techniques are also needed to pre-evaluate the energy savings in order to make a cost benefit analysis to justify the application of DCV.

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FUTURE OF DCV - WHAT IS ECONOMICALLY FEASIBLE?

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ABSTRACT

Much has been said and published on Demand Controlled Ventilation (DCV). Research and tests have shown the most common air pollutants present in buildings and the cause of their existence (human presence, emission from building materials or bad inlet air). Many methods have also been suggested on how to improve indoor air quality and/or to save energy costs. Several more or less well operating DCV systems have been introduced over the years. However, there still seems to be a major gap between scientific conclusions, presently available products and practical solutions that really can be accepted by the market. This paper discusses views formed during a recent study on gas measurement based DCV, related sensing technologies and on the actual market situation. In addition to literature studies the study has included interviews and testing of commercially available products. The text points out that technological limitations and economical constraints will most probably have a greater influence on the winning concept than earlier anticipated.

INTRODUCTION

This paper discusses views formed during a recent market and application study on Demand Controlled Ventilation (DCV). The goal of the study has been to get a better understanding on the future market needs for occupation measurement based DCV.

METHODS

The study is a synthesis of information from interviews made during company visits, conferences and trade shows and summarises the market situation merely seen from the point of view of a transmitter supplier. During 1991-92 trips in both Europe, USA and Japan, 9 building automation equipment manufacturers and 23 gas instrument manufacturers were visited. Also testing of commercially available gas sensors and transmitters have been made. Obtained test results have been compared with results from external evaluation programs in order to better understand the advantages and disadvantages of different measurement concepts.

RESULTS

General impressions

The information obtained reveals that DCV is globally still today fairly uncommon, although there are big differences between different countries. So far most installations have been made in the Northern and Central Europe as well as in North America.

Even if energy savings are still the main goal of DCV, the effects of good air quality on health and well-being are also beginning to receive attention. The effect of air quality on productivity has been increasingly emphasised, especially as an argument for using DCV in schools, conference rooms and office buildings.

Since DCV and better indoor air quality offer clear possibilities for savings both in terms of lower energy consumption and lower health care costs, legislation in this area is under development in many countries. The legislation will be developed successively: first recommendations, then regulations and laws. In many countries increased energy taxation will also indirectly give rise to extended use of DCV.

The present high transmitter prices can justify DCV only in special facilities (theatres, conference and exhibition halls etc.). Although prices will probably drop only marginally, the price reduction relative to rising energy prices is expected to be larger. It is predicted that within the next few years prices will reach a level where DCV becomes economically justifiable also in more ordinary buildings. Increasing volumes make manufacturing cost reductions possible and promote competition, resulting in still lower market prices.

Why use DCV at all?

Energy costs in buildings have been reduced in many ways over the years. In addition to traditional energy saving methods, (such as the use of better insulation, use of more cost-efficient energy forms, heat exchangers, temperature controlled systems, lower setpoint limits, clock controlled systems, energy accumulation), several DCV methods have been suggested and evaluated. Ventilation systems based on these methods are typically controlled by measuring human presence (directly or indirectly) or by measuring other physical changes in the room[1]. Although there are sensors available for the direct measurement of human presence, so far sensors for indirect measurement (based on air quality sensing) have mostly been used for the purpose. However, all DCV methods still have a common goal: to reduce energy costs and at the same time keep the indoor air quality high enough.

Measurement concepts

The simplest DCV sensors are based on **direct occupation measurement** and are typically optical or inductive devices sensitive to moving objects such as human beings. By combining such sensors with controllers and smart software the presence or absence of people in a room can be determined. Information from light switches, intelligent locking systems or ID card based security systems can also be used in occupation measurement. Unfortunately a foolproof judgement requires in most cases data from several sensors, so systems based on this approach usually are quite complicated. No commercial solution based on this concept has been found so far.

