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MODELLING THE INFLUENCE OF OUTDOOR POLLUTANTS ON THE INDOOR AIR QUALITY IN BUILDINGS WITH AIRFLOW RATE CONTROL

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SYNOPSIS

Low emitting building materials have contributed to the reduction of indoor air contaminants, and in many countries gas ranges and gas cookers are rarely used. As a result, in buildings located in urban environments, a considerable part of the contaminants in the indoor air may originate from the outdoor air.

In urban areas buildings are exposed to high concentrations of a large number of contaminants, especially during traffic peak hours. Often, the air intakes are located on the facades, and if there are no filters, the supply air will have the same content of contaminants as the outdoor air adjacent to the buildings. Where if possible, it is advantageous to place the air intakes on the roofs of the buildings (1). The higher the air intakes are placed, the better is the air quality in most cases.

To avoid exposure to high concentrations indoors due to concentration peaks of contaminants in the outdoor air, it is possible to decrease the airflow rate temporarily (2). This could be done by monitoring the concentration of carbon monoxide (CO) adjacent to the air intake. When the outdoor concentration of CO exceeds a preset limit, the fans are simply switched off, or the speed of the fans are decreased to a more suitable level.

LIST OF SYMBOLS

$\dot{V}_{source}$	internal source strength	cm^3/s
$\dot{V}_{sink}$	internal sink effect	cm^3/s
$\dot{V}$	airflow rate	m^3/s
V	volume	m^3
Δt	timestep	s
t	time	s
C_O	outdoor concentration	ppm
C_I^n	indoor concentration at current timestep	ppm
C_I^{n+1}	indoor concentration at next timestep	ppm
C_S	supply air concentration	ppm
C_E	exhaust air concentration	ppm

1 INTRODUCTION

The discussion about the VOC emission from building materials has led to more low emitting materials being used. For many buildings in urban environments this means that the main part of contaminants in the indoor air originates from the outdoor air. However, this is not always

true, for example, office buildings have many such sources indoors, like printers, copy-machines, etc.

During traffic peak hours the outdoor concentrations of contaminants are especially high. If the outdoor air flow is reduced at these times, the result will be lower concentrations of contaminants in the indoor air. This can be achieved by monitoring the concentration of CO in the outdoor air adjacent to the air intake and defining at what concentration level the air flow should be reduced.

