CONCENTRATION OF CARBON DIOXIDE MEASURED IN UNIVERSITY CLASSROOMS

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Abstract: Low concentration of carbon dioxide in the atmospheric air is considered to be a normal condition. Excessive concentration of CO\textsubscript{2} in the air may have negative influence on human’s health. Permissible level of carbon dioxide concentration in didactic facilities as well as in all other closed spaces is 1000 ppm (WHO, 2000a), as devised by the WHO Regional Office for Europe. Two varieties of measurements were taken.

1. The level of CO\textsubscript{2} concentration was examined in classrooms in which different types of ventilation systems are used.

2. The efficiency of the ventilation system was measured on the basis of the parameters of the inside air; particular attention was paid to the level of CO\textsubscript{2} concentration.

Key words: ventilation, CO\textsubscript{2} concentration.

1. Introduction

Carbon dioxide is a product of fuel combustion as well as of plant and animal metabolism. In classrooms its production is triggered by the metabolism of the people who stay in them. It is a gas that is heavier than air; as a result it accumulates in the lower parts of the rooms, in cellars, in drainage catch pits, as well as in the lowest parts of mines. Carbon dioxide is not poisonous, but excessive concentration of CO\textsubscript{2} in the air may influence one’s health in a negative way (The Engineering ToolBox, 2005).

Breathing in air that has a low concentration of carbon dioxide (according to the author’s previous research this value equals ca. 1500 ppm; other sources estimate it at 5%), increases its partial pressure in blood (hypercapnia), which results in having difficulty breathing, experiencing anxiety, stimulating the respiratory center and increasing the incidence of breathing movements. When the concentration is higher (roughly 2000 ppm), it may cause headaches and vertigo, buzzing noise in the ears, perception disorders, tachycardia, excessive sweating, as well as congestion of conjunctiva. Although in the course of this research the level of carbon dioxide in classrooms did not exceed 2000 ppm, such a situation may occur in specific conditions.

The concentration of carbon dioxide in the atmospheric air is small and is estimated at 400 ppm. Such a concentration is considered normal.

In many countries, including Poland, the ventilation systems are controlled by carbon dioxide detectors. Nevertheless, there still are classrooms which do not have any kind of mechanical ventilation. This applies especially to classrooms, with both well- and ill-fitting windows, of many prestigious universities which hold classes in very old buildings.

In rooms with no mechanical ventilation exhausting gas and odour pollution rests on gravitational ventilation, often aided by some other kind of natural ventilation. The well-fitting windows coupled with faulty design or installation of gravitational exhaust ventilation may decrease the interior air parameters, which in extreme cases may pose a threat to people’s health, and sometimes life (Targowski, 1998). To work properly, gravitational ventilation must fulfil certain conditions, the most basic of which involves supplying fresh exterior air into the room.

The recommended parameters with regard to humidity and temperature that guarantee thermal comfort are as follows (directive, 2002; Directive, 2002/91/EC):

- temperature between 20 and 30°C;
- air velocity in places where people are present between 0.15 and 0.2 m/s (up to 0.6 m/s in summer);
- relative humidity between 40 and 80% (recommended temperature observed);
- average temperature of heat radiation in the room (tantamount to the temperature of the outside walls) lower by 2 – 3°C than air temperature.

Permissible levels of CO\textsubscript{2} concentration at places such as classrooms has been set at 1000 ppm (WHO, 2000a; ASHRAE Standard 62-1989), or 1500 ppm (DIN-1946-2). In Poland there are no regulations as to the permissible levels of carbon dioxide concentration in rooms meant for general use, as the basis for our research we assumed, therefore the standards established by WHO (2000a,
2. Research

The level of CO₂ concentration was examined in rooms where different types of ventilation systems were used. The measurements were taken in selected classrooms during the heating season. Research was conducted in four classrooms. All values were recorded during a 45-minute lecture period.

