Arc 1203

1827

Air quality control: measurements and experiences

By J. Geerts (Staefa Control Systems) with the assistance of A. Grindal, H. Schiltknecht and W. Härdi

THE occupancy density and thus the hygienic load in, for example, cinemas, department stores, conference rooms and multi-purpose rooms can vary considerably. Air conditioning and ventilation systems with fixed minimum outside air change will supply too much outside air when the room is not fully occupied, ie when the hygienic load is reduced. However, this additional outside air still has to be distributed, heated and possibly humidified during heating periods, or cooled and dehumidified during cooling periods.

Air quality control adjusts the outside air volume to changes in the room air hygiene load. The contamination of room air has many causes. For example, occupants emit water vapour and carbon dioxide by perspiration and breathing. They also produce body odours. Contamination is also caused by tobacco smoke, building materials, open fires and evaporation of liquids (eg alcohol in restaurants, chloride in swimming pools, household cleaning preparations etc).

Too high a concentration of certain gases can damage health. Even low concentrations can cause discomfort and make the room air seem unpleasant. The following article describes this subjective perception of air quality.

Air quality is a complex concept which is determined by many factors. People judge air quality with their noses. Odours are noticed particularly when people enter a room. After they have been there for some time, they get accustomed to the poor air quality. The sensitivity threshold is increased. Since the various gases have different effects on odour, it is not easy to measure air quality.

A good solution for air quality

▶ 38

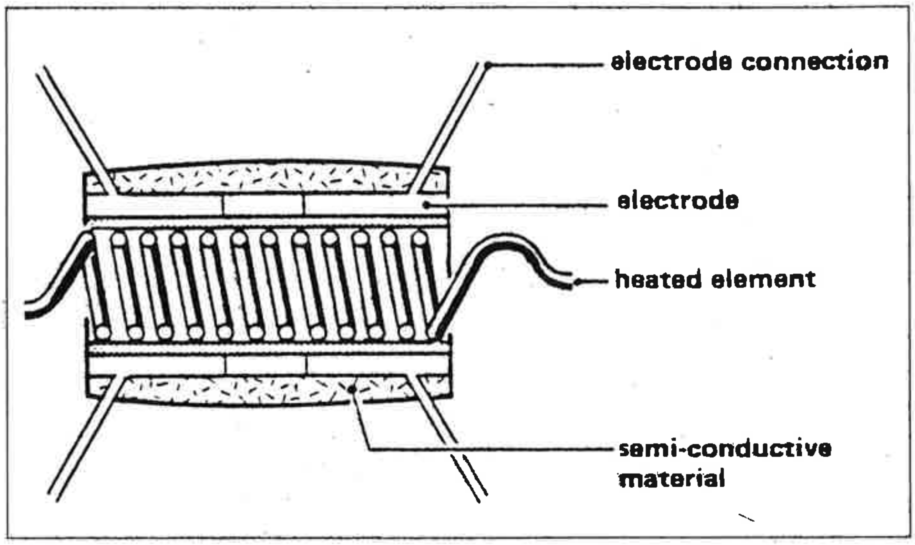

Figure 1: Gas sensor (schematic)