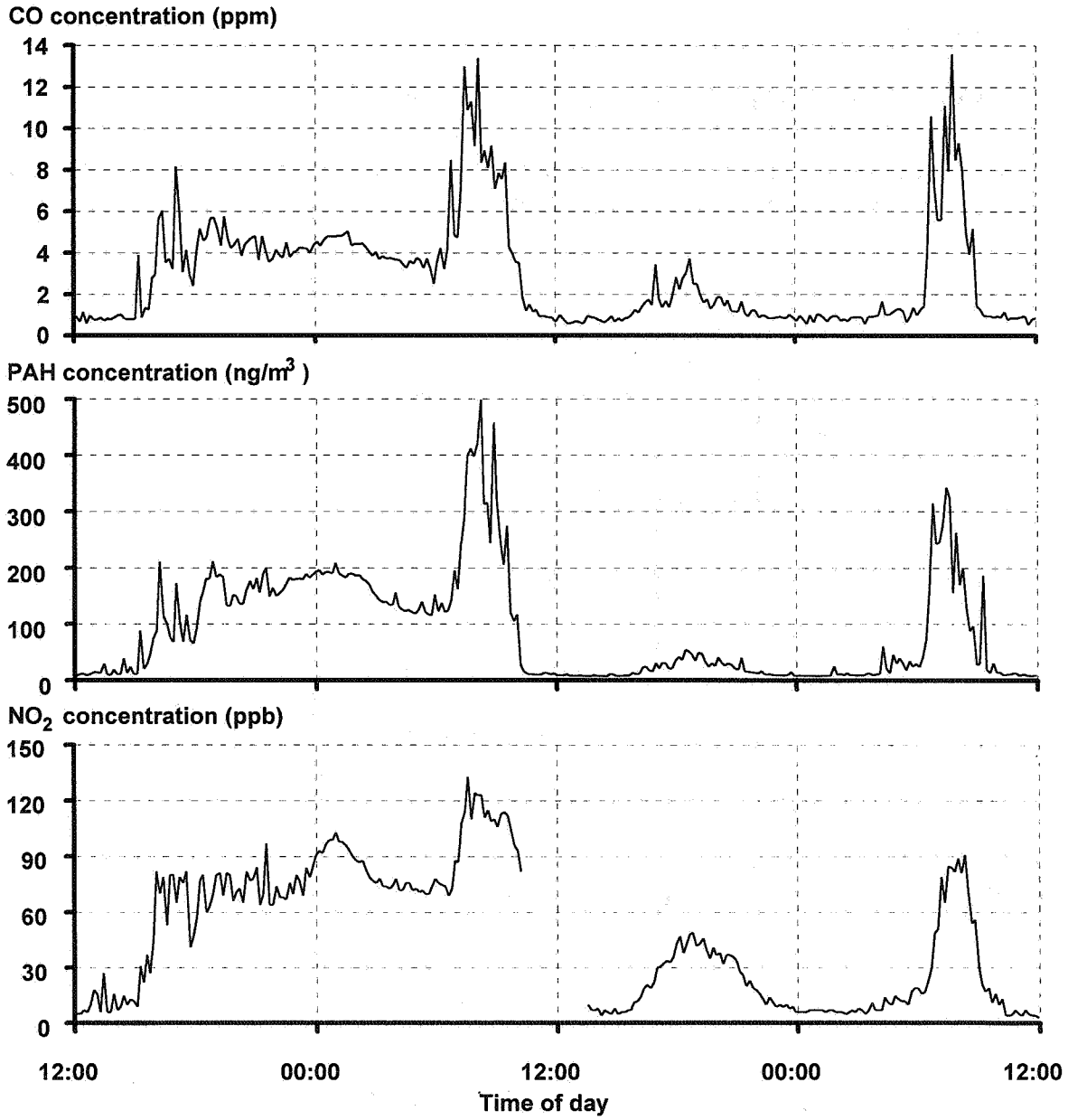

Figure 1 Outdoor concentrations for CO, PAH, and NO_2 over a period of 48 hours measured outside a building specially designed for people with allergy problems in a suburb of Stockholm.

CO is a suitable gas for indicating the amount of traffic related contaminants, and unless the occupants smoke, there are usually no sources indoors of CO. Figure 1 shows an example when the concentrations of carbon monoxide (CO), particulate polycyclic aromatic hydrocarbons (PAH), and nitrogen dioxide (NO_2) in the outdoor air were measured at the same time with three different measuring instruments. The studied compounds show a variation of similar pattern which is often the case for traffic related contaminants in urban environments (3).

2 METHODS

2.1 A model for calculation of indoor concentrations

With knowledge of the concentration of contaminants in the outdoor air and the air change rate in the building, the concentration indoors can be calculated (4-7).

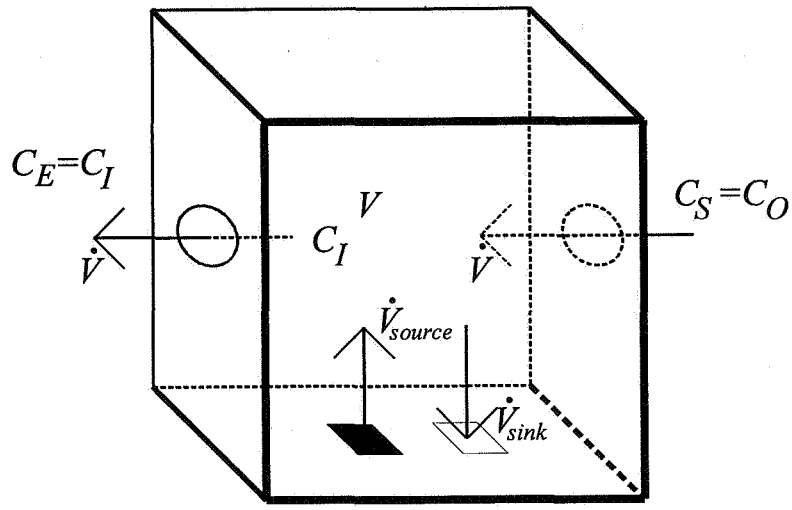

Figure 2 A ventilated room where the air is assumed to be well mixed.