**Room A** is ventilated naturally by means of gravitational exhaust ventilation system, infiltration through window frames with a high coefficient of infiltration, and the door which leads from the room into a spacious hall. The perforated suspended ceiling in the classroom and the one in the hall constitute the same construction. For that reason, the air diffuses in the space between the suspended and the constructional ceiling both in the classroom and the hall. Natural ventilation operated all the time.

**Room B** is ventilated naturally by means of gravitational ventilation system, infiltration through new window frames fitted in 2007, and the door which leads from the room into a spacious hall. The suspended ceiling in the classroom and the one in the hall constitute the same construction. Air diffuses in the space between the suspended and the constructional ceiling both in the classroom and the hall. Natural ventilation operated all the time.

In **room C**, mechanical and gravitational ventilation systems are used; the room is also equipped with modern window frames. Mechanical ventilation is switched on depending on whether there is such a need. Air in the classroom during recess was done by leaving the door ajar. Mechanical ventilation was switched off during class.

**Room D** – mechanical and gravitational ventilation systems are used; the room is also equipped with modern window frames (heat transmission coefficient is low). Mechanical ventilation is switched on depending on whether there is such a need. At the time of the research, both during the class and during the break mechanical ventilation was on; during the break also the door remained ajar.

The efficiency of ventilation was also measured only on the basis of the interior air parameters with particular emphasis on carbon dioxide concentration. These measurements were taken in four classrooms, just like the ones of carbon dioxide concentration. Research was conducted in the following conditions:

- there were no students present (no source of CO₂),
- there were no classes in the selected rooms for a period of two days, i.e. absence of a large number of people in the classrooms,

- rooms were ventilated by means of available ventilation systems.

The measurements were also taken:

- before a class with a particular group of students took place (intentionally, the room was not properly aired depending on the teacher’s preference),
- during the class itself after 45 minutes have elapsed,
- after a ten-minute break for airing (rooms A and D were aired by opening the windows after all students had left).

Just like previous research, the experiment was conducted in four classrooms. Because rooms A and B have the same ventilation systems, the airing conditions in them were identical. Room E was included in the experiment because in it air exchange operated in a completely different manner.

In **room A** all students left the classroom during the break. In **room C** not all students left the classroom during the break. In **room D** all students left the classroom during the break.

**Room E** possesses gravitational ventilation. The room has no windows; there are only double-glassed windows with draughty wooden frames that overlook a roofed patio; the room also possesses skylights in the ceiling. Natural ventilation operates all the time. All students left the classroom during the break.

3. Results

3.1. Results of carbon dioxide concentration measurements

Research was conducted during lectures so as to ensure that the activity of the people inside the classrooms was comparable. Measurements were recorded at five minute intervals due to the imperfections of the measuring equipment. Each time the conditions in the classroom changed (opening the window or the door), it was reflected by the results of the measurements. Movement in the classroom had no influence on the obtained values.

Measurements were taken in all rooms at desk-level, i.e. ca. 0.75 m from the floor. The results are slightly higher than the ones measured at the height of the student’s head when he/she was writing.

The number of students in a classroom ranged from 47% to 54% (Table 1) of the planned maximum number.

<table>
<thead>
<tr>
<th>Room</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface area m²</td>
<td>72.62</td>
<td>72.62</td>
<td>140.36</td>
<td>138.63</td>
</tr>
<tr>
<td>Capacity m³</td>
<td>217.86</td>
<td>217.86</td>
<td>421.08</td>
<td>415.89</td>
</tr>
<tr>
<td>Minimum CO₂ concentration ppm</td>
<td>580</td>
<td>684</td>
<td>700</td>
<td>680</td>
</tr>
<tr>
<td>Average CO₂ concentration ppm</td>
<td>1059</td>
<td>1214</td>
<td>837</td>
<td>730</td>
</tr>
<tr>
<td>Maximum CO₂ concentration ppm</td>
<td>1505</td>
<td>1770</td>
<td>1020</td>
<td>965</td>
</tr>
<tr>
<td>Students present %</td>
<td>49</td>
<td>54</td>
<td>45</td>
<td>47</td>
</tr>
</tbody>
</table>
3.2. Results of the ventilation efficiency measurements

Measurements were taken in all rooms at the level of a desk, i.e. ca. 0.75 m from the floor. The results are slightly higher than the ones measured at the height of the student’s head when he/she was writing.

