Carbon dioxide as the main hazard in the design of personal ventilation systems

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Abstract. Mental work, used everywhere at present, is quite diverse and is characterized by various degrees of responsibility, monotony, attention, and the level of emotional stress. To provide comfortable living conditions for a person in a permanent workplace, it is also necessary to organize air conditioning systems. The most promising for this activity are personal ventilation systems, which provide a high-quality air environment in the area of human breathing while reducing capital and operating costs in comparison with traditional (mixing, displacement ventilation). However, when designing personal ventilation systems, one should not focus on the "average reference man", but take into account the individual characteristics of the employee (age, gender, etc.) performing a specific type of mental activity. In order to clarify the actual value of carbon dioxide (with a certain degree of error) emitted by a person in a certain mental work, we perform a series of experiments. The authors conducted a significant amount of full-scale experimental investigations, the result of which is the confirmation of nature and dynamics of carbon dioxide`s changes in the room in the absence (inactivity) of ventilation systems (linear dependence), as well as the refinement of the amount of carbon dioxide emitted in a particular type of mental activity. It should be noted that this work is the beginning of large-scale scientific research designed to collect and systematize data on emissions of harmful substances from people engaged in various types of mental activity.

1 Introduction

Nowadays when designing ventilation systems of buildings, a significant amount of work falls on the development of documentation for offices. The main source of harmful substances input is a person who releases heat, moisture and gaseous substances [1, 2]. When calculating, designing and constructing the ventilation systems, it is necessary to take into account the quantity and nature of the distribution of these hazards in the room. These rooms belong to the second category and standardized parameters of the internal microclimate are provided for them: temperature, humidity, mobility. In modern world, more and more attention is paid to the quality of the indoor air environment, the main indicator of which is carbon dioxide (CO2) [3].

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The aim of this work is to determine experimentally the amount of carbon dioxide entering the room from a person engaged in mental work. Data on the amount of carbon dioxide emitted by an adult, depending on the conditions, are summarized in table 1.

Table 1. The amount of carbon dioxide emitted by an adult, depending on the conditions.

Harmful conditions	**The amount of carbon dioxide emitted by an adult, l / h**			
	[5]	[6]	[7]	[8]
Repose	23	23	23	23
Mental work	-*	23	23	23
Easy physical work	25	30	25	25
Moderate physical work	35	-*	35	35
Hard physical work	45	45	45	-*

* - no data

In our opinion, mental work as well as physical work, is different (secretary, writer, air traffic controller, etc.) and is characterized by an unequal level of emotional stress. Therefore, when calculating the amount of harmfulness, it is necessary to take into account the type of mental activity, and when designing systems for providing comfortable microclimate parameters, one should not focus on the "average reference man" [4], but have regard to its individual characteristics (age, gender, etc.). In order to clarify the actually emitted carbon dioxide (with a certain degree of error) by a person in a particular mental work, we will perform a series of experiments.

2 Experimental

Let at the initial moment of time the concentration of carbon dioxide in the room air is C_0^{co2}, mg / m3. If at this moment the source of emission of harmful substances with an intensity of M_{CO2}, mg / h begins to operate in the room, then the equation of the balance of harmful substances at any time has the form [4]:

$$M_{CO2}d\tau - V_{room}dC = 0, \tag{1}$$

where V_{room} is the volume of room, m3.

The equation is valid under the assumption that harmful substances are distributed evenly throughout the entire volume of the room, and the desired concentration of the harmful substance C^{co2}, mg / m3 is an average volume value.

Integrating the equation (1) from 0 to τ (arbitrary time) and solving the current concentration of C^{co2}, we obtain:

$$C^{co2} = C_0^{co2} + \frac{M_{CO2}}{V_{room}}\tau \tag{2}$$

Thus, the amount of carbon dioxide M_{CO2}, mg / h entering the room when performing mental work, is determined by the formula:

$$M_{CO2} = \frac{(C^{co2} - C_0^{co2})V_{room}}{\tau} \tag{3}$$

In this case, the main source of harmful substance emission is a person, therefore it is necessary to take into account his physiology [5] and features when performing various types of activities [6].

According to [7], the minute expiratory volume of respiration, i.e. the volume of air inhaled (or exhaled) for 1 minute Ve, l / min, is equal to:

$$Ve = Vt \times f, \quad (4)$$

where Vt - expiratory tidal volume, l; f - respiratory rate, 1 / min

The frequency of adult respiratory rate at rest can undergo significant fluctuations from 10 to 18 in a minute [7, 8] (in average of 14 / min); due to individual indicators of external respiration, the normal respiratory rate varies from 16 to 25 per minute [8].

