Extended Abstract

Method for Estimation of CO₂ Gains from Persons in Builidings †

Antonio Rodero [1],* and Dorota Anna Krawczyk [2]

[1] School of Engineering Sciences of Belmez, University of Cordoba, 14240 Cordoba, Spain
[2] Faculty of Civil and Environmental Engineering, Bialystok University of Technology, 15-351 Bialystok, Poland; d.krawczyk@pb.edu.pl.
* Correspondence: a.rodero@uco.es; Tel.: +34-957-213-054
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Abstract: Carbon dioxide concentration is an important parameter to know Indoor Air Quality of a building. One of the most important sources of CO_2 in poor ventilated building is human activity. This work presents a method for experimental determination of human CO_2 generation rate based on measuring of time evolution of indoor CO_2 concentration. The method is applied to 5 rooms of an educational building from Bialystok (Poland). Similar carbon dioxide gains were obtained in all rooms, around 0.0046 L/s, which correspond to theoretical CO_2 generation rates of a sedentary activity for persons, males and females, between 21–30 years old, characteristics of occupants of analyzed rooms.

Keywords: Indoor Air Quality; IAQ; indoor CO_2 concentration; CO_2 gains from person

1. Introduction

A good quality of indoor air (IAQ) in buildings is important in terms of health and thermal comfort of the occupants. As noted by Śmiełowska et al. [1] poor indoor air quality may significantly affect an increase in the incidence of various types of civilisation diseases. Carbon dioxide (CO_2) concentration is a parameter commonly used as an indicator of this quality. CO_2 itself is not harmful potentially, however its excessive exposure is found to cause drowsy, fatigue and lower performance at work. According ASHRAE standard this concentration should not exceed 2500 ppm, being 1000 ppm recommended upper limit [2]. Knowledge of CO_2 concentration helps also to know adequate ventilation rates in building. One of most important parameters influencing changes in CO_2 concentration in buildings with high people density are CO_2 gains from users, therefore it is necessary to know gain values related to various people activities. As showed by Liu et al. [3] and Orava et al. [4] a human metabolic rate does not only vary with activity intensity but also can be affected by factors such as temperature variation, clothing diversity, gender difference and microclimate. Persili and Jonge [5] introduce the following equation to estimate the CO_2 gains from person or human CO_2 generation rate, g:

$$g[\text{L/s}] = 0.000569 \ RQ \ BMR \ M \tag{1}$$

where RQ is a respiratory quotient (ratio of the volumetric rate at which CO_2 is produced to the rate at which oxygen is consumed in respiration) with a value approximate of 0.85, BMR is basal metabolic rate in MJ/day that is energy requirement for the diary life (maintenance of body temperature, brain function, and cardiac and respiratory function) and depend of age and mass of the person, and M is metabolic rate in met, that depends of physical activity [6,7].For male adults from 21 to 50 years old with sedentary activity (Met M = 1.2), BMR varies between 8.00 and 8.24

MJ/day and CO_2 gains between 0.0050 and 0.0052 L/s. For female adults, BMR and CO_2 gains are lower, between 6.16 and 6.49 MJ/day and between 0.0039 and 0.0041 L/s, respectively.

This work presents a method for experimental determination of this CO_2 gain based on the dependence of CO_2 concentration on time. This method is introduced in the next section. The method was applied to several rooms of an educational building located in Poland with high occupancy and low ventilation intensity.

2. Material and Method

As has been mentioned, the method is based on measurements of time evolution of CO_2 concentration. Previous studies showed that this evolution can be well described by the mathematic expression given in [8] and presented in [9]:

$$C_{CO_2 in} = \frac{T_{in}}{P_{in}(1 + ACH\, t)} \left[C_{CO_2 in(t=0)} \frac{P_{in(t=0)}}{T_{in(t=0)}} + \left(gN \frac{R}{\mu_{CO_2} V} + C_{CO_2 out} \frac{P_{out}}{T_{out}} ACH \right) t \right] \quad (2)$$

where: ACH—the air change rate [1/h], t—time [h], P—pressure [Pa], $C_{CO_2 in}$—carbon dioxide concentration in indoor air [ppm], $C_{CO_2 out}$—carbon dioxide concentration in outdoor air [ppm], V—the volume of indoor air [m³], g—CO_2 gains from a person [g/(h per)], N—number of people occupied a room in this instant t, T—temperature [K], R—gas constant, μ_{CO_2}—the molar mass of carbon dioxide.

