (Jan. 15).
8. Liu, R.T.; Raber R.R.; and Yu, H.H.S. 1991. "Filter Selection on Air Engineering Basis." Heating/Piping/Air Conditioning, May.
9. Yu, H.H.S. and Raber R.R. 1990. "Implications of ASHRAE Standard 62-1989 on filtration strategies and indoor air quality and energy conservation." Proceedings of The Fifth International Conference on Indoor Air Quality and Climate, Toronto, Canada, July 29 - Aug. 2.

MIXED-GAS OR CO_2 SENSORS AS A REFERENCE VARIABLE FOR DEMAND-CONTROLLED VENTILATION

Simon Meier

Staefa Control System AG, Research Department, Stäfa, Switzerland

ABSTRACT

The purpose of the investigation was to gather information about the currently available types of sensor with regard to their suitability for providing a reference variable for demand-based ventilation, and to be able to estimate the associated energy-saving potenital. To this end, the air quality was measured continuously for a week in each of the following areas at the University of Zurich: the staff restaurant, a lecture hall for 300 people, and a large sports hall. The sensors used to measure indoor air quality were mixed-gas sensors [1] and CO_2 sensors. In order to evaluate the effect of temporarily switching off the ventilation system, the plant was operated manually at times.

It was found that, compared with conventional time-switch control, significant energy savings can be made by operating the plant on the basis of air quality demand, and that this does not significantly affect the comfort of users of the spaces. CO_2, released by respiration, serves as an indicator for the presence of people. Mixed-gas sensors respond to oxidisable gases and vapours. In addition to body odours, therefore, these sensors also measure the majority of other variables which affect air quality.

In a subsequent phase, the ventilation systems in the staff restaurant and sports hall will be operated on a demand basis, using mixed-gas sensors for the reference variable, so that the actual energy savings achievable can be quantified.

INTRODUCTION

In order to save energy, thereby reducing the burden on the enviroment, the majority of ventilation and air conditioning systems today are controlled by time programmes. The switch times are normally selected in such a way that the rooms are ventilated throughout the potential period of occupancy.

Experience shows that the number of occupants assumed at the design stage proves in practice to be the exception. In many rooms, moreover, the level of occupancy fluctuates widely over the day. This means that systems could be switched off at times, or at least operated at lower fan speeds, without any noticeable loss of comfort. In practice, however, this is rarely done manually. Sensors are therefore required, which will measure the ventilation demand. What is needed is a sensor which can quantify the quality of the air as registered by the human nose. Ideally, this would be a decipol sensor [2].

At present, however, there are no decipol sensors, and it is unlikely that they will ever exist in an ideal form. Experiments conducted within the framework of the "Demand-controlled ventilation" project of the International Energy Agency, IEA, (ANNEX 18) have shown, however, that there are essentially two types of sensor currently available for the quantification of indoor air quality [3, 4]. These are the CO_2 sensor and the "mixed gas" sensor [1].

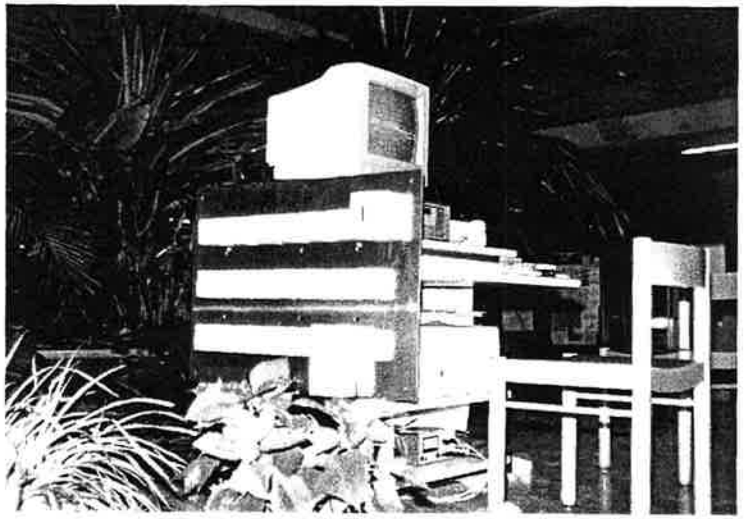
TEST SET-UP - AIM OF THE EXPERIMENT

In order to judge the suitability of the various sensors on the market, Staefa Control System spent five weeks in the winter of 1992 on extensive measurement in five areas at the University of Zurich suitable for demand-based ventilation. Staefa conducted these experiments in collaboration with the "Department for mechanical and electrical plant and air hygiene" of the Canton of Zurich, responsible for the operation of the plant. The areas selected were the restaurant, a lecture hall for 300 people, a three-court sports hall, a cloakroom and a fitness gym.