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[1]Footnote: The DCV has often been misleadingly connected to the so called "sick building syndrome". Although this "syndrome" certainly is serious indoor air quality problem that could be cured with excess ventilation, it is not sensible nor economically feasible to solve it by DCV. DCV should be designed for normal ventilation control conditions

Mixed gas transmitters [1] are sensitive to more than one air pollutant. They incorporate typically a single non-selective ceramic gas sensor, which is sensitive both to CO and hydrocarbons; they detect human presence in the room by measuring "human odours and/or cigarette smoke". The advantage of mixed gas transmitters is their fairly competitive price, but their long-term stability is poor and they are difficult to calibrate. Their humidity and temperature dependence is typically large. In rooms where CO_2 is the dominating air pollutant, mixed gas sensors will not react unless there also are hydrocarbons present. Although the measurement concept in principal makes sense, the main problem with mixed gas sensors is their non-specific behaviour, poor stability and corresponding need for frequent recalibration. Mixed gas transmitters are manufactured by several companies [2], which mostly use Figaro's sensor elements in their transmitters.

Carbon dioxide sensors [1] are most commonly used in DCV. These sensors are normally based on infrared absorption and are thus fairly selective to CO_2. These transmitters work excellently in rooms where smoking is prohibited and where the occupancy changes randomly. The disadvantages of CO_2 sensors are their high prices and their insensitivity to cigarette smoke; some CO_2 transmitters are also sensitive to temperature and humidity. The most inexpensive transmitters are also fairly unstable, so they have to be recalibrated regularly. Half a dozen manufacturers produce CO_2 transmitters suitable for DCV [2].

During the EIA's "Lüftungsforschung für die Praxis" seminar in Zürich [3] in May 1992 an idea of **a combined CO_2 and mixed gas** transmitter for DCV applications was suggested by Mr. Philippe Bachmann of Aritron Instrumente AG. The advantage of a combined CO_2 and mixed gas transmitter would be to ensure a reasonable stable operation with an infrared CO_2 sensor, but to get a certain sensitivity to cigarette smoke and odours with the ceramic mixed gas sensor. The principle is interesting, but probably too expensive for the volume market. Since no obvious correlation exists between CO_2 and mixed gas sensor signals, the unstable ceramic sensor will be difficult to calibrate automatically. Transmitters based on this concept will most likely need frequent recalibration.

A combined CO_2 and CO sensor has also been suggested for DCV. As in the case of the combined CO_2 and mixed gas sensor this arrangement, preferable based on two selective IR sensors, would be sensitive both to CO_2 and cigarette smoke. This arrangement would be more specific and more stable than the CO_2/mixed gas sensor combination, but would also be too expensive for the volume market.

Other gas sensors [4] could also be used for DCV, but are clearly limited to ventilation of special facilities such as road tunnels, garages, cellars, mines, process rooms and chemical storage. In these cases a variety of different sensor types are used, depending on the gas in question. Except for CO sensors (smoke detection) and VOC sensors (odour detection) these sensors are typically not suitable for the ventilation of ordinary rooms. However, in the long run technologies such as "electronic noses" (utilising integrated sensor arrays in combination with neural reasoning) might become mature enough also for DCV.

The winning concept?

Although the suitability of the different DCV concepts for different facility types has been discussed earlier in several papers, a synthesis of the views obtained during this study is presented in Table 1.

Table 1. Suitability of the different DCV concepts for different types of facilities, from the point of view of both technological as well as economical competitiveness. The matrix is a synthesis of information from earlier published reports, interviews and obtained test results.

Target	Direct occup. meas.	Mixed gas	CO_2	CO_2/ mixed gas	CO_2/ CO	other gases
Public spaces						
non-smoking areas	NA	poor	exlnt	good	good	NA
smoking areas	NA	satisf.	poor	satisf.	good	NA
Skyscrapers	satisf.	poor	exlnt	good	good	NA
Offices						
non-smoking areas	satisf.	poor	exlnt	good	good	NA
smoking areas	poor	satisf.	poor	satisf.	good	NA
Labs, storage etc.	NA	poor	poor	poor	poor	good
Private homes						
non-smoking	satisf.	poor	exlnt	good	good	NA
smoking	satisf.	satisf.	poor	satisf.	good	NA
Hotels						
non-smoking rooms	satisf.	poor	exlnt	good	good	NA
smoking rooms	satisf.	satisf.	poor	satisf.	good	NA
Restaurants	poor	satisf.	poor	satisf.	good	NA
Tunnels, garages	satisf.	satisf.	poor	satisf.	satisf.	good (CO)

