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LONG-TERM MONITORING OF INDOOR AIR QUALITY AND CONTROLLED VENTILATION IN PUBLIC BUILDINGS

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Abstract

Long-term monitoring of radon, aerosol and carbon dioxide concentrations was carried out in two Finnish public buildings. In each case, a distinct periodic behaviour of pollutant concentrations was observed. CO_2 and aerosol showed maxima during the working hours, but the fluctuations of the aerosol concentration were faster and more irregular. The radon concentration peaked at night and on weekends, dropping off rapidly in the working day mornings when ventilation was turned on. Reasons for the concentration fluctuations are discussed shortly in terms of indoor sources and periodic ventilation. A case study of CO_2-controlled ventilation was conducted in one of the buildings. The estimated daily energy savings were 13-20 %, and no significant changes in the pollutant concentrations could be observed.

Introduction

Indoor air quality of public buildings (offices, schools, hotels, restaurants, etc.) has become an inherent part of indoor air pollution studies. It contributes significantly to the total exposure of the general public and thousands of workers to many air pollutants. On the other hand, the ventilation of public buildings accounts for about 10 % of the total energy consumption of buildings in Finland (3). Thus, the potential energy savings in public buildings are large, but any energy conservation measures must be based on sufficient knowledge of indoor pollutant concentrations and their dependence on different ventilation strategies.

In public buildings, indoor pollutants and factors affecting indoor air quality differ somewhat from that encountered in common residences. The building occupancy is often heavy and periodic, and modern mechanical ventilation systems are widely used. The most common indoor pollutant sources include people, their movements, building materials, tobacco smoke and copy machines. Although many authors have studied indoor pollution in public buildings (1,2,12,14-17,21), data on the long-term behaviour of the pollutants are scarce. In this paper, we present the results of continuous aerosol, radon and CO_2 measurements carried out in two Finnish public buildings. Results of a case study of CO_2-controlled ventilation are also discussed.

Experimental

Two school buildings with office spaces were selected to serve as study sites: a university building at the Tampere University of Technology and a high-school building located close to Tampere. Both buildings utilize modern, controllable ventilation systems, but the air is recirculated and filtered only in the latter. In both cases, the occupancy and ventilation are periodic (confined to working hours), but irregular evening occupancy is not uncommon. Several hundreds of people use these buildings daily.

Radon concentration was measured continuously using a self-developed monitor, which is a modified ionization chamber, where the effect of decay products has been eliminated (for a detailed description of the method, see ref. 6). A modified electrical aerosol monitor developped by Lehtimäki (10), was used to measure the aerosol concentration. This device is especially sensitive to fine particles, and can be calibrated to different size distributions.

Carbon dioxide concentration was measured with MIRAN 1A infrared spectrometer. Some long-term measurements of relative humidity and temperature were also made. A self-developed data logger was used for data collection. The data was transferred to computer for further processing.

Results and discussion

The concentrations of aerosol and CO_2 during a 25 days period (in late August and September) in the exhaust air of the university building are shown in Figure 1a. The radon concentration during the same period is plotted in Fig. 1b.

These figures clearly reflect the effects of periodic ventilation and occupancy on pollutant concentrations. CO_2 is produced by the occupants and shows maxima during the day. The concentration decreases rapidly as people leave the building and the ventilation is still on. Maximum concentrations are of the order of 500 ppm. Aerosol concentration shows the same periodic behaviour, althought less regularly, and often with rapid fluctuations. It is evident that the main factors controlling the aerosol concentration in this building are occupant movements, smoking (less so) and outdoor aerosol concentration.

The correlation coefficient of CO_2 and aerosol concentrations is 0.94, calculated from the data in Fig. 1a. This rather good correlation should not obscure the fact that the rapid and large fluctuations of the aerosol concentration make its applicability to ventilation control questionable. However, in spaces where smoking is the dominant source of indoor aerosols, aerosol soncentration may well reflect the ventilation need and hence the use of an aerosol monitor could be justified.

The radon concentration also displays the same periodic behaviour, but in this case the source term (exhalation from the soil) is constant and the concentration depends almost solely on the ventilation rate. The concentration increases to (or close to) an equilibrium level during nights and weekends, and decreases rapidly in the mornings when the ventilation is turned on. As in the case of CO_2, this periodic behaviour can be modelled adequately by the well known first order differential equation (see refs. 4,5,9,11,18,22). This model can also be used inversely to determine the ventilation rate from the radon concentration. This is indicated in Fig. 2., where the slope of the radon "decay" curve on a log-normal scale gives an estimate of the ventilation rate.