The main objectives of the experiments were:

- To gather information about the suitability of the various types of sensor to provide a reference variable for demand-based ventilation (including signal range and control parameters)
- To enable us to estimate the potential for improvement compared with the current situation (time-switch control, and CO_2 control in the lecture hall).

Using two commercially-available CO_2 sensors (Aritron AROX 425 AA, Sauter EGQ 10) and 17 mixed-gas sensors, the air quality was measured continuously for a week in each area, with samples taken once per minute by a computer, and the data saved. The 17 mixed-gas sensors were type FRA-Q1 indoor air quality sensors from Staefa Control. Two of these sensors were fitted conventionally, with the Figaro TGS 812 sensor element. To assess the properties of other potentially suitable Figaro sensor elements (of which there are now approximately 20 types) under practical conditions, the TGS 812 sensor elements in the remaining sensors were replaced with types TGS 800, TGS 821, TGS 822, TGS 825, and TGS 880. The indoor air temperature and humidity were also measured with Staefa sensors. The measurement set-up is shown in Figure 1.



Throughout the measurement period, someone was present whenever the rooms were in use, to observe the measurement process and to try to interpret unexpected signals. This person also recorded the number of people present in the room.

To determine the system response, the ventilation system was switched off manually for certain periods. At times, questionnaires were used to record the reaction of those present.

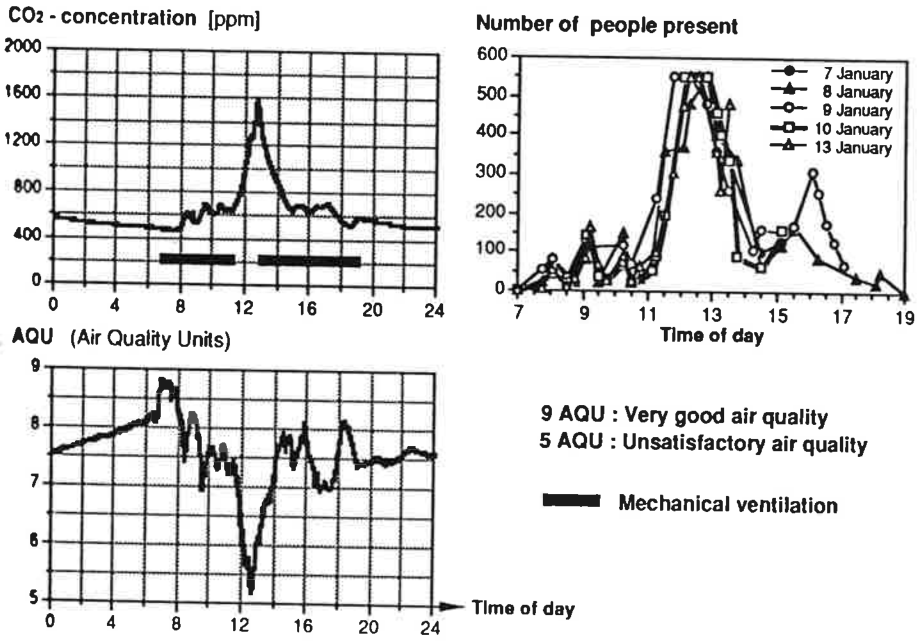
EXPERIMENTS IN THE STAFF RESTAURANT

a) TEST ENVIRONMENT - INITIAL CONDITIONS

The University restaurant is a modern concrete building with a high proportion of glazing, and a floor area of 950m². The restaurant seats 550. The single-stage ventilation system is operated from 06.15 to 18.15 during the week, and is switched off at weekends. During the midday period and, when necessary, in the evenings, the extract fan over the deep-frier is temporarily switched on manually. This affects the total volume of air, but not significantly. The volume flow of the ventilation system is 17 600 m³/h. This corresponds to 32.0 m³/h and seating space, or 18.5 m³/h and m². The air is supplied and extracted conventionally.

b) DATA MEASURED OVER A 24-HOUR PERIOD

As an example, Figure 2 shows a record of the variables relevant to air quality measured on the 10th January 92:



- At night, with the mechanical ventilation switched off, the air quality improves steadily, owing to infiltration resulting from the fact that the building is not airtight.