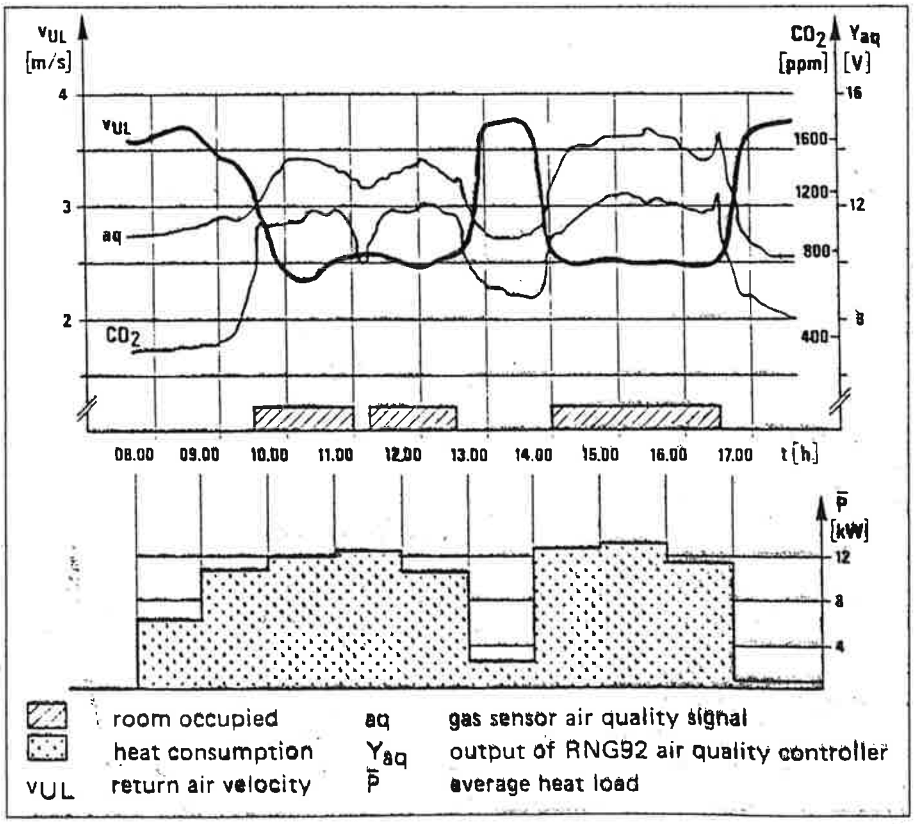

Figure 2: Sensor signals, return air velocity and heat consumption (lecture room in Zurich)

34 ◄ control is offered by the gas sensor developed on the Taguchi principle. This sensor consists basically of a heated element inside a semi-conductive tube (zinc dioxide) (see Figure 1).

The semi-conductive material is porous and has a large surface area which is able to adsorb oxidisable gases. During this adsorption process electrons are released, which increases the conductivity of the semi-conductor. The process is reversible. If the gas concentration decreases, the gases are diffused from the semi-conductor. The sensor responds very quickly, ie within a few seconds. It is not subject to wear, which means it will operate reliably for years. It responds with varying degrees of sensitivity to many different gases such as hydrogen, carbon monoxide, hydrocarbons, alcohols, esters, benzene, etc. The sensor also responds to water vapour.

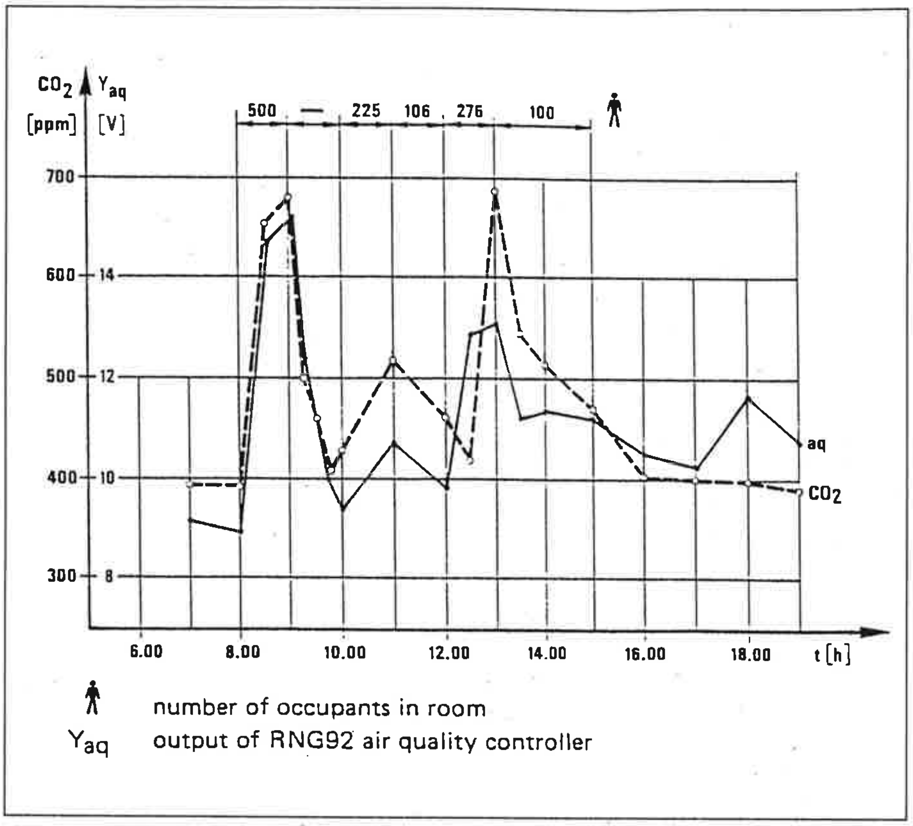

Figure 3: Lecture room at Trondheim University: comparative measurements

Air quality measurements

The gas sensor was used for measurements in various types of rooms: offices, theatres, gymnasia, multi-purpose halls and lecture rooms. The purpose was to compare the gas sensor signal with the room air hygiene load caused by people, tobacco smoke and various forms of contamination. Simultaneously, the carbon dioxide content of the room air was measured.

