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SIMULATION OF CO_2 CONCENTRATION FOR DETERMINING AIR CHANGE RATE

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ABSTRACT

The CO_2-concentration of room air provides an indicator for the air quality in spaces without smokers. A classroom with mechanical ventilation has been evaluated for eighteen months using such a technique. These measurements were made within the framework of the research project Gumpenwiesen. A model to calculate the CO_2 concentration as a function of occupancy, activity level of the occupants and air change rate was developed. It was validated using the measurement data. The daily profile of CO_2 concentration and the duration of time when the limit of 1500ppm is exceeded can be predicted. The prediction can be made for any time step and any room. The model is useful as a planning tool for fixing the necessary air change rates for occupied rooms.

1. MINIMUM OUTSIDE AIR SUPPLY RATE

The CO_2-Concentration is a measure of room air quality. The maximum level of CO_2-concentration in room air for hygienic reasons (non smoking area) is given by Prof. Wanner (ETH Zurich) for classrooms as 1500 ppm (Ref. 1). The minimum air supply rate per person can be calculated by using the following formula, where the CO_2-production per person is dependent on the activity of the person.

$$V = \frac{C}{Kzul - Ka} 10^3 \qquad (1)$$

V= Minimum outside air supply rate in m3/h person
C= CO_2-production in l/(h person)
Kzul= max. allowed CO_2-concentration in the room air (ppm)
Ka= CO_2-Concentration in the outside air (300 ppm)

The calculated minimum outside air rate for rooms, where smoking is not allowed, are given in Table 1 for two CO_2-concentration levels.

Activity	CO_2-Production 1/h person	Outside Air Supply Rate for CO_2 max. 1500 ppm m3/h person	max. 1200 ppm m3/h person
resting	12	10.0	13.3
sitting	15	12.5	16.7
light work	23	20.2	25.6
medium work	30	25.0	33.3
hard work	>30	>25.0	>33.3

Table 1: Minimum outside air supply rate for non smoking rooms (Ref. 2)

2. INSTANTANEOUS CO_2-CONCENTRATION IN A ROOM

In rooms where incoming air is perfectly mixed with room air, the instantaneous CO_2-concentration in the room air can be calculated using the following formula:

$$Kt = Ka + (KO-Ka)\, e^{-nt} + \frac{Ctot\,(1 - e^{-nt})}{n\,I}\, 10^6 \qquad (2)$$

Kt= CO_2-Concentration in the room air at time t (ppm)
Ka= CO_2-Concentration in the outside air (300 ppm)
KO= CO_2-Concentration in the room air at time 0 (ppm)
Ctot= CO_2-production in the room (m3/h)
n= air change rate (1/h)
I= room air volume (m3)
t= time difference (h)

3. CO_2-VARIATION IN THE MEASUREMENT ROOM

In one of the classrooms of the measured building "Gumpenwiesen", the CO_2-concentration was monitored using a gas analyser during the 18-month measurement period. A typical profile for a day is shown in figure 1. The measured and calculated CO_2-concentrations can also be compared in this figure. The agreement between the two curves shows, that its possible to calculate the CO_2-concentration in the room air at any given time, if one knows the parameters on which it depends (perfect mixing provided):

- number of people
- length of occupancy
- CO_2-production per person (activity)
- air change rate (natural and mechanical ventilation)
- room volume

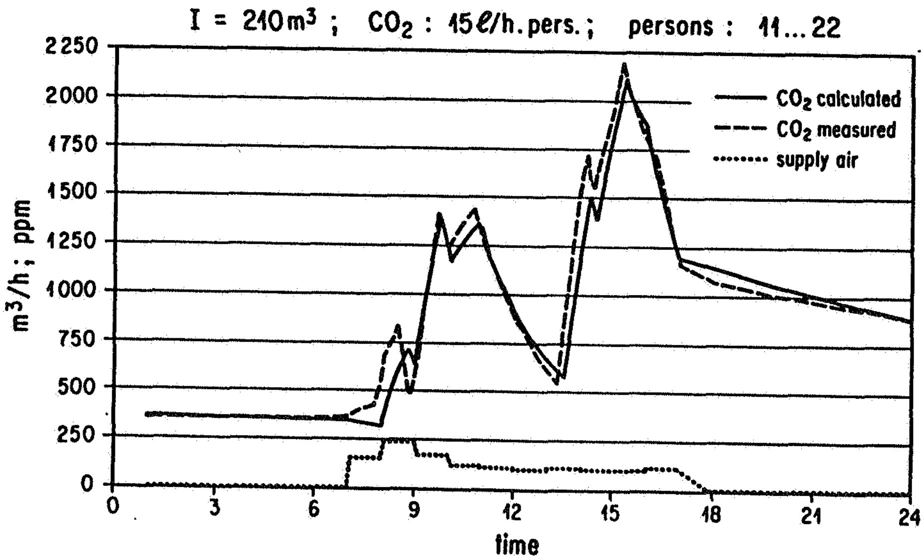

Figure 1: Comparison of measured and calculated CO_2-concentrations for the 13th May 1986.