- When the mechanical ventilation is switched on in the morning, the air quality measured by the mixed-gas sensor improves, without there being any change in the CO_2 concentration level (emissions from interior furnishings and fittings are removed by ventilation).
- The air quality deteriorates or improves temporarily in accordance with the relationship between the number of occupants and the ventilation rate. The trend however, is a continual deterioration. The fluctuations are a very accurate reflection of occupancy peaks during the breaks between lectures.
- At 11.30 a.m. the ventilation is switched off manually, and not switched on again until there are complaints of unsatisfactory air quality.
- When the ventilation is switched on again, the air quality improves very quickly. Both the mixed-gas sensor and the CO_2 concentration show a gradual return to the level measured in the morning, and the air quality again deteriorates or improves according to the number of people present.
- At 18.15 the ventilation system is switched off via the management system, and at 19.00 hours the restaurant is closed - as can be seen from the air quality signals.

The measurements clearly show that both mixed-gas and CO_2 sensors are suitable for registering the changing levels of occupancy in the restaurant. On the basis of the measured signals, both types of sensor can be used to provide a reference variable for demand-based ventilation. The question is, however, which of the two sensors is more suitable.

MIXED-GAS OR CO_2 SENSORS FOR A REFERENCE VARIABLE FOR DEMAND-BASED VENTILATION IN RESTAURANTS ?

When the concentration level of CO_2 in the air is used as the reference variable for demand-based ventilation, the underlying assumption is that humans are the main source of air pollution. In a restaurant, however, this is scarcely the case. In addition to the number of people present, other sources of odour, such as smoking at times outside the main meal period (11.30 to 13.30) and the smell of food during the main meal period cause a significant variation in the odour load. There is also a basic load caused by emissions from interior furnishings and fittings. As Figure 2 shows, mixed-gas sensors, which respond to oxidisable gases and vapours [5], produce relevant signals.

To make it possible to discuss the differences between the two types of sensor, the CO_2 concentration and the load measured by the mixed-gas sensor (AQU) were plotted against each other (Figure 3). To facilitate the interpretation of the results, the following were differentiated: main periods of use, and increasing and decreasing CO_2 concentration levels (occupancy levels).

- In the period from 7.00 to 11.00 the curves calculated from the data coincide with the increase and decrease in the CO_2 concentration level. A good approximation of the curves can be achieved using a linear model ($r^2 = 0.90$). The main loads in this period are smoking, people and refreshments (coffee etc.).
- In the main meal period (11.30 to 12.30), with the ventilation switched off, the air quality deteriorates rapidly (Fig. 2). Again, the relationship between the two measured variables can be approximated with a linear model ($r^2 = 0.96$). However, the curves are significantly flatter than during the morning. This may be due to the fact that there is almost no influence from smoking. According to the research of Professor Fanger, smoking represents a source strength of 25 olfs compared with 1 olf for a non-smoker in a sedentary occupation [6]. Mixed-gas sensors are very responsive to tobacco smoke [5]. Measurements show, however, that the mixed-gas sensor also responds to food smells.
  In contrast to the period from 7.00 to 11.00, the curves calculated from the data do not coincide with the increasing and decreasing CO_2 concentration levels. Compared with the signal range of approximately 3 AQU in an occupied space, the offset of 0.7 AQU between the two curves, is large. There is currently no plausible explanation for this difference.
- In the period between 15.00 and 19.00 the curves are steeper, on average, than in the period from 7.00 -11.00. This could be due an increase in smoking compared with the morning. After 18.15, i.e. when the ventilation is switched off, there is again a parallel offset between the curves, similar to that which occurs in the morning.

