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CO_2 as indicator for the indoor air quality

General principles

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1 Introduction

The role of CO_2 to control the indoor air quality in buildings is based on the fact that CO_2 developed by people breathing may be used as a marker for the bio-effluents produced by people. The use of CO_2 for the steering of ventilation systems is only appropriate in the case that no other pollutant is more dominant for the indoor environment. For instance when a person is taking a shower in a bathroom, moisture will be the more dominant pollutant. Nevertheless the use of CO_2 as marker for the indoor air quality is widely used. CO_2 sensors are often used in demand controlled ventilation to control bio-effluents from humans.

2 Indoor air quality and CO_2

CO_2 is produced by breathing. Exhaling air from a person contains approximately 4 % CO_2 (whereas the outside air contains about 0.04% or 400 ppm). The relation between the activity of a person and his exude of bio-effluents, such as sweat and related body odour, is an implicit assumption. CO_2 at concentrations below 10.000 ppm is a harmless inodorous gas. High concentrations (approximately around a few percent) in the indoor environment may influence the frequency and depth of breathing of a person. Sensitive people for instance people with CNSLD (Chronic Non-Specific Lung Disease) may have problems at much lower concentrations. Outdoor air contains about 400 ppm of CO_2. The outdoor CO_2 is mainly influenced by combustion products for instance from heating systems, traffic and industry. The CO_2 level outdoors has slowly increased over the last decennia. Very roughly speaking an increase of 1 ppm per annum over the last decennia occurred. Depending on the outdoor location and local emission sources, the outdoor level –may go up to 500...800 ppm. The higher concentrations are found on very busy traffic crossings. Nowadays for calculations, an outdoor concentration of 380 ppm is frequently used. It is important to recognise that the use of indoor CO_2 levels as a tracer for the indoor air pollution due to occupancy should concern the increase of CO_2 above the outdoor level and not the absolute CO_2 level.

There are CO_2 sources other than from persons in the indoor environment, for instance CO_2 emissions from open gas appliances, cigarette smoking and pets.

The CO_2 production per person is depending on:

- age, weight and length
- gender
- pregnancy
- activity

There is data available to consider all the above parameters on the production of CO_2 by persons [1].

Until the age of about 14 – 15 years there is not much difference in CO_2 production by persons due to gender. Above that age, differences occur. Men are typically taller and will be on average heavier in weight and so producing some more CO_2. But the most important parameter for adults is the activity level. In general the CO_2 production is almost proportionally to the activity level.

For a sedentary adult the CO_2 production is about 5.6 10^{-6} m³/s.

2.1 Some data on CO_2

CO_2 is an odourless gas.
Molecular weight is 44 g/mol

More data can be found in the following references:

- Wikipedia (http://en.wikipedia.org/wiki/Carbon_dioxide)
- Chemical-Abstract-Service (CAS) nr: 124-38-9
- European Inventory of Existing Commercial chemical Substances (EINECS) nr: 204-696-9

Since CO_2 is harmless at normal indoor levels, the limits in terms of concentration are not very well defined.

- A concentration of 10 % or 100.000 ppm will definitely lead to death.
- In submarines 3 % and in air-raid shelters 2% is used to determine the capacity of the air supply.
- In occupational hygiene generally 5000 ppm or 0.5% is used as a limit value. The basis for it is not quite clear.
- For indoor air quality 1000 to 1500 ppm or (0.1- 0.15 %) is widely used.

The basis for it goes back to the year of 1858. Max von Pettenkofer from Germany published his paper *"Ueber den Luftwechsel in Wohngebäuden"* [2] which means *"About the air change in residential buildings"*. On the basis of odour produced by persons he advised to use 1000 ppm as the hygienic limit. He assumed about 500 ppm outside CO_2 concentration. So he actually advised to limit the increase in CO_2 above outside levels to about 500 ppm. An absolute CO_2 concentration of 0.1 % or 1000 ppm is since then used around the world as "Pettenkofer-zahl" (Pettenkofer number). This 1000 ppm leads depending of the outdoor concentration and the activity of persons to an outside airflow rate of about 10 dm³/s.

Around 1935 Yaglou [3] from the USA did a study about minimum ventilation. He came to the conclusion that visitors of a room assess the air quality much more critically than persons who were already in the room. One of his conclusions was that CO_2 is not the right marker for the body odour. Nevertheless he advised roughly the same outside airflow rates as used before, 7- 8 dm³/s per person.

Cain at all [4] studied around 1983 the relation between perceived indoor air quality and came to the conclusion that there is not much difference in CO_2 perception for occupants in a room even when the ventilation rate varied a factor of 4. For visitors however the difference is remarkable (see ***Table 1***).

Table 1 : Percentage of persons who scored acceptable against flow rate per person

Ventilation rate per person	% of odour acceptance	
m³/h	Visitors	Occupants
9	68	96
18	75	96
27	79	92
36	81	95

CO_2 is quite often used as a basis for evaluation of bio-effluents in ventilation standards and regulations.

- In ASHRAE standard 62- 2 for residential buildings CO_2 is used for the part of the ventilation that is related to persons. The applied CO_2 concentration is 1000 ppm.
- In European Standardization a CEN standard 15251 [5] is published. In this standard there are four categories for ventilation related to body-odour nuisance. A relation between body-odour nuisance and the CO_2 concentrations is assumed for so called "low emission buildings". That means buildings in which occupancy is the dominant source of the pollution. The four categories lead to flow rates varying from 4 to 10 dm³/s per person corresponding to CO_2 concentration levels of about 350-800 ppm above outside. The figures in this standard are based on the work of P.O Fanger [6]

Table 2 : Categories used in CEN standard EN 15251 with the relation between CO_2, percentage dissatisfied and flow rate.

Category	CO_2 above outdoors ppm	Expected Percentage Dissatisfied %	Air Flow per person dm^3/s
I	350	15	10
II	500	20	7
III	800	30	4
IV	>800	>30	< 4

3 CO_2 sensors

Already back in 1992, within IEA ECBCS the Annex 18 Demand Controlled Ventilation was carried out. As a result of that annex two important and still useful reports were published: One report concerning a market survey of sensors and another one on testing of sensors [7] [8]. Since 1992 a lot has happened in relation to especially CO_2 sensors. The availability of sensors, the accuracy, the stability and the price has radically changed (See ***Figure 1***).

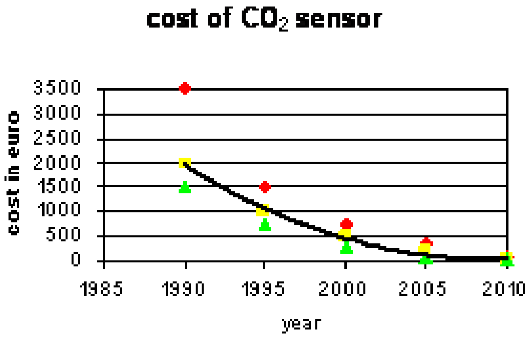

Figure 1 : Prices for CO_2 sensor over time

The price for a CO_2 sensor in 2008 is below € 50. For an innovative ventilation system costing in total about € 2500 – 4000 per dwelling, the relative cost for CO_2 sensors is in the range of 5 – 10 %. Not only has the cost gone down, the performance has improved in most cases. The specifications of these sensors in terms of accuracy and stability have also improved. Most of the new generation sensors even have a feature for auto calibration.

4 References

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The Air Infiltration and Ventilation Centre provides technical support in air infiltration and ventilation research and application. The aim is to promote the understanding of the complex behaviour of the air flow in buildings and to advance the effective application of associated energy saving measures in the design of new buildings and the improvement of the existing building stock.