Since public spaces are the largest market segment by far and since smoking in public spaces is more or less prohibited in most industrialised countries, the most competitive "general" solution for DCV would be CO_2 measurement. However, it has to be noted that CO_2 based DCV is still not suitable for all types of facilities. The best all-round solution seems to be the combined CO_2/CO measurement, although these types of transmitters would be difficult to make so inexpensive that they could be used in all types of facilities.

When can DCV be economically justified?

The economical justification of DCV depends very much on the individual application, but the pay-back time for a DCV investment should typically be as short as 1-3 years. Depending on the efficiency of the DCV system, up to 20-30 % of the annual energy costs could be saved [5]. This means that the DCV transmitters including additional cabling and other installations have to cost less than a few years energy savings. A system of this kind also has to be a competitive investment when compared to other means of saving energy (efficient heat exchangers etc.). Higher energy prices and increased energy taxation will clearly increase the popularity of DCV (a new energy crisis would thus rapidly increase the market demand).

Although an increase in the use of DCV will depend on many factors, the high price of transmitters at the moment limits their use to special facilities. Lower transmitter prices are needed before DCV can be used in more ordinary spaces.

An important characteristic in DCV transmitters is their long-term stability. If the stability is poor, the transmitter needs frequent recalibrations in order to operate according to specifications. In practice the recalibration is often neglected, which in the long run undermines the potential for energy savings. Even if recalibrations are made, the costs of frequent recalibrations should not be forgotten (See Figure 1).

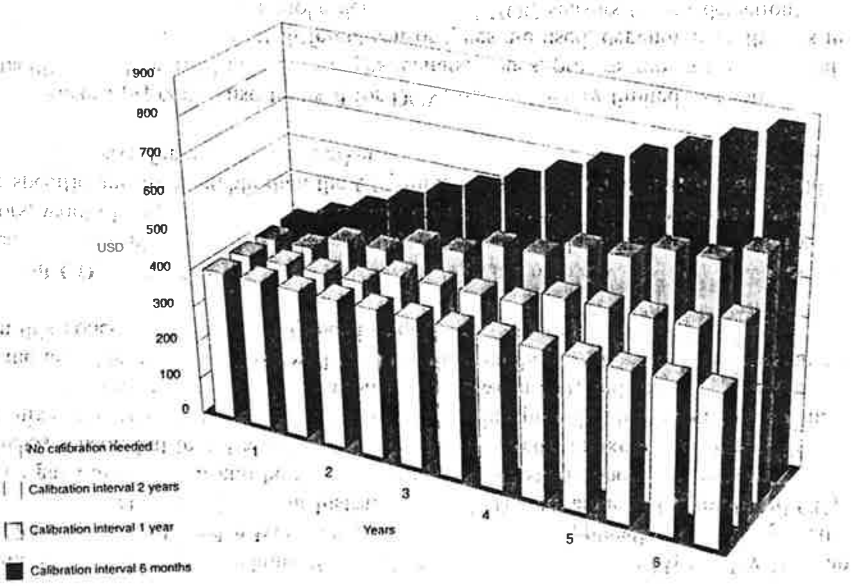

Fig. 1. An invented example on how the maintenance costs vary with calibration interval. The purchase price of the transmitters in the example is 400 USD. The costs of an average calibration are assumed to be 40 USD. The costs of a transmitter with 6 months calibration interval are more than twice as much as the costs of a transmitter that needs no calibration.

The level on which DCV will be implemented in practice has a direct bearing on the transmitter quantities and prices. If used only on building level, annual transmitter volumes will not grow much more than during recent years. But if floor or department level or in the long run even room level DCV becomes popular, the quantities will grow considerably. It is a chicken and egg situation, since volumes are needed in order to get prices down and volumes can not be generated without low enough prices.