The number of students in a classroom ranged from 20% to 60% of the maximum number.

3.3. Discussion of carbon dioxide concentration measurements results

Maximum permissible concentration of carbon dioxide in classrooms is 1000 ppm. During research, initial CO$_2$ concentration ranged from 580 to 700 ppm (Tab. 1).

The distribution of carbon dioxide concentration during a 45-minute period is linear (Fig. 1). The value in a particular classroom depends on the number of students present and, perhaps most significantly, on the type of ventilation system installed.

![Graph showing carbon dioxide concentration in classrooms during a 45-minute class.]

The highest value (1770 ppm) was recorded in the classroom which possesses only gravitational ventilation and in which the old windows were replaced with new well-fitting ones (Tab. 1). During previous research, a series of measurements was recorded in the same classroom with the same number of students present and before new windows were fitted. The maximum CO$_2$ concentration after 45 minutes was 1368 ppm. At the time of the research, the level of concentration among students dropped after 35 minutes had elapsed; upon leaving the classroom after 45 minutes some students complained about having a headache. Students stayed for about 10 to 15 minutes in a room where CO$_2$ concentration exceeded 1500 ppm.

CO$_2$ concentration in a room with the same gravitational ventilation but with old windows was lower by 20%. The old type of window frames infiltrates the air from the outside into the room thus diluting any pollution.

People who stay in rooms where mechanical ventilation was not installed resort to opening the windows in order to air the classroom, even if the temperature outside is below 0°C. The lowest value of CO$_2$ concentration was recorded in the classroom where mechanical ventilation operates non-stop. In the classrooms which possess mechanical ventilation, infiltration through window frames practically does not exist.

After a two-day break from classes, the concentration of carbon dioxide in every classroom selected for research was similar and amounted to 500 ppm, i.e. almost the value observed in outside air.

3.4. Discussion of ventilation efficiency measurements results

The concentration of carbon dioxide in the rooms after a two-day period from the last class conducted there ranged from 474 ppm to 547 ppm (Tab. 2). Such a concentration is higher than that observed in outside air by 20 – 35%. After 45 minutes of class with 20% of the maximum number of students present, the CO$_2$ concentration amounted to 754 ppm in the room where the mechanical supply – exhaust ventilation operated all the time; and up to 1368 ppm in the room with gravitational ventilation (Fig. 2) and 60% of the maximum number of students present (Tab. 3).

<table>
<thead>
<tr>
<th>Room</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature °C</td>
<td>21.7</td>
<td>19.9</td>
<td>20.4</td>
<td>18.6</td>
</tr>
<tr>
<td>Humidity %</td>
<td>38</td>
<td>40.4</td>
<td>39.5</td>
<td>37.2</td>
</tr>
<tr>
<td>CO$_2$ concentration ppm</td>
<td>547</td>
<td>478</td>
<td>474</td>
<td>488</td>
</tr>
<tr>
<td>Students present %</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 2. CO$_2$ concentration after a two-day period from the last class in the room.

<table>
<thead>
<tr>
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<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature °C</td>
<td>22.9</td>
<td>21.7</td>
<td>21.0</td>
<td>20.0</td>
</tr>
<tr>
<td>Humidity %</td>
<td>37.3</td>
<td>35.1</td>
<td>31.0</td>
<td>47.0</td>
</tr>
<tr>
<td>CO$_2$ concentration ppm</td>
<td>1368</td>
<td>975</td>
<td>754</td>
<td>1274</td>
</tr>
<tr>
<td>Students present %</td>
<td>60</td>
<td>20</td>
<td>20</td>
<td>50</td>
</tr>
</tbody>
</table>

Table 3. CO$_2$ concentration after 45 minutes of class.