Rooms without smokers

In rooms where smoking is prohibited and where occupants are the only source of contamination, the gas sensor responds to odours caused by breathing, perspiration and flatulence. In the lecture room in the Zurich area, which we used for our measurements, the air is supplied directly at the seats, whereas the extraction grilles are located near the lighting in the false ceiling. The gas and CO_2 sensors were installed in this false ceiling. At first the correlation between room load and gas sensor signal was poor. The sensor scarcely responded at all to the changing room occupancy but it did respond to the air conditioning system switching on and off. The reason was that the air stream in the false ceiling overcooled the heated sensor and this temperature reduction caused the sensor sensitivity to change.

A good correlation was achieved after a specially designed sensor model for duct installation, which was unaffected by air flow, had been installed.

Figure 2 shows the measured results. The lecture room was fully occupied with about 300 people in the morning and afternoon. The gas sensor signal increased when the students entered the room at 9.30am: deterioration of air quality. During the short break at 11.00am, the occupants left the lecture room for 15 minutes. The sensor showed the air quality improving during the lunch break, after which the sensor responded again to the re-contamination of the air. The measured results with the CO_2 sensor were similar.

In the lecture hall at Trondheim University the signals of several CO_2 and gas sensors were compared with each other. Smoking was not permitted. A precise count of the occupants was made while the measurement was carried out. Figure 3 shows the measured value curves for comparative measurements in the extract air duct. Both sensors responded quickly to changes in occupancy. These measurements likewise show a good correlation between the two sensor types.

In sports halls, body odours due to perspiration cause a relatively large room air hygiene load. Both sensor types responded to this hygiene load. The measured value curves clearly indicate the high emission of CO_2 and body odours. The gas sensor responded with a delay of about 30 minutes, presumably because the body odour was first absorbed by the clean clothing before being emitted to the air.

Rooms with smokers

Tobacco smoke represents a heavy room air hygiene load. It has been shown to contain more than 2,000 different components (Bibliography 2). This shows the complexity of the term air quality. The gas sensor is sensitive to tobacco smoke, as measurements in an office equipped with a VAV system show. Figure 4 shows the measured value curves of both sensors. The gas sensor responds quickly and sharply to cigarette smoke in the room. The CO_2 content, however, increases by only a negligible amount in a smoky atmosphere. It cannot therefore be taken as a criterion for air quality in this case.

Other sources of air contamination

Formaldehyde, which is released from some building materials, can cause irritation of the eyes and respiratory tracts. Tests with the gas sensor show that it registers this form of contamination but it is not sensitive enough to register the low concentrations at which some discomfort can start.

Air quality control

As already mentioned, air quality control adjusts the outside air volume ► 40

38 ◀ to the actual demand, ie the hygienic load of the room. The upper limit of this air volume is defined by the size of the equipment and air ducts. The lower limit can be adjusted by incremental or proportional control of fan speed or by return air mixing in return air systems.

Control system in the Oslo concert hall

The small auditorium in this concert hall has 200 seats. An air conditioning system supplies 9000 m^3/h air. Before the control system was modified, the outside air dampers had the following minimum positions:

during performances:	50% open
day mode:	10% open
night mode:	0% open (100% return air).

The three positions were controlled by a time clock. By measuring the air volume, it was determined that the outside air volume did not change proportionally to the damper positions. When the dampers were 10% open, 18% outside air was supplied; when the dampers were 50% open, 90% outside air was supplied.

After air quality control (with the Taguchi sensor and the Staefa Control System RNG92 proportional controller) had been installed, the outside air volume could be controlled precisely in accordance with the actual demand. For this, the controller P band and the set point had to be adjusted accurately during commissioning.