It has been argued whether room level DCV can be generally justified at all. Obviously also here the transmitter price will be critical; room level control seems realistic in schools, conference rooms and maybe also in hotels, hospitals and certain offices.

DISCUSSION

Increasing energy prices and energy taxation will make energy saving crucial in all areas - also by means of DCV. Traditional methods to save energy will still be utilised whenever feasible. The alternatives with the best energy savings/cost ratios will be chosen and even plain temperature controlled systems will still be used in many cases.

The breakthrough in DCV is likely to happen within the next few years. The growth is expected to increase as a result of both decreasing transmitter prices as well as a result of increasing energy prices. In addition to price, long-term stability and easy calibration have to be considered when investing in DCV.

The market growth will at first be a result of a more complete use in the most obvious areas of DCV, such as schools, conference rooms, theatres, music and exhibition halls. Since the implementation of DCV in old buildings often requires modifications in the ventilation system, the majority of targets will be new buildings at the beginning.

Although the mixed gas measurement concept is theoretically sensible, there are some serious difficulties with using and maintaining these types of transmitters. The winning DCV concept will be based on CO_2 measurement, although other concepts will not disappear completely. Even if CO_2 transmitters can not be used in all types of facilities, they will still be the one most commonly used, not only because CO_2 is an objective indirect parameter for human presence, but since CO_2 measurement is the only simple and reliable solution. As an evidence of this, ASHRAE has chosen CO_2 as the main alternative for DCV [6]. A technically still better all-round solution would be a combined CO/CO_2 transmitter, but it would most probably be too expensive for general use.

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WATER VAPOR PRESSURE CORRECTION OF SEMICONDUCTOR GAS SENSORS FOR MONITORING INDOOR AIR QUALITY AND ITS EVALUATION

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ABSTRACT

Semiconductor gas sensors for IAQ monitoring were used together with monitors of temperature, humidity, carbon dioxide and suspended particles in offices. Temperature and humidity(water vapor pressure) correction for the sensors was shown to be effective. In a series of investigations of offices in which handling conditions of air dampers and dust collectors were set manually. the relationships between the sensor outputs and the concentration of VOC and IAQ voting values as well as the other contaminants were studied.

INTRODUCTION

This study was performed in order to establish a suitable IAQ monitoring method in controlling healthy and comfortable office environments. IAQ in offices has been evaluated by concentration of perspective matter, besides carbon dioxide, carbon monoxide, nitrogen dioxide and suspended particles for health. Perspective air quality, governed by volatile organic compounds(VOC) and some kinds of suspended particles is a direct indication factor for comfort. However, methods and practical sensors for the air quality monitoring are not established.

Semiconductor gas sensor is one of IAQ monitors. The practocal use of semiconductor gas sensors, responding to gaseous reductans such as VOC and carbon monoxide, was doubtful, because of the effect of moisture on the sensor output. In this study, the effect of temperature and moisture correction was examined on sensor output characteristics.

The sensors were applied to a series of environmental comprehensive investigations in offices. The measurement with sensors was carried out parallel to that of VOC, carbon dioxides and suspended particles through four seasons. The levels and characteristics of VOC and relationships between VOC and sensor outputs as well as concentration of other contaminants and voting values were observed. The relationship of cause and effect in indoor pollution is shown in Fig.1 which lists the contribution of four kinds of source to odor generation (1), environmental factors and sensing/humane sensation. The environmental factors contain only main factors such as VOC.

MATERIALS AND METHODS

Semiconductor gas sensor: Slection criteria of semiconductor gas sensors applied in the investigation are shown in Table 1. They were on the market and assembled in test units with output terminals. Any one of the five kinds of sensors is slightly different from the others in gas selectivity and sensitivity, because of the dopant for n-type semiconductor. The gas selectivity of sensors is relative and each one of them responds to all reductive gases. The relative outputs from the sensors were recorded in the datarecorder. The data were corrected later with the room temperature and water vapor pressure(WVP) which were calculated with the temperature and humidity measured simultaneously.