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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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 as a surrogate measure of indoor air quality and recent work has shown a theoretical relationship between CO_2 concentration and air exchange rate in occupied buildings, where CO_2 is primarily in proportion to the number of occupants. Much research work has been done with CO_2 demand-controlled ventilation in the form of case studies [1], computer simulation, and controlled test condition. Saving in energy consumption reported from 8 to 40% [1,2]. One study reported a 70% reduction in running time, a 90% reduction in energy consumption, and a 20% reduction in maintenance, and another study reported that the DCV to be more efficient that a heat recovery system [see ref.1].

FIELD MEASUREMENTS

This study compares the indoor environment created by two different types of ventilation control systems in an eleven-storey office building. Each floor was serviced by its own independent, yet identical, ventilation system. Furthermore, each floor was occupied by approximately 100 white collar workers, but since the building was open to the public, the number of people varied. The occupation density was approximately 6 people/100 m^2. The heating, ventilation and air conditioning system consisted of double duct constant air volume system with fresh air intake and exhaust on each floor. The fresh air dampers of one floor was controlled by the indoor CO_2 concentration level, and the fresh air dampers of the other floor was controlled by the mixing temperature.

The following parameters were measured: dry-bulb temperature, relative humidity, air change rates, formaldehyde, VOCs, CO_2, dust, energy consumption and occupant perception. Operative temperature and relative humidity were monitored at nine locations per floor, and the air change rates measured using the trace gas decay technique. Formaldehyde and VOCs were measured at three sampling stations for a duration of three consecutive days each month. A direct reading instrument was used to measure CO_2 for three consecutive working days each month at ten sampling locations. The dust was collected for a period of three 10 hour working days each month. Questionnaires were used to measure the subjective response of the occupants to their environment.

Measurements indicated that the concentration of contaminants levels (formaldehyde, VOCs, dust) remained well below the recommended limit (Figure 1). The air temperature and relative humidity measurements showed that these parameters did not always remain within the ASHRAE comfort limits. The energy consumption of the HVAC system of the floor with DCV (8^{th} floor) was lower by 12% than that of the floor with the conventional control system (9^{th} floor). The monthly energy consumption by the DCV system was always less than that of the other system, except for two months where the CO_2 controlled system had a higher energy consumption [1]. The payback period was calculated using a pre-determined cost schedule, and was found to be 0.4 years.

The average response rates to the questionnaires for the 8^{th} and 9^{th} floors were 60% and 56% respectively, which is an adequate number. The results of the questionnaires showed that most of the time the occupant felt that the temperature was comfortable except for a few cases where the occupants felt cool. The air was considered to be slightly dry to dry all of the time for the majority of the occupants. The ventilation was considered to be adequate on the 8^{th} floor at all times, except for a few cases where it was found to be drafty. The ventilation was never considered adequate by the majority of the occupants on the 9^{th} floor. The air quality on both floors was considered satisfactory for less than half of the time by

the majority of occupants of these floors.

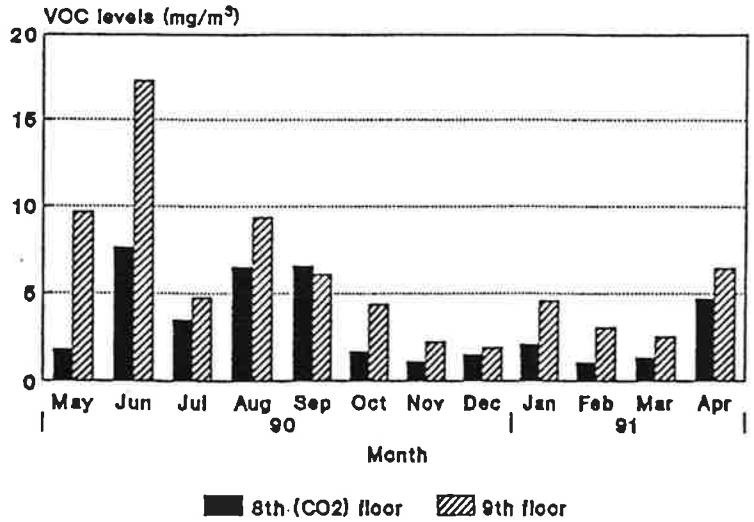

Fig. 1. VOCs Concentration

COMPUTER SIMULATION

The evaluation of energy impact of the DCV system implies:

1. Hourly calculation of indoor contaminants concentration, by taking into account factors such as volume of space, occupancy density, emission rate, ventilation rate or air infiltration.
2. Comparison between the estimated indoor contaminants concentration and the maximum acceptable value; if this value is exceeded then the ventilation rate is increased, and the indoor contaminant concentration is estimated again; this iterative process continue until the indoor contaminant concentration is lower than or equal to the maximum acceptable value.
3. Estimation of the energy consumption and cost of the building.

The MICRO-DOE2 program (3) is well-known for its capabilities to evaluate the energy performance of large buildings with complex HVAC systems and schedules of operation. However, the evaluation of DCV systems cannot directly be done. MICRO-DOE2 program allows the user to modify some calculations performed within the LOADS and SYSTEMS blocks, without recompiling the program, by using the Functional Values feature (4). To evaluate the impact of DCV system on the energy consumption and cost, a computer model of a large existing office building, previously developed by using the MICRO-DOE2 program, was modified to integrate the calculations indicated earlier.