When the auditorium is not used during the day (Figure 5 — I) no outside air demand is signalled. The demand only starts when preparations for the performance of a dance group are made in the auditorium (II). The outside air volume increases during the performance (III). On the following day the situation is found to be similar.

However, the choir rehearsing in the auditorium needs only a little outside air in comparison with the dance group.

With fixed damper position — ie before the control system was modified — too much outside air was supplied because the damper positions were not linear. Air quality control corrects these positions when the outside air volume exceeds the actual demand.

Air quality control in a lecture room

The outside air volume in the Zurich lecture room mentioned earlier is also ▶ 43

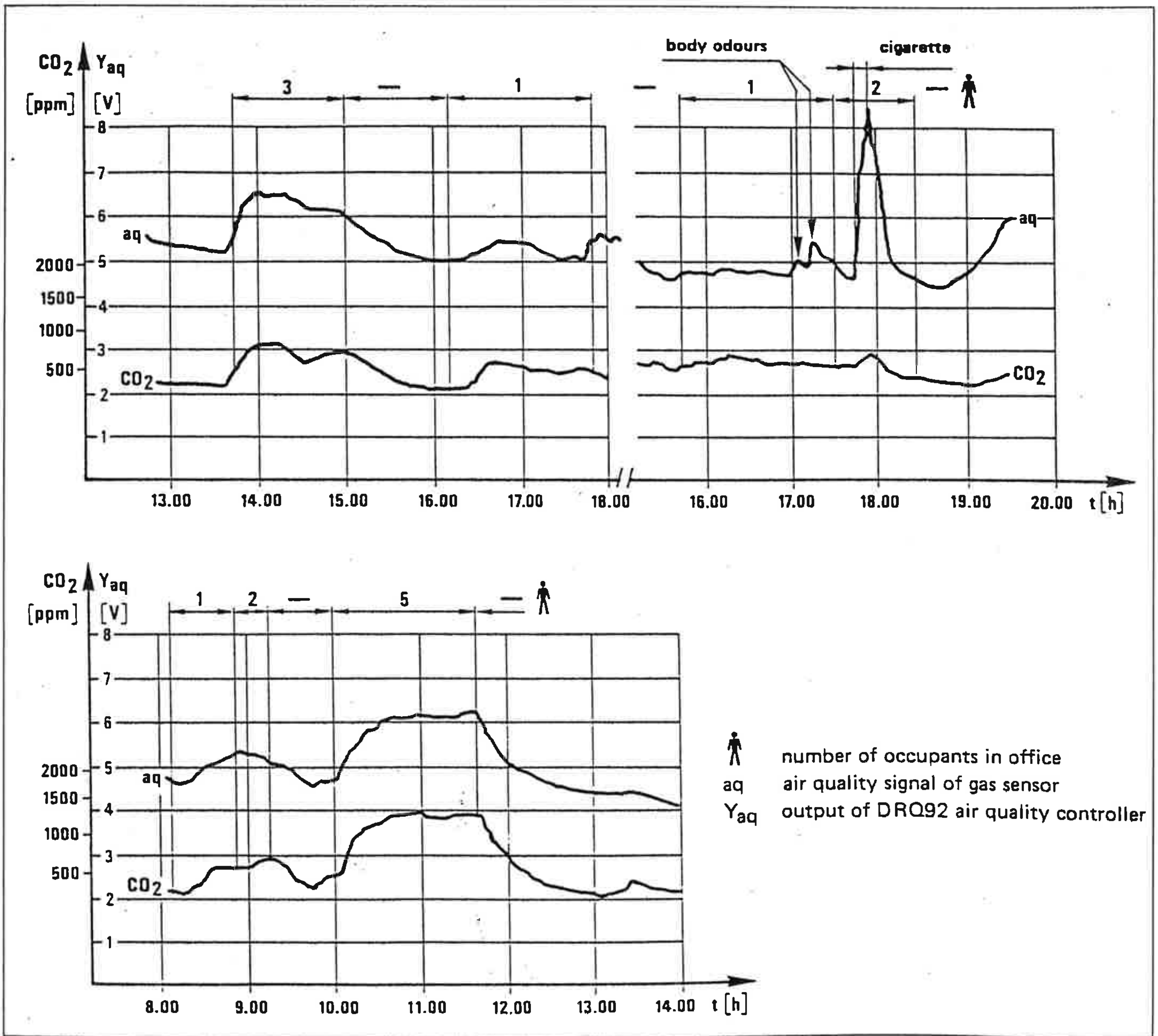

Figure 4: Comparative measurement between CO_2 content and gas sensor in an office

40 ◄ controlled by a gas sensor signal. The partial air conditioning system has a capacity of 16,000 m^3/h and is only switched on when the hall is occupied. A room supply air cascade controls the heating coil, the dampers and the cooling coil in sequence. During heating operation or at outside temperatures above 22°C, the minimum outside air proportion defined by the system design is 33%. This percentage is reduced by the air quality control. The effect of air quality control was determined by measuring the return air volume.