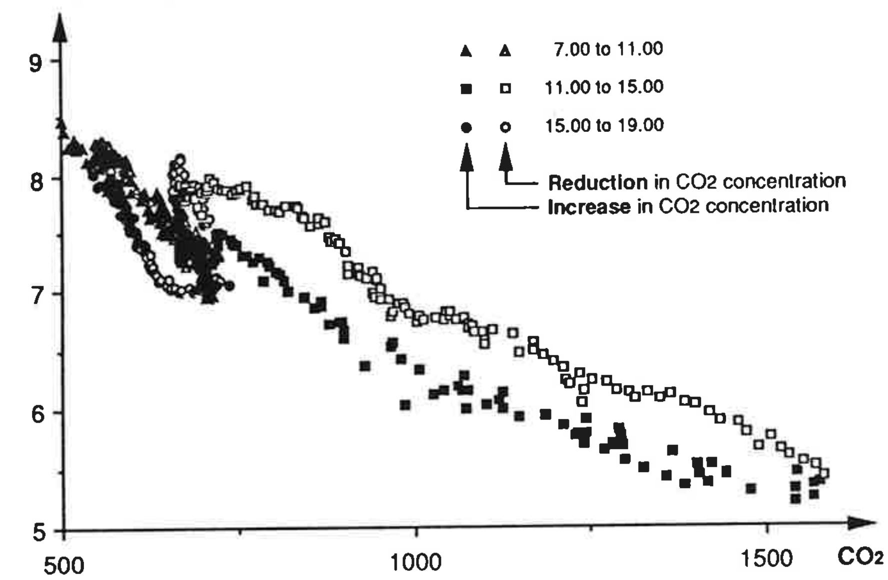


Fig. 3. Relationship between the measured CO_2 concentration and the measured values from the mixed-gas sensors, differentiated by time of day and increasing / decreasing CO_2 concentration levels.

To determine whether or not this method of representation is genuinely useful, it will first be necessary to examine the other days, and more importantly, to apply the same approach to measurements in spaces used for other purposes. The relationship between the measured values from mixed-gas sensors (AQU) and the odour load as perceived by the human nose (decipol) will be the subject of a separate research project.

ESTIMATING THE ENERGY SAVED BY DEMAND-BASED VENTILATION

The measured values can be used to estimate the reduction in operating hours achievable by changing to a demand-based ventilation system. If, for example, a level of

20% dissatisfied persons is accepted (ASHRAE definition for accepted air quality [7]) then, based on the research of Fanger [2], an outside air volumetric flow rate of 8.24 l/s and olf, i.e. approximately 30 m^3/h and olf is required. If the restaurant is fully occupied, and if the occupants were the only source of pollution (= 550 olfs) the installed air volume flow of 17 600 m^3/h would be suffcient during the peak midday period (Fig. 2). Observations while measurement was in progress show that with the ventilation running, the air quality during this period was always satisfactory, despite the additional load caused by food smells. Outside the main meal period, the average level of occupancy is fewer than 100 people. Over the daily 12-hour period during which the ventilation system is in operation, the average occupancy level is less than 25% of the maximum capacity of the restaurant. Owing to smoking the olf load outside the main meal period is significantly higher, as shown in Figure 3, (steeper curve). If the setpoint for the control system were set to 6.5 AQU for example, (average of peak values during the midday peak with ventilation fully on) the system operating hours could readily be reduced by 30% using demand-controlled ventilation with a mixed-gas sensor for the reference variable.

An estimate of the energy used for distribution and to condition the air to the supply temperature shows that in the case of on/off operation with a conventional system using a plate exchanger for heat recovery, approximately 25 500 kWh per year (approx. 1/3 electricity, 2/3 heating) can be saved (for the climate of Zurich). For a system of this size, the cost of installing demand-based ventilation using a mixed-gas sensor for a reference variable can be recouped within a few months [8].

ACKNOWLEDGEMENTS

I should like to thank Mr. B. Brechbühl of the "Department for mechanical and electrical plant and air hygiene" of the Canton of Zurich, Switzerland (ATAL) for permission to carry out the measurements, and for his support throughout the project, and Mr. C. S. Nagy (Staefa Control) and Mr. E. Heim (ATAL) for performing the measurements and analysing the results. Last but not least, I should like to thank Mrs. M. Minster for the excellent translation of the paper.