When we multiplied concentration by factor (1 + ACH t), this expression is transformed into a linear dependence on time with slope, m, equal:

$$m = \frac{T_{in}}{P_{in}} \left(gN \frac{R}{\mu_{CO_2} V} + C_{CO_2 out} \frac{P_{out}}{T_{out}} ACH \right) \quad (3)$$

In low ACH condition, the second term of the parenthesis can be neglected and slope can be used directly to estimates CO_2 gain by person, g:

$$m = \frac{T_{in}}{P_{in}} gN \frac{R}{\mu_{CO_2} V} \quad (4)$$

But if ventilation influence is not neglected or you need more accuracy, gain by user can be obtained directly from Equation (3). To test the method, it was applied to rooms of an educational building located in Poland (Bialystok University of Technology), a meeting room with a mobile wall, two computer laboratories and a project room. Measurements in the meeting room were conducted with different occupancy (23 and 55 persons) and two sizes (215 and 318.8 m²). Similar percentage of males and females were during measurements. Characteristics of these rooms during measurements are shown in Table 1.

Table 1. Parameters of rooms and atmospheric conditions during measurements.

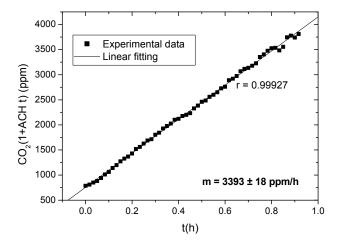|	Volume (m³)	Number of people	ACH (h⁻¹)	Outdoor Pressure (hPa)	Outdoor Temperature (K)	Outdoor CO₂ Concentration (ppm)	Indoor Presure (hPa)	Indoor Temperture (K)
Meeting RoomMeasurments 1	215	23	0.37	1000	262	400	1000	291.5
Meeting RoomMeasurments 2	318.8	55	0.55	1020	269	390	1020	295
Computer Laboratory 1	212.6	14	0.33	975	266	400	977	297
Computer Laboratory 2	215	15	0.3	1017	270	390	1017.5	298
Project Room	217	17	0.4	976	264	400	976	297

Measurements of indoor CO_2 concentration, temperature, pressure and humidity of indoor air were conducted using a multi-function meter TSI 9565 1.0 m above the floor.

3. Results and Discussion

Example of temporal variations of CO_2 concentrations multiplied by (1 + ACH t) factor is represented in Figure 1 together its linear fitting (meeting room in measurement 2). It is observed good agreement with linear behaviour predicted by theory. In all cases, correlation factors are higher to 0.99. Slope of the linear fitting, m, allows us to obtain the CO_2 gains g from Equation (4). These gains are also calculated directly from Equation (3) to know influence of ventilation on the method.

Figure 1. Temporal variations of CO_2 concentrations multiplied by (1 + ACH t) factor for meeting room in measurements in measurement 2.

Results of g calculations for five measurements are shown in Table 2. For g values obtained from Equation (4), neglecting ventilation contribution, values are too high compared with theoretical values for similar male and female percentage. Dispersion of obtained g values for different rooms is also too high. If correction by including ACH effect is made, the values of CO_2 gains are similar in all rooms, about 0.0046 L/s, and agree with theoretical value with sedentary activity (M = met) and similar male and female contribution. Exception is measurement in the computer laboratory 2, where g is 0.00424 L/s. This low value is due probably to a higher woman percentage in this case.

Table 2. Results of g calculations.

	Slope m (ppm/h)	g without ACH (g/h)	g without ACH (L/s)	g with ACH (g/h)	g with ACH (L/s)
Meeting Room-Measurments 1	2115 ± 36	35.4 ± 0.6	0.00501 ± 0.00009	32.5 ±0.6	0.0046 ± 0.00009
Meeting Room -Measurments 2	3393 ± 18	34.87 ± 0.18	0.00493 ± 0.00003	32.45 ± 18	0.00459 ± 0.00003
Computer Laboratory 1	1365 ± 11	36.10 ± 0.29	0.00510 ± 0.00004	32.16 ± 0.29	0.00455 ± 0.00004
Computer Laboratory 2	1286± 11	33.32 ± 0.28	0.00471 ± 0.00004	29.98 ± 0.28	0.00424 ± 0.00004
Project Room	1646 ± 28	35.74 ± 0.61	0.00505 ± 0.00009	31.84 ± 0.61	0.00450 ± 0.00009

4. Conclusions

This work presents an experimental method to determine CO_2 gains from persons in the building based on measurement of temporal evolution of CO_2 concentrations in low ventilated rooms. In a first approximation, ACH can be neglected in the calculations, but if more accuracy results are necessary, effect of ventilation have also to be included, as has been demonstrated in this paper. Proposed method was verified by experiment in selected rooms of the educational building in Bialystok, Poland. Despite the fact that rooms with low ventilation were selected (ACH = 0.3–0.55 h^{-1}), corrections for this effect have been necessary in the calculations. Values of gains by person in all rooms, except one, were similar around 0.0046 l/s, that agrees with gains from young person with sedentary and M = 1.3 met. This preliminary results shows that introduced method is useful for determination human CO_2 gains generation rate in the experimental conditions studied in this

paper, sedentary activity and low-medium ACH. It is necessary in further works to check the method with other conditions of activity, metabolic rate and ventilation.

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