From equation (4) it follows that the minute volume of breathing for adult (with a tidal volume of 0.5 l) is from 5 l / min (300 l / h) to 12.5 l / min (750 l / h) of air.

According to [8], the minute volume of breathing during mental work, including the mental and emotional components, (in the absence of prolonged emotional stress associated with the reactions of the vegetative nervous system and expressed by the mood of a person in the form of joy, anger, sorrow) will be compared with a state of repose.

During physical activity, in accordance with an increase in oxygen demand, the minute volume of breathing also increases, reaching 120 l / min (trained people) under conditions of maximum load [8, 9]; an untrained person with maximum muscle work has the minute volume of breathing which does not exceed 80 l / min [9].

The composition of respiratory gases inhaled and exhaled by a person in a calm state (at sea level) is presented in table 2.

Table 2. Composition of inhaled and exhaled air under normal conditions.

Air	**Gas content, %**		
	O_2	**CO_2**	**N_2**
Inhaled	20.94	0.03	79.03
Exhaled	16.30	4.00	79.70
Alveolar	14.20	5.20	80.60

Due to the fact, that the concentration of carbon dioxide in the exhaled air (table 1) is approximately 4% (3.4 ... 4.7%), the total amount of carbon dioxide exhaled will be from 12 l / h (respiratory rate is 10 / min) to 30 l / hour (respiratory rate is 25 / min), see Figure 1.

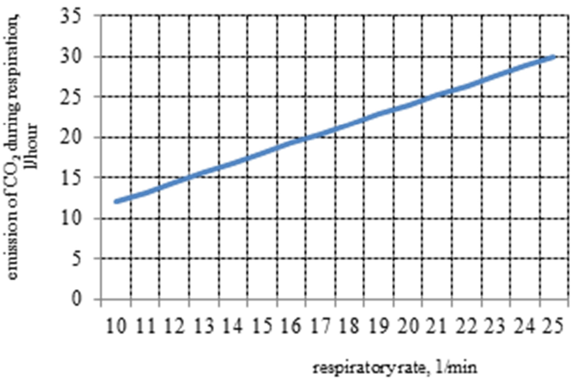

Fig. 1. Emission during respiration of CO_2 at different frequencies of respiratory movements.

We performed an experimental determination of the amount of carbon dioxide entering the room from a person engaged in mental work. Measurements of changes of CO2 concentration were carried out in a room, the geometric characteristics of which are shown in Figure 2.

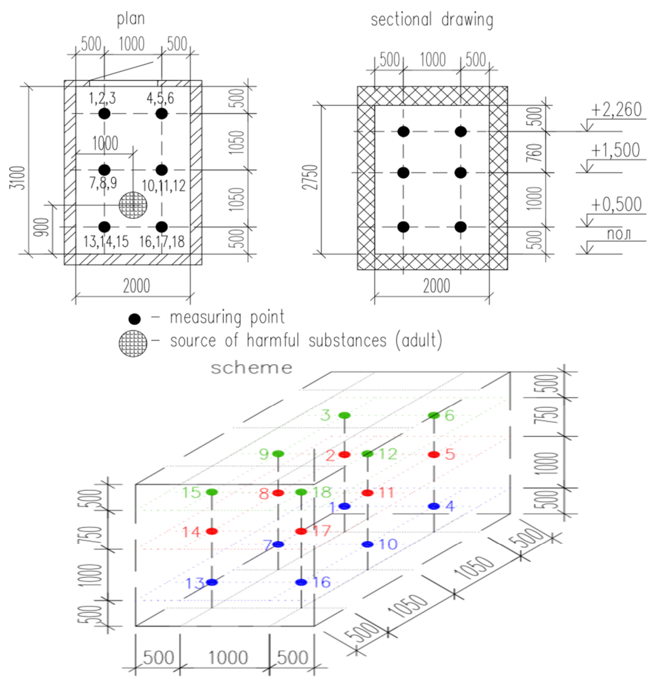

Fig. 2. The geometric characteristics of the room and measuring points.

To measure the change of carbon dioxide concentration, the PCE-GA 70 combined indoor air quality assessment instrument was used (Figure 3).

Appearance of the device	The main technical characteristics
	Concentration measurement range of CO_2 - 0…6000 ppm; Concentration accuracy of CO_2 - ± 3% ±50 ppm; Concentration measurement resolution of CO_2 - 1 ppm Temperature measurement range -20°C…+60°C; Temperature accuracy ±0,5°C; Temperature measurement resolution - 0,1°C Range of measurements of relative air humidity - 10%...95%; Relative humidity measurement accuracy ±3%; Relative humidity measurement resolution - 0,1%.