REFERENCES

1. S. Meier: Mixed-gas and CO_2 sensors - A comparison, CCI 6/91. English version available as staefa know-how No. 20.
2. P.O. Fanger: Introduction of the olf and the decipol Units to Quantify Air Pollution Perceived by Humans Indoors and Outdoors. Energy and Buildings, 12 (1988)
3. Demand Controlled Ventilating System - State of the Art Review, edited by W. Raatschen, IEA, Energy Conservation in Buildings and Community Systems Programme. Annex 18, February 1990.
4. P. Fahlen, H. Andersson. S. Ruud. Demand Controlled Ventilating Systems: Sensor Tests. IEA, SP REPORT 1992:13, Swedish National Testing and Research Institute, Energy Technology, Boras
5. S. Meier: Mixed-gas sensors for a reference variable for demand-based ventilation. HeizungKlima 4/1992, p.97-100. English version available as staefa know-how No. 23.
6. Recknagel, Sprenger Hönmann, Heizung + Klima Technik, 92/93, p. 72 [7] ASHRAE Standard 62-1989, Ventilation for Acceptable Indoor Air Quality, p. 3
8. S. Meier: Kundennutzen einer Bedarfslüftung. Internal, unpublished study of customer-benefits of demand-based ventilation.

VENTILATION RATE AND AIRFLOW MEASUREMENTS USING A MODIFIED PFT TECHNIQUE

Henk J.TH. Bloemen[1], Arnoud P. Verhoeff[2], Thécla T.M. Balvers[1], Pieter van der Torn [3] and Joop H. van Wijnen[2]

[1] National Institute of Public Health and Environmental Protection, Bilthoven, The Netherlands
[2] Public Health Service, Amsterdam, The Netherlands
[3] Public Health Service, Rotterdam, The Netherlands

ABSTRACT

The ventilation rate and the airflows in buildings are important both for the management of (health) complaints related to indoor air quality, and for the assessment of the penetration of outdoor air pollutants into indoor air. A relatively simple method that provides reliable information on the ventilation rate and airflows over longer periods is needed. The BNL/AIMS PFT technique, initially developed by Dietz et al. [1], was modified using commercially available components. Three different perfluorcarbons; perfluordimethylcyclobutane, -methylcyclopentane and methylcyclohexane, were used as tracers. Source strengths were constant within 3% for periods of six weeks at temperatures ranging from 20 to 27 °C. Passive sampling was feasible using Carbotrap as adsorbent. The adsorption and desorption efficiencies were approximately 98%. Samples were analyzed using capillary gas chromatography, a porous-layer open tubular column (Al_2O_3) and electron capture detection. The accuracy of the tracer analysis at concentrations usually obtained for ventilation measurements was within 5 to 10%. In a pilot study the mean coefficient of variation was approximately 5%. The location of the sampling tube and of the source in the room had no significant influence. The mean ventilation rate in the living rooms and bedrooms was 1 and 1.7, respectively. The variation in time was small. The ventilation rate of the living room was higher in older dwellings and/or if occupants were smokers. The ventilation rate of the bedroom was higher in flats than in single-family dwellings and in older dwellings; the rate was also higher if the occupants were smokers and rose with an increasing number of occupants.

INTRODUCTION

The ventilation rate of and the air exchange rates in dwellings and buildings are relevant parameters to making extrapolation of indoor air pollution measurements possible. The ventilation rate is an important parameter for the evaluation of indoor air quality measurements initiated by (health) complaints. When hazardous chemicals are accidentally emitted into outdoor air, the assessment of potential penetration of these pollutants into buildings and the potential exposure is, for example, defined by the air infiltration rate. To identify the location and strength of sources in the indoor environment ventilation rates, as well as air exchange rates, may be of use.

To measure these parameters under normal occupancy conditions a simple method that provides reliable information over relatively long periods and does not affect the behaviour of the occupants is required. The BNL/AIMS (Brookhaven National Laboratory Air Infiltration Measurement System) technique developed by Dietz et al. [1] using perfluortracers (PFT) combines most of the required characteristics but lacks the possibility of applying the method using readily available equipment. Since the development of the BNL/AIMS technique substantial progress has been made in the production of capillary gas chromatography columns and instrumentation. Considering the necessity for measuring ventilation rates and air exchange rates as part of limited and extensive indoor-air quality studies, the BNL/AIMS method was modified using commercially available equipment, allowing the method to be adopted by more