The cumulative frequency distribution of the the hourly maximum CO_2-concentration in the measurement room is shown in figure 2. When the room air supply system was on, and more than one person was in the room, then the 1500 ppm maximum level was exceeded 30.7 % of the time. The outside air supply of 9 m3/h per person is too small (following table 1: 12.5 m3/h per person is required).

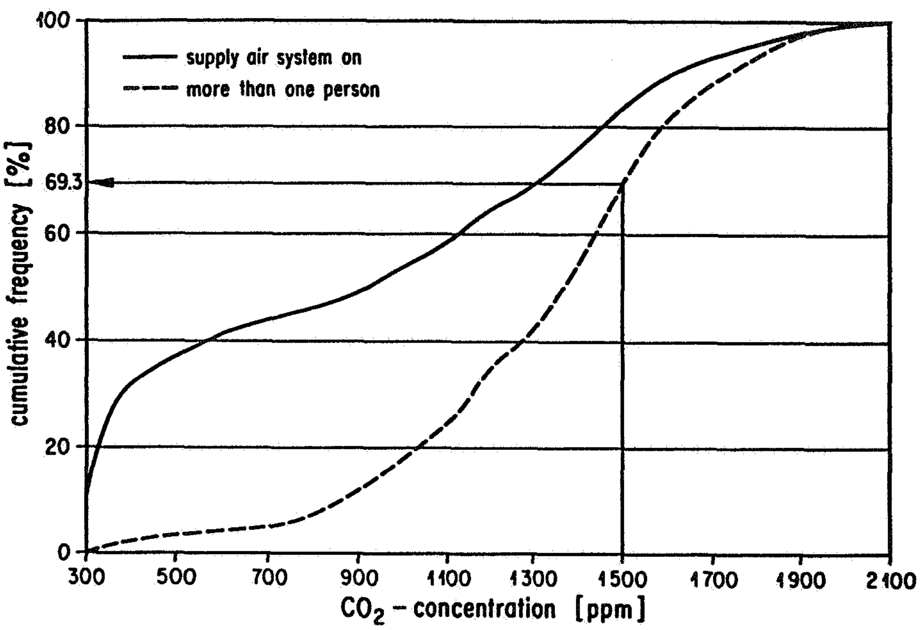

Figure 2: Cumulative frequency distribution of the the hourly maximum CO_2-concentration in the measurement room

The required conditions in the classroom are shown in figure 3 with the occupancy schedule for the room shown in figure 4. The maximum CO_2-concentration of 1500 ppm was never exceeded, if the fresh air intake was 11.2 m3/h person. Due to the breaks, the hourly average of fresh air intake needs not be as high as given in table 1.

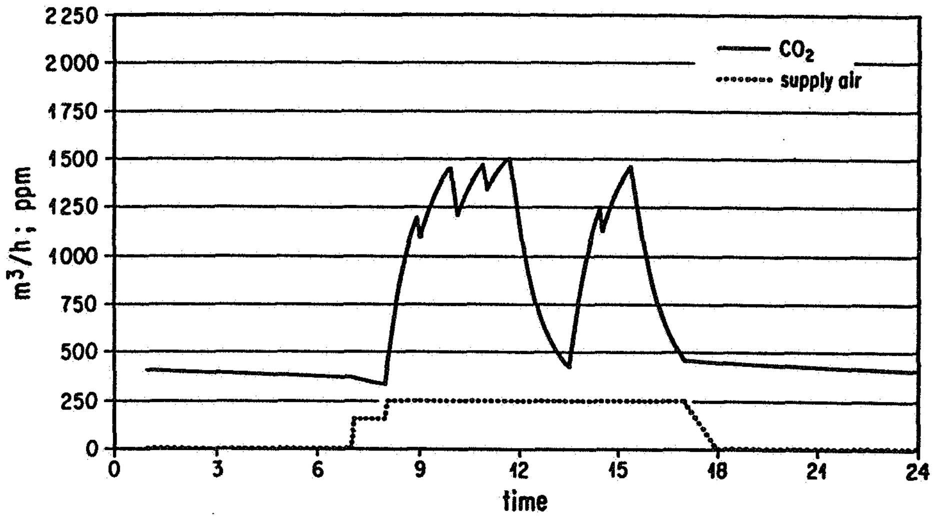

Figure 3: Calculated CO_2-concentration (outside air supply rate: 11.2 m3/h person)