Fig. 3. Appearance and technical characteristics of the PCE-GA 70 combined indoor air quality assessment instrument.

Work sequence:

Taking into account the geometric characteristics of the room, it was broken down with the placing of measuring points in plan and in height (Figure 2). There is one workplace in the room (Figure 4).

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Fig. 4. The room of mental work with the location of one permanent workplace.

There is a person (male, 30 years old) in the room (Figure 4), engaged in mental work at a laptop (creative work, design). Measurements were carried out continuously for an hour, for each of the points indicated in Figure 2: a device, which fixes and stores in automatic mode on a PC with an interval of 60 seconds of the value of carbon dioxide concentration was installed (Figure 3). These values, issued in tabular form, were subsequently used for graphing in Excel. After an hour, the device was moved to another calculated point and the initial concentration of carbon dioxide of 450 ppm was achieved by airing or turning on ventilation. During the experiment, there were no internal and external disturbing influences capable to change the mobility of air in the room or affect the amount of harmful substances emitted. The experiments were carried out for two days (nine points per day), ceteris paribus.

3 Evaluation

As a result, we obtained curves of distribution in space and changes in time of carbon dioxide concentration values (Figure 5).

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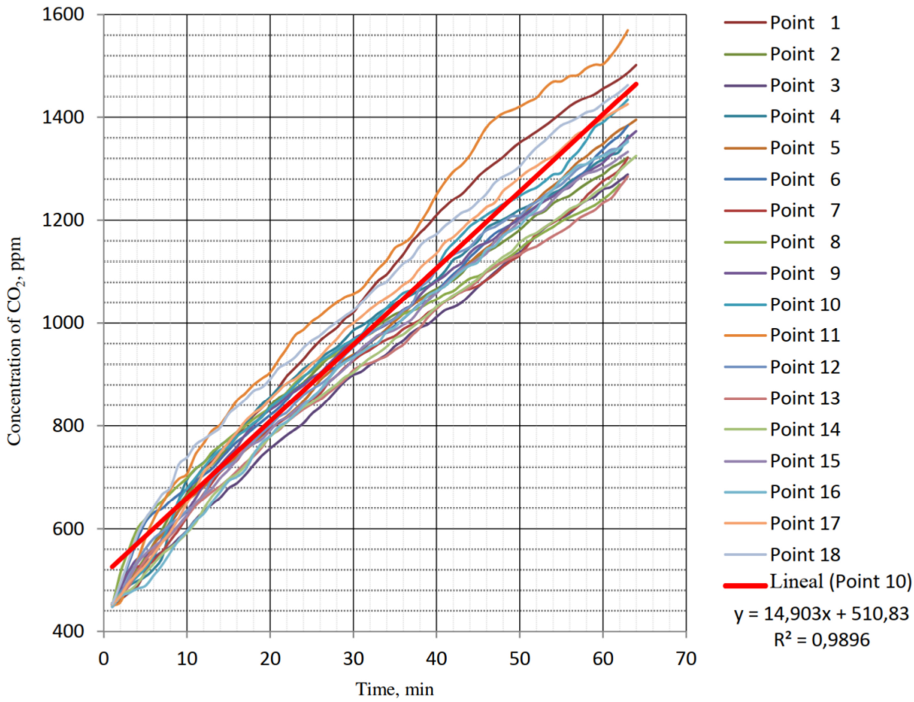

Fig. 5. Distribution and excursion in the concentration of carbon dioxide.

Based on the obtained experimental data, we establish the amount of carbon dioxide from a person during an hour for points that are different in plan and volume of the room according to Fig. 2 (table 3).

Table 3. The amount of CO_2 from a person for different points in the room.