Using the symbols in Figure 2, a balance equation can be established.

$$\dot{V} \cdot C_O + \dot{V}_{source} = \dot{V} \cdot C_I + \dot{V}_{sink} + V \cdot \frac{dC_I}{dt} \qquad (1)$$

Equation (1) is valid under the assumption that the air is well mixed. In practice this is not completely true, but the deviation is often rather small. Equation (2) is the analytical solution to equation (1) for constant outdoor concentration and constant airflow, source strength, and sink effect.

$$C_I(t) = C_O + \frac{\dot{V}_{source} - \dot{V}_{sink}}{\dot{V}} + \left(C_I(0) - \frac{\dot{V}_{source} - \dot{V}_{sink}}{\dot{V}} - C_O \right) \cdot e^{-\frac{\dot{V}}{V} \cdot t} \quad (2)$$

where:
$C_I(0) = C_I(t = 0)$

Equation (2) can be used to calculate the indoor concentration when the mentioned parameters are constant. The numerical solution, equation (3), obtained by the Euler method enables a variation of the parameters when calculating the indoor air concentration.

$$C_I^{n+1} = \frac{\dot{V}_{source} - \dot{V}_{sink} + \dot{V} \cdot \left(C_O - C_I^n \right)}{V} \cdot \Delta t + C_I^n \quad (3)$$

The measurements, presented in figure 3, were carried out with continuous monitoring by a Brüel & Kjær 1302 instrument. The measurements were made inside and outside a residential building in a suburb of Gothenburg. An air change rate of 0.5 h^{-1} was measured in the apartment studied.

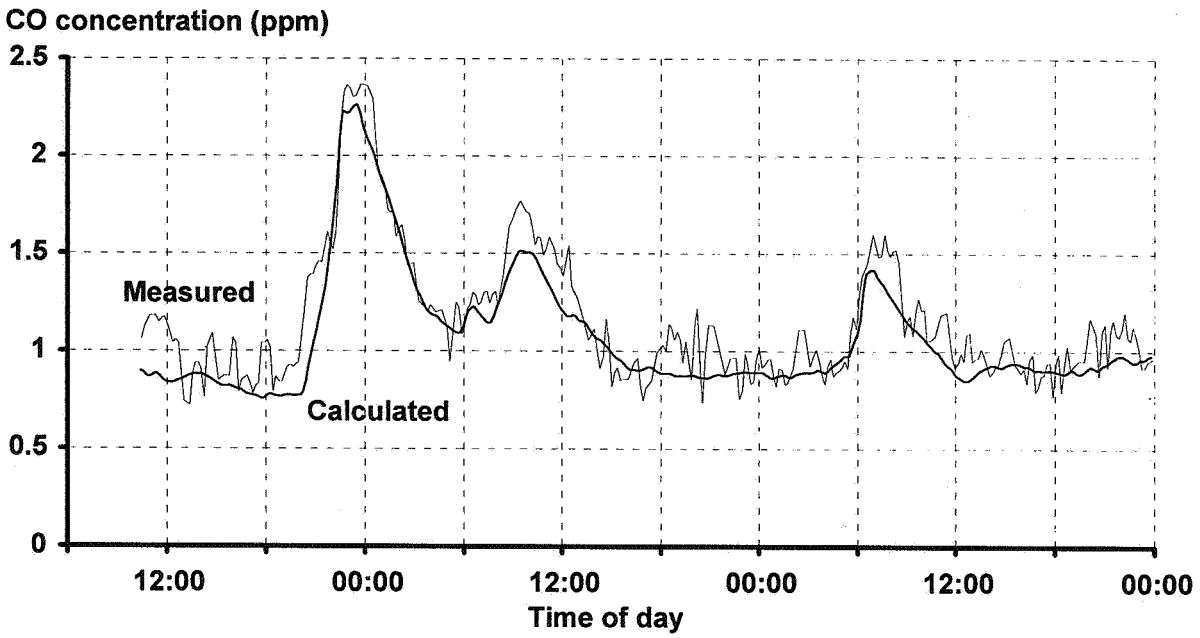

Figure 3 Concentration of carbon monoxide indoors in a residential building, measured values and values calculated with equation (3).

The measurement data on the outdoor concentration of CO was used in equation (3) to achieve the calculated indoor concentration in figure 3. The correlation coefficient is 0.91 between the measured and the calculated concentrations. The accuracy of the calculated

concentration is influenced by the length of the timestep and the accuracy of the measured air change rate used as input data to equation (3).

2.2 Dynamic modelling at variable air change rate

The air change rate in, for instance, residential buildings is typically 0.5 h^{-1}, whereas in office buildings the air change rate is usually 1.0 h^{-1} or higher. When the fans are turned off in a building with exhaust or balanced ventilation, the air change rate will not be reduced to zero, but more likely to about 0.1 h^{-1}, which is used in the example below.