Figure 2 illustrates the gas sensor signals (Y_{aq}) and the measured air velocity values (v_{UL}). As the air quality deteriorates, the return air volume is reduced because more outside air is demanded. As the quality of the room air improves during the lunch break, a lower outside air volume is required and the return air volume is increased accordingly. The air quality in a fully occupied room depends on the minimum outside air volume required per person. Air quality control does not influence this value. During partial occupancy, the outside air volume is appropriately reduced by air quality control but only in cases where handling the outside air would mean unnecessary energy consumption. The P band offset of this control means that even if the room air load is low, there is still some improvement in air quality.

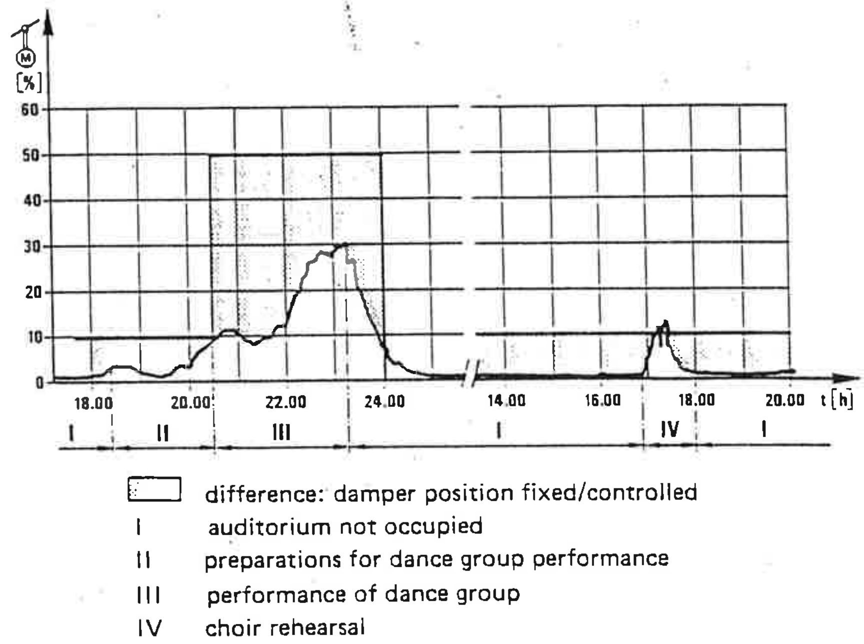

Figure 5: Damper positions in the system installed in the Oslo concert hall

Energy calculations

The momentary heat balance of a room can be used to determine the heating or cooling output which is necessary to maintain the temperature at a desired level. For our purposes, we shall examine a heating and cooling coil without humidification with fixed load. The output P_Z which has to be provided is as follows (not allowing for the heat exchange with adjoining rooms):

$$P_z = P_{TR} + P_L - P_S - P_i \text{ (kW)} \quad (1)$$

P_{TR} = transmission losses

$$= \frac{1}{1000} \Sigma_i k_i.A_i.\Delta T \text{ (kW)}$$

k_i = thermal conductance of walls (W/m^2k)

A_i = surface of walls (m^2)

ΔT = differential outside temperature (T_a) — room temperature (T_i) (K)

P_L = ventilation losses = $\rho.c.V.\Delta T$ (kW)

ρ = density of air (kg/m^3)

c = specific heat of air (kj/kgK)

V = outside air rate (m^3/s)

P_S = solar radiation (kW)

P_i = internal heat production = $P_p + P_B + P_M$ (kW)

P_P = heat gain from people (kW)

P_B = heat gain from lighting (kW)

PM = heat gain from equipment (kW)

At a certain outside temperature (defined in the following as the heating limit) the internal heat gain is equal to the heat loss. Above the heating limit, the temperature in the room will increase or the extra load will have to be cooled. Below the heating limit when occupancy varies, heating energy can be saved by reducing the outside air volume.