Several measurements in the high-school building revealed similar daily concentration patterns as in Figs. 1a-b. (longest measuring periods were 40 days). The use of this building is heavier than that of the university. This is reflected in the somewhat higher aerosol and CO_2 concentrations and especially in the steeper and higher concentration peaks. The daily maxima of CO_2 concentration were about 800 ppm. The use of return air filtration did not remove the effect of a strong indoor aerosol source. Simultaneous measurements of aerosol concentrations in the exhaust air and in one of the class rooms showed that local concentrations can be considerably (up to three times) higher than the average concentration in the exhaust air. It should also be noted that although these two concentrations varied in phase, the higher class room concentrations may well give a better estimate of the daily exposure of the students.

Additional measurements of the aerosol concentration in the class room were made using an optical particle counter (Royco 218). Results of a two weeks measuring period revealed that the concentrations of fine and coarse aerosols (>0.7 and >2 μm, respectively) correlate well with each other. Both of these also show a good correlation with the output of the electrical aerosol monitor.

One potential application of the monitoring of indoor pollutant concentrations is the control of ventilation by demand. Earlier studies have focused on CO_2-controlled ventilation (7,8,13,19,20,23). These have shown that considerable energy savings can be achieved, if the CO_2 concentration is used as an indicator of building occupancy and hence of the ventilation need. In this project, a case study of CO_2 -controlled ventilation was conducted in the university building.

Figure 3. shows the CO_2 concentration and the control voltage of the exhaust fan during the experiment. The fans were controlled by the indoor CO_2 concentration using a P-controller and frequency converters. If we assume a linear relationship between the fan control voltage and the total energy consumption of the ventilation system, the daily energy savings can be estimated from Figure 3. These vary between 13 and 20 percent in this experiment.

The radon concentrations did not rise significantly during the experiment, but a slower morning decrease of the concentration was observed. The peak concentrations of CO_2 remained also unchanged, but this was caused by the set values of the converter, which allowed the maximum fan speed to be reached. From this and earlier experiments one can conclude that the CO_2 -controlled ventilation works and may give a good economical result. Its effect on indoor air quality is, however, a complicated problem. Although in our experiment no significant changes in the air quality were observed, this result cannot be generalized, since the effect of different ventilation systems on most indoor pollutants is largely unknown.

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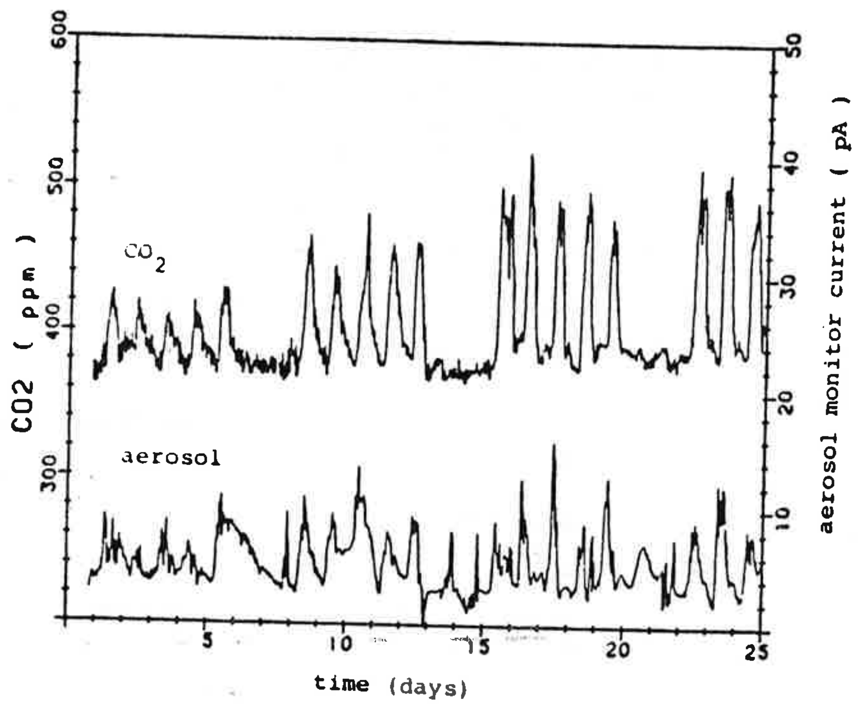

Figure 1a. Aerosol (below) and CO_2 (above) concentrations in the exhaust air of the university building during a 25 days measuring period in late August and September, 1982.