One type of modelling is done by reducing the air change rate from 0.5 h^{-1} or 1.0 h^{-1} to 0.1 h^{-1} in equation (3) when the outdoor concentration of CO exceeds a specified limit. To do this, only monitoring of the outdoor concentration is needed.

Another type of modelling requires that both the outdoor and the indoor concentration of CO are monitored and compared. This helps to decrease the indoor concentration faster after a peak in the outdoor concentration. The indoor concentration can be higher than the outdoor concentration even if the outdoor concentration exceeds the specified limit, and in such cases the fanspeed should not be reduced. This happens when the outdoor concentration has been exceeding the limit substantially for a long time and then decreases rapidly.

3 RESULTS

To illustrate the effect of airflow rate control, measurement data for the CO concentration in the outdoor air during 24 hours is used, see figure 4. The average concentration of CO in the outdoor air during these hours was 1.68 ppm. The air samples of the outdoor air were taken on the balcony of an apartment in a building specially designed for people with allergy problems. The building is situated in a suburb of Stockholm.

In figure 4 the calculated indoor CO concentration is also shown both for constant and controlled air change rates. The calculated average concentration of CO for the indoor air indicates that the calculated concentrations in figure 4 are correct, when the air change rate is constant. The calculated average concentration indoors during the 24 hours in question is 1.65 ppm, with an air change rate of 0.5 h^{-1}. When the air change rate is kept constant at 1.0 h^{-1}, the calculated concentration indoors is 1.69 ppm. In reality, the average indoor concentrations should be the same as the outdoor concentration, but the calculated values show good agreement.

In table 1, for an air change rate of 0.5 h^{-1}, and in table 2, for an air change rate of 1.0 h^{-1}, the average CO concentration in the indoor air can be seen with different specified outdoor concentration limits, and single and double sensor monitoring.
The maximum increase of carbon dioxide (CO_2) during the periods with decreased air change rate is also given in tables 1 and 2. CO_2 is often used as an indicator of indoor air quality (8)

and is used here as an example of a contaminant emitted from a source indoors. During periods with reduced air change rate, the amount of contaminants entering with the supply air will decrease, but at the same time the concentrations of contaminants originating from sources indoors will increase. The source strength of CO_2 is set to 18 l/h, which represents a person at sedentary activity, and the space is given a volume of 36 m^3. Assuming an outdoor concentration of CO_2 at 400 ppm this gives an equilibrium concentration of 1400 ppm when the air change rate is 0.5 h^{-1}, and for an air change rate of 1.0 h^{-1} the equilibrium concentration is 900 ppm.

Table 1 The average CO concentration and the maximum increase in CO_2 concentration over 24 hours with an 18 l/h CO_2 source strength and a volume of 36 m^3. The different concentration limits determine when the air change rate is switched from 0.5 h^{-1} to 0.1 h^{-1} and vice versa.

CO concentration limit (ppm)	Average CO concentration (ppm)	Decrease in CO concentration	Maximum increase in CO_2 concentration (ppm)
1.0	1.10	33 %	1732
1.5	1.15	30 %	1028
2.0	1.19	28 %	850
2.5	1.23	25 %	728
3.0	1.25	24 %	727
1.0*	1.07	35 %	1354
1.5*	1.14	31 %	997
2.0*	1.19	28 %	850

* double sensor monitoring, i.e. monitoring of both indoor and outdoor concentration

Table 2 The average CO concentration and the maximum increase in CO_2 concentration over 24 hours with a 18 l/h CO_2 source strength and a volume of 36 m^3. The different concentration limits determine when the air change rate is switched from 1.0 h^{-1} to 0.1 h^{-1} and vice versa.

CO concentration limit (ppm)	Average CO concentration (ppm)	Decrease in CO concentration	Maximum increase in CO_2 concentration (ppm)
1.0	1.04	38 %	1798
1.5	1.12	34 %	1141
2.0	1.17	31 %	939
2.5	1.22	28 %	790
3.0	1.24	27 %	790
1.0*	1.01	40 %	1395
1.5*	1.12	34 %	1096
2.0*	1.17	31 %	939

* double sensor monitoring, i.e. monitoring of both indoor and outdoor concentration

The higher the maximum increase in CO_2 concentration, the lower the CO concentration limit is, since the timeperiod with reduced air change rate will be longer. The increase in CO_2 may, in this case, be a minor problem when the concentration peaks are one to two hours long.