Example:

A conference room with 40 seats and a ventilation system (heating operation only has an average occupancy level of 20 people).

Operating times:	Monday-Friday 08.00-17.00
Room temperature:	20°C during operating time 18°C outside operating time
Outside air rate:	1,200 m^3/h (during operating time)
Outside wall area:	135 m^2
Average U value:	1 W/m^2K
Internal heat gain:	1.8 kW (20 people) + 1.4 kW (lighting) = 3.2 kW
Solar radiation:	none

First the heating limit during the occupancy time is calculated. The heating limit is derived from the following condition: Load supplied=0. The equation (1) is consequently:

$$P_{TR} + P_L - P_S - P_i = 0$$

If $\rho = 12$ kg/m^3 and $c = 1$ kj/kgK the result is as follows:

$\Delta T = 6K$

The heating limit is therefore at $20 - 6 = 14$°C.

Figure 6 illustrates this calculation in graph form (line defined as 100% AU=outside air). If the outside air volume is reduced to 50%, which is possible with partial occupancy, the line becomes flatter and will intersect the horizontal axis at 10.5°C. This represents the corresponding heating limit. The same result is achieved with the equation (1) if V is 600 m^3/h ($\Delta T = 9.5$ K).

The area between the two lines on the graph (100% AU and 50% outside air) shows the energy saving at various outside temperatures.

A similar calculation is possible for the required cooling output, although the situation is more complex due to the varying solar radiation. A reduction in ventilation results in lower cooling output if the outside temperature is higher than the room temperature (in Figure 6 room temperature = ► 44