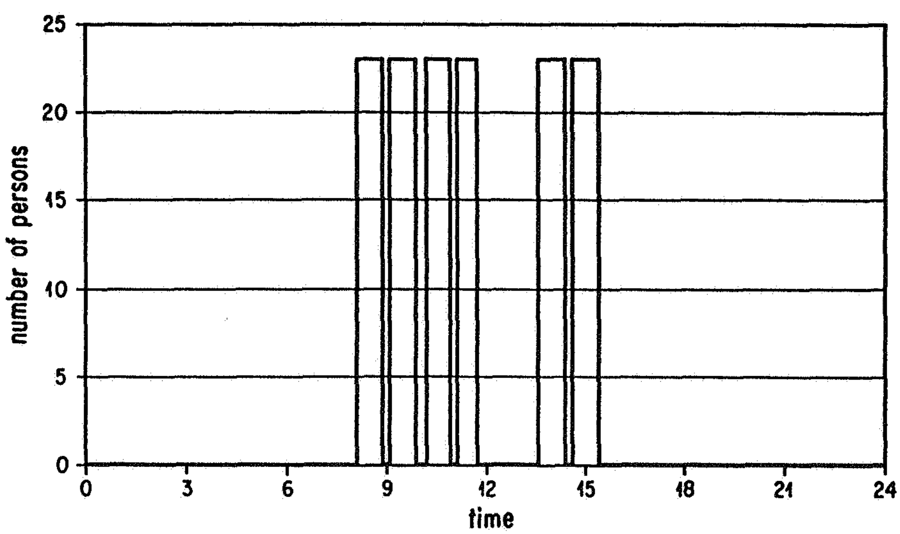

Figure 4: Occupation schedule for figure 3.

4. COMPUTER PROGRAM

The formula (2) was put into a spreadsheet program using a time step of six minutes. With this program it is possible to obtain a realistic view of the CO_2 variation quickly and easily. Especially in rooms where a large number of people is coming and going, the model can be used, to reduce the outside air supply rate.

The software is already used in Switzerland for different purposes.

CO2-CONCENTRATION IN ROOM AIR   Software by Th. Baumgartner

INPUT:		**Hints for the INPUT:**	
Room volume:	210 m3		
Outside air rate:	11.8 m3/h Pers	Schedule of persons:	
Numbers of persons:	22 Pers	0: occupied from:	8.00-17.00
Schedule of persons:	2	1: like 0 + rest from	12.00-14.00
		2: like 1 + each hour 6 Min. break	
Schedule of system:	2	Schedule of the vent. system:	
		0: running from:	8.00-17.00
Calculated values (outside air):		1: like 0 + aditional:	7.00- 8.00
Supply air volume:	259.6 m3/h	2: like 0 + aditional:	17.00-18.00
Air change rate:	1.24 1/h		
		Results: (during occupation)	
Other parameters:		CO2-Limit:	1500 ppm
CO2-production:	15 1/h Pers	CO2-Room> CO2-Limit:	0 h
Max. CO2-value:	1500 ppm	% of occupation:	0 %
CO2 of outside air:	300 ppm	Max. CO2-concentr.:	1495 ppm
Natural ventilation:	.06 1/h	Aver. CO2-concentr.:	1245 ppm

Table 2: Sample input of the spreadsheet program

5. CONCLUSION

In this paper a model was presented to calculate the variation with time of CO_2-concentration in perfectly mixed room air, provided that occupancy, activity level, air change rate and room volume are known. The results of the model were compared with measurements in a mechanically ventilated classroom. The model provides a tool to determine minimum outside air supply rates for rooms with a significantly fluctuating occupancy. This air supply rate is smaller than the one calculated with standard methods. In the future the model may as well be used for other pollutants where the production rate varies rapidly with time.

6. REFERENCES

(1) Wanner H.U., Fecker I, Personal Communication
(2) Handbuch der Klimatechnik, Bd.I, p. 95,
C.F. Müller Verlag, Karlsruhe 1986