The base case was developed by considering the following parameters:
- rate of emission of CO_2 is equal to 0.30 L/min·person,
- occupancy is constant from 9:00 to 18:00, at an average density of 14 m^2/person,
- HVAC systems operate from 3:00 to 23:00, with a maximum supply air flow rate of 11.4 L/s·m^2,
- outside air is brought into the building between 3:00 and 23:00, at a constant rate of 10 L/s·person, which corresponds to about 6.5% of the total air supply rate,
- indoor air temperature is kept at 22.5±1°C between 5:00 and 20:00, while outside this interval the set-point temperature is 16.0°C,
- outside the occupancy hours the infiltration rate corresponds to about 0.4 ach, while during the operation of HVAC system it is only 10% of the maximum value,
- mixing coefficient in the room is equal to 0.7,
- CO_2 concentration in the outdoor air is 380.0 ppm.

The CO_2 concentration in the indoor air was then calculated by using the one-compartment model, as well as some indices defining the energy performance of the building (e.g., energy budget, energy cost, peak electric demand, electricity used by the pre-heating coil).

The case of DCV system was simulated by assuming the same conditions as in the base case, with the following differences:
- during the operation of HVAC system and outside the occupancy period, that is from 3:00 to 9:00 and from 18:00 to 22:00, a constant ventilation rate of 2.5 L/s·person is supplied into the building to evacuate other pollutants; the concentration of CO_2 in the indoor air is calculated every hour,
- during the occupancy period, that is from 9:00 to 18:00, the ventilation system supplies a minimum rate of outdoor air of 2.5 L/s·person; if the concentration of CO_2 exceeds 800.0 ppm, then the required ventilation rate is calculated to maintain this maximum acceptable value.

In the case of DCV system, four different situations were analyzed:
- Case A, where the occupancy density is constant between 9:00 and 18:00, as it is in the base case,
- Case B, where the occupancy density is reduced to 90% of the maximum capacity used in the case A; during the lunch pause (12:00-13:00) the occupancy drops at 45% of the peak value,
- Case C is similar to the case B, except that the occupancy density is reduced to 80% of the case B,
- Case D is similar to the case B, except that the occupancy density is reduced to 70% of the case B.

The computer simulation were performed for the winter operation conditions, between January 1 and May, and between October 10 to December 31.

Four indices of the energy performance are used in this paper for comparison: whole building energy use, whole building energy cost, peak electric demand and electricity consumption for pre-heating the outdoor air. Figure 2 shows the reduction of three indices, which is expected to be obtained by using the DCV system over the conventional systems. For instance, for the case C (80% occupancy) the total energy use of the building is reduced by 10.6%, the total energy cost by 5.2% and the peak electric demand by 16.6%. Since the

reduction of electric demand is of a major concern in winter, these results show a particular impact with respect to this parameter.

It is interesting to notice that the savings obtained in the case A (100% occupancy) with respect to the conventional system are about 7.7% for the energy use and electric demand, and 1.9% for the energy cost. These savings can also be obtained by a conventional system, where the ventilation rate outside the occupancy hours is kept at a minimum corresponding to 2.5 L/s·person, and then increased during the occupancy to the value of 10 L/s·person. In this case, the potential impact of the DCV system appears only when the interior occupancy varies during the day. The larger the occupancy variation, the larger energy savings are obtained. These savings can be called "net savings", and in this paper are calculated by subtracting the savings of cases B, C and D from that of case A. Therefore, the "net savings" of the case C are the following: energy consumption 2.9%, energy cost 3.3%, and peak electric demand 9%.

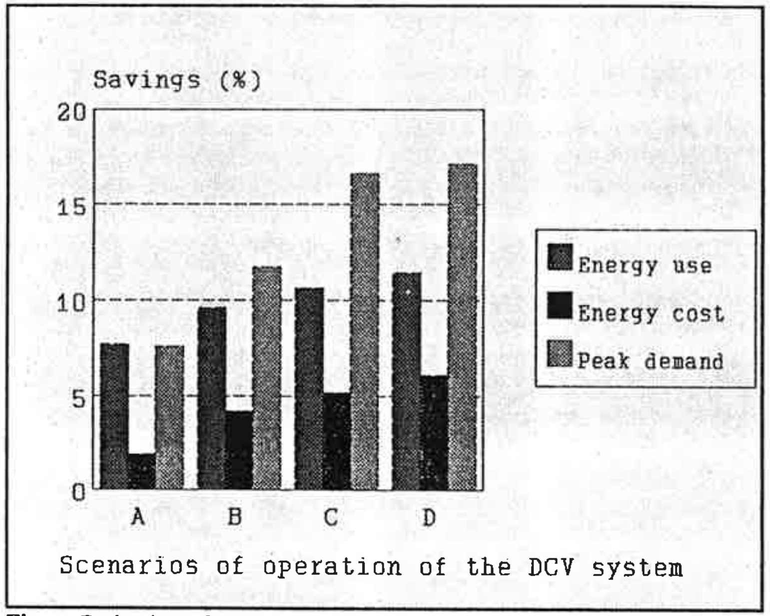

Fig. 2. Reduction of energy use and cost due to the DCV system compared with the conventional system.

The energy used by the pre-heating coil is reduced by 55% in the case C with respect to the conventional system, while the "net savings" are about 44%.

DISCUSSION

Experience with DCV is still very limited, and the observation cannot be generalized. however, it has been shown that DCV does not worsen indoor air quality and thermal comfort. The optimum location of sensors is a very important matter in the use of DCV. This can be accomplished by the application of Computer Fluid Dynamics models [5]. Simulation 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. However, the world-wide potential for energy savings based on DCV is huge.