Number of point	Value of CO_2. ppm			Δ CO_2. mg/m^3	G. mg/h	G. kg/h	G. m^3/h	G. l/h
	initial	final	Δ CO_2					
1	447	1502	1055	1929.95	32906	0.0329	0.01665	16.646
2	449	1322	873	1597.01	27229	0.0272	0.01377	13.774
3	452	1289	837	1531.15	26106	0.0261	0.01321	13.206
4	454	1364	910	1664.69	28383	0.0284	0.01436	14.358
5	455	1395	940	1719.57	29319	0.0293	0.01483	14.831
6	452	1383	931	1703.11	29038	0.0290	0.01469	14.689
7	452	1321	869	1589.69	27104	0.0271	0.01371	13.711
8	449	1270	821	1501.88	25607	0.0256	0.01295	12.954
9	451	1373	922	1686.65	28757	0.0288	0.01455	14.547
10	453	1434	981	1794.58	30598	0.0306	0.01548	15.478
11	450	1569	1119	2047.02	34902	0.0349	0.01766	17.656
12	447	1355	908	1661.03	28321	0.0283	0.01433	14.327
13	451	1285	834	1525.66	26013	0.0260	0.01316	13.159
14	452	1325	873	1597.01	27229	0.0272	0.01377	13.774
15	448	1333	885	1618.96	27603	0.0276	0.01396	13.964
16	447	1352	905	1655.55	28227	0.0282	0.01428	14.279
17	452	1425	973	1779.94	30348	0.0303	0.01535	15.352
18	453	1463	1010	1847.63	31502	0.0315	0.01594	15.936
mean	*450.78*	*1375.556*	*924.8*	*1691.73*	*28844*	*0.02884*	*0.01459*	*14.591*

value								

Table 3 shows that the mean value of the final concentration of carbon dioxide is 1375.6 ppm and corresponds to the value at point 9 of the room (see Fig. 2). It can be seen from the obtained experimental data (see Fig. 5) that the change in carbon dioxide concentration during an hour is described by a linear function with a high degree of reliability of the approximation R2 = 0.9896:

$$y = 14{,}903 \times X + 510{,}83. \quad (5)$$

Compare the resulting equation (5) with (2). These are equations of right lines describing changes in the concentration of a harmful substance in a room in the absence of ventilation, obtained theoretically [6] and experimentally. We solve equation (3), substituting the required values obtained as a result of the experiment:

$$C_0^{CO2} = 451\ \text{ppm} = 825\frac{\text{mg}}{\text{m3}}$$

$$C^{CO2} = 1373\ \text{ppm} = 2512\ \text{mg/m3}$$

$$V_{pom} = 17{,}05\ \text{m3}$$

$$M_{CO2} = \frac{(2512 - 825) * 17{,}05}{1} = 28763\ \text{mg/h}\ (14{,}55\ \text{l/h})$$

So, we determined that the amount of carbon dioxide into the room from a person engaged in mental work is 14.6 l / h. Compared the resulting number with table 1 (for mental work), it is clear that the number 14.6 is less than the number 23 by 36.52%.

4 Conclusions

The linear dependence (5) of the change in the concentration of the harmful substance (CO2), which is confirmed by the formula (2) [10], has been experimentally established.

The amount of CO2 input into the room from a person engaged in mental work was obtained (14.6 l / h). This value is included in the range defined by Figure 1, made according to the data of [11].

Figure 1 shows that the amount of CO_2 entering the room from a person is in a wide range; it depends on the individual characteristics and type of work [12]. However, the average value is 21 l / h, which corresponds to the data in table 1.

It should be noted that when designing general exchange of ventilation systems in public buildings, data oriented to a "average reference" man [12-14] specified in should be used: the amount of carbon dioxide intake is 23 l / h.

When designing personal ventilation systems in the rooms of mental work, it is necessary to know the data of the end user in order to clarify the amount of incoming hazards and determine the estimated air exchange.

Personal ventilation system is a promising direction for creating comfortable parameters of the air environment at permanent workplace of the rooms of mental work.

Physiologically intellectual (mental) activity is characterized by a brain tension based on the concentration of attention on a limited circle of phenomena or objects. Therefore, the distinguishing features of mental work are considered to be a high strain of the central nervous system and sensory organs with limited physical activity. The body's response to mental work changes significantly if it occurs against the background of emotional experiences. Troubles and excitement, anger and impatience, tension in a compressed time frame affect the circulatory system. Mental work is quite diverse: scientist, accountant, student, manager, air traffic controller, secretary, etc. Each profession is characterized by a different degree of responsibility, monotony, attention, level of emotional stress. Mental work is performed by people of different ages, gender, nationalities, having different physiological characteristics.

All of the above affects the amount of carbon dioxide emitted by a person during the performance of a particular mental activity. In our opinion, it is necessary to conduct numerous experimental studies aimed at studying the amount of carbon dioxide emitted by people, depending on the nature of mental work, as well as taking into account their physiological and other characteristics.

To conduct further scientific research the authors at the Department of Housing and Communal Services of the Federal state budget educational institution of Voronezh state technical university have created in one of the laboratories the conditions for implementing measures to collect and systematize data on the emissions of harmful substances from people engaged in various mental work.

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