<table>
<thead>
<tr>
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<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature °C</td>
<td>21.1</td>
<td>21.7</td>
<td>20.7</td>
<td>20.1</td>
</tr>
<tr>
<td>Humidity %</td>
<td>28.4</td>
<td>35.3</td>
<td>30.5</td>
<td>47.8</td>
</tr>
<tr>
<td>CO$_2$ concentration ppm</td>
<td>672</td>
<td>933</td>
<td>616</td>
<td>1403</td>
</tr>
<tr>
<td>Students present %</td>
<td>0</td>
<td>10</td>
<td>10</td>
<td>50</td>
</tr>
</tbody>
</table>

Table 4. CO$_2$ concentration after a ten minute break.

After a ten minute break in the classroom where windows were open throughout the break and all students left the room, the concentration of carbon dioxide dropped considerably to 672 ppm (Fig. 2). In the room where the mechanical ventilation remained switched off and some of the students stayed in the room, the concentration of carbon dioxide reached 975 ppm (Tab. 4).

Temperature in the rooms ranged from 18.6°C to 22.9°C (Tab. 2, 3, 4). Temperature fluctuations did not have any significant influence on the difference in the density of air and carbon dioxide. Relative humidity ranged from 28.4% after a 10 minute airing period to 47% after 45 minutes of class had elapsed, during which students were writing a test (Tab. 4).
4. Summary

Bearing in mind the need of maintaining hygienic standards both at work and when studying, the significance of a proper ventilation system cannot be overestimated.

Although the type of ventilation is of utmost importance, the habits and needs of people staying in a room constitute the crucial factor when mechanical ventilation is not switched on automatically.

The lowest CO₂ concentration was recorded in classrooms which possess mechanical ventilation. Nevertheless, even with mechanical ventilation operating non-stop, the level of CO₂ concentration reaches 1000 ppm with 50% of the students present.

When fitting in new windows in the classrooms and another rooms (Targowski, 1998) is not accompanied by installing either mechanical or additional gravitational ventilation system, the level of CO₂ concentration rises considerably, as evidenced by the author’s own research and that conducted by Sowa (2002). As a result, among people staying in the room the level of concentration drops and other complaints such as headaches occur.

In the classroom where mechanical ventilation was not installed and in which the old ill-fitting windows were replaced with new ones, CO₂ concentration exceeds maximum permissible value and amounts to 1770 ppm with 50% of the students present (Fig. 2).

The analysis of tables 2 – 4 proves that even without mechanical ventilation it is possible to preserve very good parameters of air in classrooms. The graph (Fig. 2) also shows that it is possible to lower the CO₂ concentration most effectively by means of natural ventilation. Airing the room for only ten minutes resulted in a quick drop of the concentration of carbon dioxide. Such a level could be kept during classes if the windows remained open all the time but there exist many factors which preclude such a possibility. Airing is not possible in every situation, since it can be particularly troublesome in bad weather (frost, gale, rain, heat wave).

In the case when there is no ventilation at all, after a 45 minute period of class and with 50% of the maximum number of students present, the value of hygienic minimum (1000 ppm) was exceeded; but with 20% of the maximum number of students present, CO₂ concentration dropped to 975 ppm.

The best conditions were observed in the room where mechanical ventilation operated all the time.

After a two-day break between classes, CO₂ concentration in all researched rooms was similar and amounted to ca. 500 ppm – a value comparable to the one in atmospheric air. This proves that gravitational ventilation is effective only when there are none or very few people present in a particular room.

5. Conclusion

Air exchange in all classrooms should comply with all the values that ensure comfort to people. This applies especially to carbon dioxide concentration. Mechanical ventilation when switched on considerably diminishes the concentration of carbon dioxide, which is particularly important as far as the hygiene of studying and working is concerned. Although the type of ventilation system clearly is vital, the decisive factor involves individual habits and needs of the people staying in the room. When the ventilation system is supervised directly by a particular person in charge, the air’s parameters in a room may diverge from the accepted standards.

Research has confirmed that the quality of air in classrooms in Poland does not differ significantly from the one observed in other European countries. Even though this particular research was conducted at a university, the values are comparable.

Carbon dioxide concentration should become one of the major parameters that define the quality of air indoors.

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