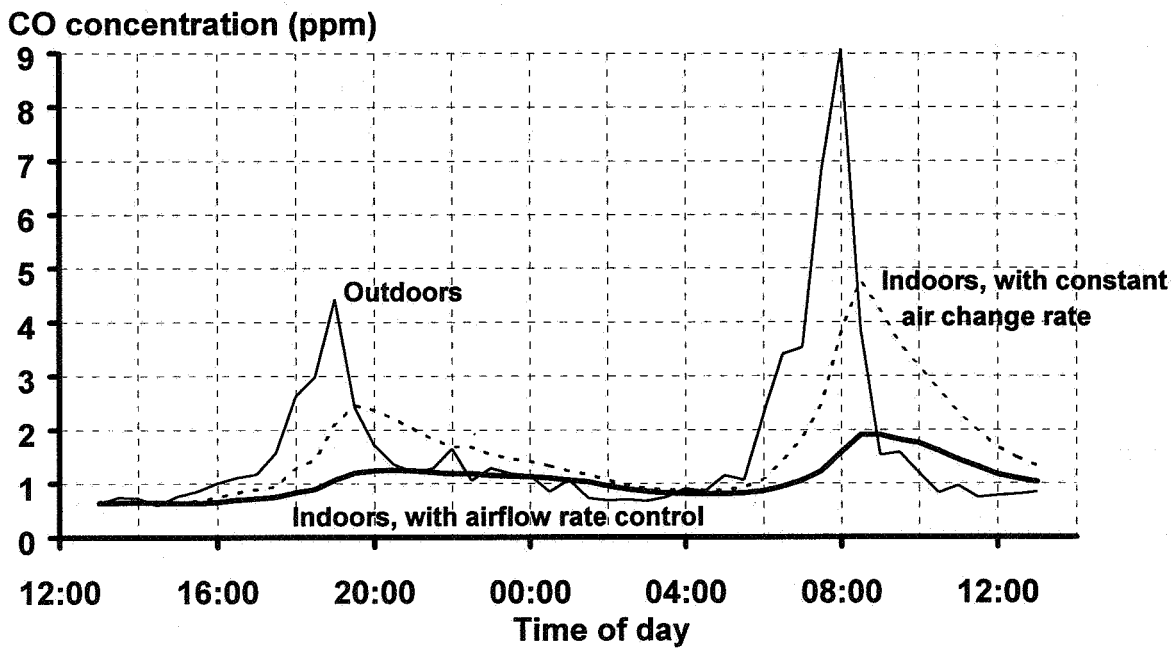

Figure 4 The carbon monoxide concentrations over 24 hours. The outdoor concentration was measured and the indoor concentration was calculated with equation (3) using an air change rate of 0.5 h^{-1}. The indoor concentration with airflow rate control, the thick line, was obtained with a CO limit of 1 ppm and double sensor monitoring.

4 DISCUSSION AND CONCLUSIONS

A tendency can be seen regarding single or double sensor monitoring, i.e. the effect of double sensor monitoring is more evident when the concentration limit for CO in the outdoor air is set low. As can be seen from table 1, the average CO concentration will, in the case of 1 ppm limit, an air change rate of 0.5 h^{-1}, and double sensor monitoring be 35 % less than the average concentration with constant air change rate. In the case of the specified limit being 1 ppm, however, it seems unrealistic regarding the high concentration of CO_2, or concentrations of other contaminants originating from indoor sources.

When the air change rate is 0.5 h^{-1} and the concentration limit is 1 ppm, the maximum CO_2 concentration is higher than 3000 ppm in the example studied. The concentration will be even higher if the time of high outdoor CO concentration is longer. The longest time above 1 ppm is approximately 4 hours in that example but, for instance, during inversion the CO concentration can be higher than 1 ppm for more than 24 hours.

For the air change rate 0.5 h^{-1}, the average CO_2 concentration over the 24 hours shown in figure 4 is 2010 ppm and in cases when the air change rate is 1.0 h^{-1} the average CO_2 concentration will be 1350 ppm, which might be more acceptable. Whether the contaminants from indoor sources or the contaminants originating from outdoors are most important from a health point of view may vary from case to case, the example presented should be regarded as a demonstration of the method of air quality controlled airflow reduction.

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