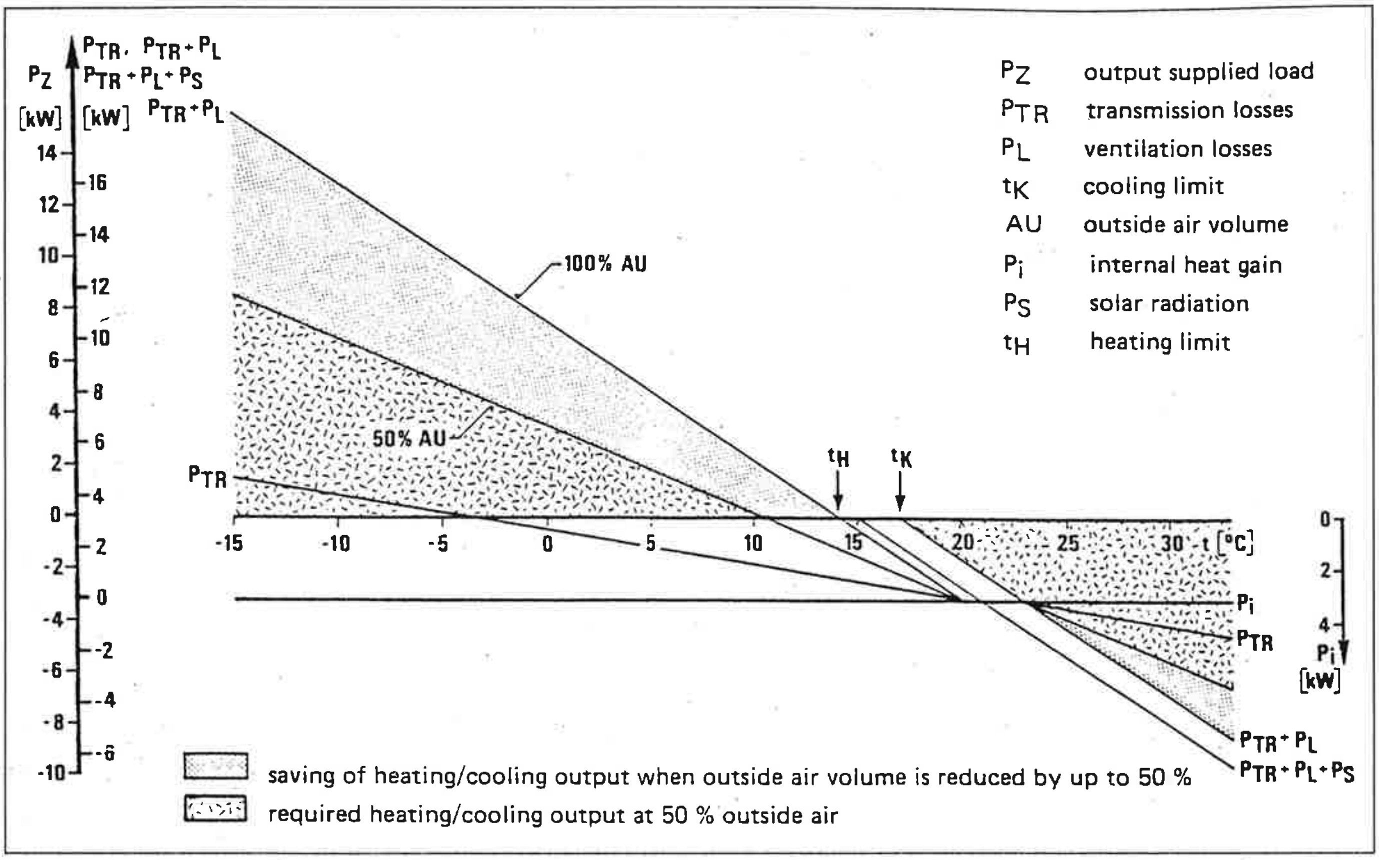

Figure 6: Heating and cooling output for conference room as a function of the outside temperature (during operating time)

43 ◀ 23°C during cooling operation).

The annual consumption can be calculated as follows: If the heat losses ($P_{TR}+P_L$) are higher than the internal heat gain, heating is necessary. The annual heating energy demand E_H is:

$$E_H=(\rho.c.V+0.001.\sum_i A_i).Gr_x \quad (kW) \quad (2)$$

Where Gr_x=degree hours in relation to heating limit T_x:
Sum of hourly temperature differential between heating limit and outside temperature.

$$\sum_k (T_x-T_a)\ k\ [Kh]\ T_x=\text{heating limit}$$

In Holland (de Bilt, Utrecht province) the degree hours for a reference year have been calculated (Bibliography 8). Using these figures in relation to the conference room described in the above example, the following is obtained.

100% outside air:
Gr 14°C=10990 Kh (Monday-Friday: 08.00-17.00 h)

50% outside air:
Gr 10.5°C=6680 Kh (Monday-Friday: 0800-17.00 h)

Depression period:
Gr 18°C=53290 Kh

By using formula (2) for calculating the heating energy demand we arrive at Table 1.

With controlled outside air volume the annual energy saving relating to the total heat requirement of heating and ventilation systems is thus 28%.

The heating energy required for the lecture room in the Zurich area when the outside air volume is controlled was measured in the air ducts. For this, 4 PT100 temperature sensors were used on both the inlet and outlet side of each supply air device. A velocity sensor controlled the supply air volume. A computer used the measured data to calculate the energy consumption every 45 seconds. Figure 2 shows the average heat output P for every hour over a working day at an outside temperature of 6°C and a room temperature of 22°C. At full occupancy and an outside air rate of about 5,300 m^3/h, the output was approximately 12 kW. When the outside air volume was reduced during the lunch break and after the lecture, the output immediately decreased.

The achievable energy savings depend largely on the particular situation. As shown in Figure 6, the saving potential decreases as the internal heat gain increases. Large savings can be achieved in rooms with high outside air volume per person (rooms with smokers) and low occupancy. To make reliable predictions, a calculation must be made for each particular case. The measurements with the gas sensor produced the results in Table 2 in respect of savings and pay-back for the additional equipment installed.

In the auditorium and the sports hall the percentage energy saving is less than in the concert hall due to the larger internal heat gain. The pay-back period was calculated on the basis ▶ 50

	fixed outside air volume	*controlled outside air volume*
During operating time	5,880	2,240
Outside operating time	7,190	7,190
Total	13,070 kWh/a	9,430 kWh/a

Table 1

	Savings %	*Pay-back period* *kWh/a*	*Years*
Concert Hall, Oslo	40	500,000	1
Auditorium, Trondheim	12	23,000	1.5
Sports Hall, Oslo	10	33,000	4.3

Table 2

44 ◄ of the absolute saving and the costs of carrying out the measurements and delivering and commissioning the air quality control plus, in the first example, some modifications to the system.