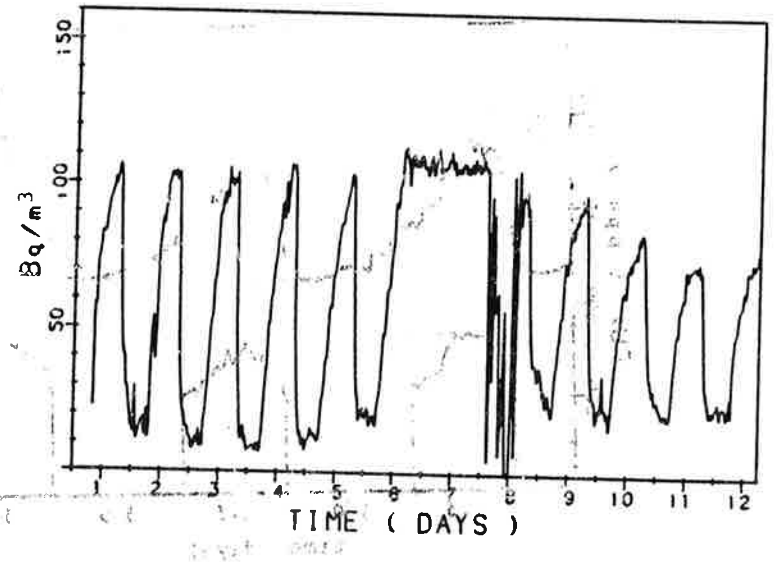

Figure 1b. Radon concentration in the exhaust air of the university builing during 12 days in late August and early September, 1982.

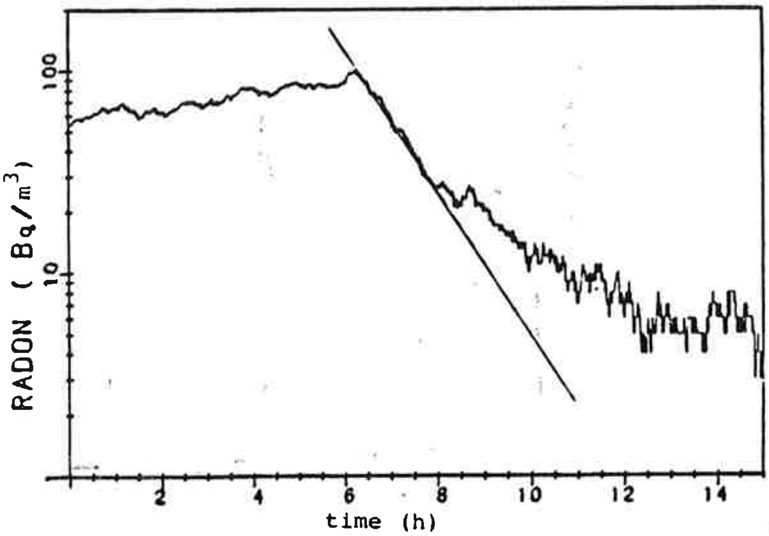

Figure 2. Estimation of the ventilation rate from the radon concentration using the slope of the morning "decay" curve (0.8 per hour in this case).

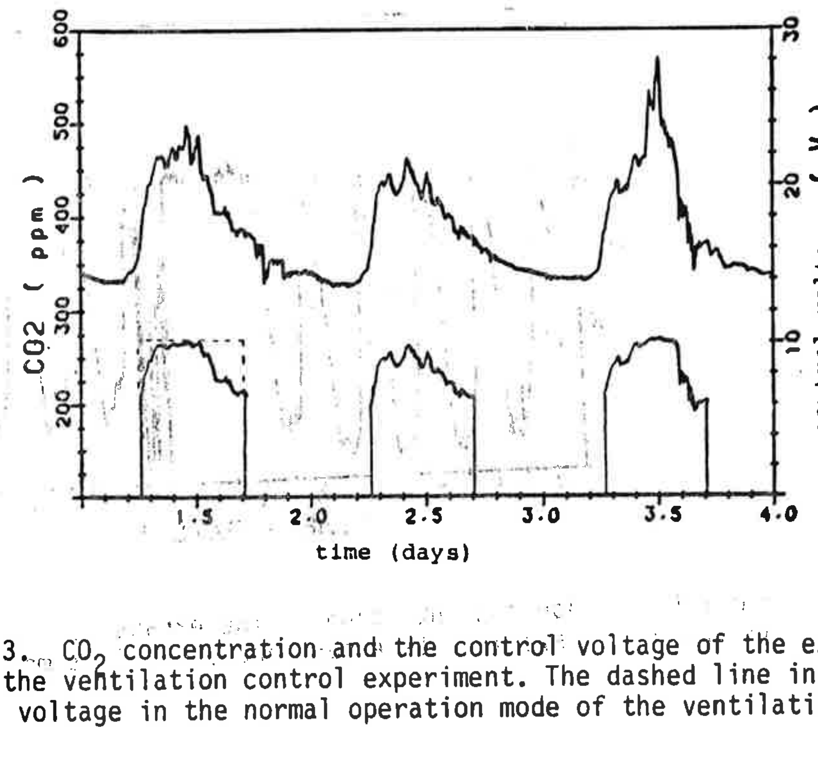

Figure 3. CO_2 concentration and the control voltage of the exhaust fan during the ventilation control experiment. The dashed line indicates the control voltage in the normal operation mode of the ventilation system.