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SIMULATION OF CO₂ CONCENTRATION FOR DETERMINING AIR CHANGE RATE

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ABSTRACT

The CO₂-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 CO₂-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 CO₂ concentration and the duration of time when the limit of 1500 ppm 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 CO₂-Concentration is a measure of room air quality. The maximum level of CO₂-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 CO₂-production per person is dependent on the activity of the person.

\[ V = \frac{C}{K_{zul} - K_a} \times 10^3 \]  

(1)

\( V = \) Minimum outside air supply rate in m³/h person  
\( C = \) CO₂-production in l/(h person)  
\( K_{zul} = \) max. allowed CO₂-concentration in the room air (ppm)  
\( K_a = \) CO₂-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 CO₂-concentration levels.

<table>
<thead>
<tr>
<th>Activity</th>
<th>CO₂-Production 1/h person</th>
<th>Outside Air Supply Rate for CO₂ max. 1500 ppm m³/h person</th>
<th>Outside Air Supply Rate for CO₂ max. 1200 ppm m³/h person</th>
</tr>
</thead>
<tbody>
<tr>
<td>resting</td>
<td>12</td>
<td>10.0</td>
<td>13.3</td>
</tr>
<tr>
<td>sitting</td>
<td>15</td>
<td>12.5</td>
<td>16.7</td>
</tr>
<tr>
<td>light work</td>
<td>23</td>
<td>20.2</td>
<td>25.6</td>
</tr>
<tr>
<td>medium work</td>
<td>30</td>
<td>25.0</td>
<td>33.3</td>
</tr>
<tr>
<td>hard work</td>
<td>&gt;30</td>
<td>&gt;25.0</td>
<td>&gt;33.3</td>
</tr>
</tbody>
</table>

Table 1: Minimum outside air supply rate for non smoking rooms (Ref. 2)
2. **INSTANTANEOUS CO₂-CONCENTRATION IN A ROOM**

In rooms where incoming air is perfectly mixed with room air, the instantaneous CO₂-concentration in the room air can be calculated using the following formula:

\[
K_t = K_a + (K_0 - K_a) e^{-\frac{nt}{n l}} + \frac{C_{tot} (1 - e^{-nt})}{10^6}
\]

- \(K_t\) = CO₂-concentration in the room air at time \(t\) (ppm)
- \(K_a\) = CO₂-concentration in the outside air (300 ppm)
- \(K_0\) = CO₂-concentration in the room air at time 0 (ppm)
- \(C_{tot}\) = CO₂-production in the room (m³/h)
- \(n\) = air change rate (1/h)
- \(I\) = room air volume (m³)
- \(t\) = time difference (h)

3. **CO₂-VARIATION IN THE MEASUREMENT ROOM**

In one of the classrooms of the measured building "Gumpenwiesen", the CO₂-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 CO₂-concentrations can also be compared in this figure. The agreement between the two curves shows, that its possible to calculate the CO₂-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
- CO₂-production per person (activity)
- air change rate (natural and mechanical ventilation)
- room volume

\[
I = 240 \text{ m}^3; \quad \text{CO}_2: 45 \ell/h \cdot \text{pers.}; \quad \text{persons: 41...22}
\]

![Figure 1: Comparison of measured and calculated CO₂-concentrations for the 13th May 1986.](image-url)
The cumulative frequency distribution of the hourly maximum CO₂-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 hourly maximum CO₂-concentration in the measurement room](image)

**Figure 2:** Cumulative frequency distribution of the hourly maximum CO₂-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 CO₂ 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 CO₂-concentration (outside air supply rate: 11.2 m³/h person)](image)

![Figure 4: Occupation schedule for figure 3.](image)
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 CO₂ 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.

<table>
<thead>
<tr>
<th>CO₂-CONCENTRATION IN ROOM AIR</th>
<th>Software by Th. Baumgartner</th>
</tr>
</thead>
<tbody>
<tr>
<td>INPUT:</td>
<td>Hints for the INPUT:</td>
</tr>
<tr>
<td>Room volume: 210 m³</td>
<td>Schedule of persons:</td>
</tr>
<tr>
<td>Outside air rate: 11.8 m³/h Pers</td>
<td>0: occupied from: 8.00-17.00</td>
</tr>
<tr>
<td>Numbers of persons: 22 Pers</td>
<td>1: like 0 + rest from 12.00-14.00</td>
</tr>
<tr>
<td>Schedule of persons: 2</td>
<td>2: like 1 + each hour 6 Min. break</td>
</tr>
<tr>
<td>Schedule of system: 2</td>
<td>Schedule of the vent. system:</td>
</tr>
<tr>
<td></td>
<td>0: running from: 8.00-17.00</td>
</tr>
<tr>
<td></td>
<td>1: like 0 + aditional: 7.00- 8.00</td>
</tr>
<tr>
<td></td>
<td>2: like 0 + aditional: 17.00-18.00</td>
</tr>
<tr>
<td>Calculated values (outside air):</td>
<td>Results: (during occupation)</td>
</tr>
<tr>
<td>Supply air volume: 259.6 m³/h</td>
<td>CO₂-Limit: 1500 ppm</td>
</tr>
<tr>
<td>Air change rate: 1.24 l/h</td>
<td>CO₂-Room+ CO₂-Limit: 0 h</td>
</tr>
<tr>
<td>Other parameters:</td>
<td>% of occupation: 0 %</td>
</tr>
<tr>
<td>CO₂-production: 15 l/h Pers</td>
<td>Max. CO₂-concetr.: 1495 ppm</td>
</tr>
<tr>
<td>Max. CO₂-value: 1500 ppm</td>
<td>Aver. CO₂-concetr.: 1245 ppm</td>
</tr>
<tr>
<td>CO₂ of outside air: 300 ppm</td>
<td></td>
</tr>
<tr>
<td>Natural ventilation: .05 l/h</td>
<td></td>
</tr>
</tbody>
</table>

**Table 2: Sample input of the spreadsheet program**

5. **CONCLUSION**

In this paper a model was presented to calculate the variation with time of CO₂-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 Klima technik, Bd.I, p. 95,
    C.F. Müller Verlag, Karlsruhe 1986