Conclusion

The Taguchi gas sensor is capable of measuring the degree of air contamination. The sensor signal acts on the fan speed or on a mixing air damper via a proportional controller. This makes it possible to reduce the minimum outside air volume required during full occupancy on the basis of the effective air quality, thus saving heating and cooling energy expended on handling and distributing the outside air. The extent of the saving depends heavily on the internal heat gain, the outside air rate per person and the room occupancy. To be able to make a reliable prediction of savings and payback on the additional equipment required, a separate energy calculation therefore needs to be made in each case.

Bibliography

1. P.O. Fanger and B. Berg-Munch, "Ventilation strategies for the control of body odour".
2. J.D. Spengler and Ken Sexton, "Indoor air pollution: a public health perspective", *Science*, Vol. 221, 1983.
3. H. Loewer, "Mensch und Raumluft — Gedanken zum wirtschaftlichen", Einsatz lüftungstechnischer Massnahmen, Ki Klima-Kälte Heizung, 5/1983.
4. D. Södergren and A Punttila, "A CO_2-controlled ventilation system".
5. S.R. Morrison, "Semiconductor gas sensors", *Sensors and Actuators*, 2/1982.
6. J. Geerts and A. Dollfus, "What energy savings can be achieved by SCS-occupancy control and SCS-air quality control in ventilation systems", *SCS-okay*, 3/1983.
7. C. Specker, "Reducing ventilation losses by means of air quality control," Energy saving control applications (1) SCS-Special print, 1983.
8. R. Thys, "Weergegevens gebaseerd op het referentiejaar", Interne Publikatie, Technische Hogeschool, Eindhoven, 1980.

Installations

Bi-parting doors for dairy warehouse

THE first installation of a fully automatic bi-parting version of the Fermatic 3300 series sliding door track system, supplied by Fermod Ltd, has been completed by Deejay Coldstores Ltd of Kings Lynn, at the new Job's Dairies warehouse complex at Sunbury Cross.

The 10,000 sq ft cold store facility is now fully operational and will supply dairy products to Marks and Spencer and Sainsbury's, among others, and provide total chilled distribution for the Sperrings chain throughout the south of Britain. Distribution is carried out 24 hours a day, six days a week in Job's own fleet of 30 16-ton lorries.

The speed and efficiency of handling at Job's new warehouse is further enhanced by the bi-parting door systems which all use the new Fermatic track on doors supplied by Hemseck Doors Ltd. Ease and speed of access are essential requirements at this store, and the Fermod fittings cater for this.

Designated the 3370DV, the track is unusually simple in design; a single motor lifts and slides the door, and uses only one continuous chain. Smooth operation is ensured by the use of a self-regulating clutch which provides immediate reversal of the direction of travel and eliminates chain snatch. The bi-parting door operates at 1 m per second, twice the speed of a single leaf door. An automatic safety edge strip on both doors provides instant reversal on contact. In the event of a power failure all door systems can be operated manually.

The track itself is of the patented Fermatic design, dropping the door downwards and inwards to give a perfect hermetic seal. The working parts are fashioned from zinc bichromated steel and are located inside the main track which acts as its own cover. The gasket which was specially developed for the 3300 series is now supplied complete with pre-formed mitres corners to assist in making the perfect seal.

Fermatic sliding door track in use at the new Job's Dairy warehouse complex

Manual and single leaf models of this track are also available, for doors with a weight not exceeding 200 kg and a width of up to 3.24 m. The largest tracks available from Fermod are the Fermatic 4400 series which will carry doors of 400 kg, with a single leaf width up to 6.24 m.

To cater for the increasing demand for sliding door tracks to operate on lightweight doors, Fermod previously introduced the Fermatic series 200 of lightweight extruded alloy tracks. These are ideal for small retail outlets where space is at a premium, or to give personnel access to a large chamber. This range is suitable for door apertures up to 1.5 m wide.

The Fermoflex range of flexible curtains has been designed for refrigeration applications. The extruded strips in the Fermoflex RL 2500 series have rounded edges to ensure that they do not cut any person walking through the aperture, and they remain flexible right down to −50 deg C.

The Fermod range also includes a venting port which is important in today's modular cold rooms, which are completely hermetically sealed. This pressure balancing valve allows the air pressure built up during defrost to be vented, thus eliminating structural stress to the cold room walls and ceiling, and balancing the reduction of internal pressure which occurs during "pull-down".

For more details circle 102