Level of Total Volatile Organic Compounds (TVOC) in the context of Indoor Air Quality (IAQ) in Office Buildings

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Abstract. This paper is focused on the quality of the indoor environment in terms of Total Volatile Organic Compounds (TVOC) in the office buildings. Working in the office is one of the most common occupations in developed countries of the world. Employees spend up to 25% of their time in the workplace each year. Obviously, the internal environment affects not only the health of workers but also their performance and productivity. Observe the long-term level of Total Volatile Organic Compounds in the context of Indoor Air Quality (IAQ) in a single cellular office is subjected within the presented study. IA-Quest (Indoor Air Quality Emission Simulation Tool) developed by the National Research Council is used for emission of VOCs from building surface materials and furnishings in time. The simulation and monitoring of TVOC concentration are carried out in two phases. In the first phase, only building materials such as walls, doors, floor, ceiling, window, etc. are considered. In the second phase, the basic furniture including the office table and chair, coffee table, 2 chairs and wardrobe are included in the calculation. TVOC concentration values in a furniture room are 10 - 15% higher than in a room without furniture.

1. Introduction

People spend up to 90 percent of their time in buildings. A quality indoor environment is therefore very important. Poor and inadequate quality is linked to a number of health problems of building users [1]. In exceptional cases, it may also be related to premature morbidity/mortality [2,3]. Overall exposure levels of pollutants inside buildings are usually higher than outdoor. One of the key objectives of any commercial office building is to provide a place for people to work. Working in the office is one of the most common occupations in developed countries of the world. The usual standard working time is 8 hours per day, i.e. 40 hours a week. From this, it can be concluded that people spend 20 - 25% of their time at work every year.

Indoor air quality (IAQ) in office buildings not only has a major impact on the performance and productivity of users but especially on their health. Indoor air quality in working places is generally considered as one of the most reliable environmental risks to human health [4]. Prolonged stay in spaces with high levels of pollutants is associated with Sick Building Syndrome (SBS). The quality of the indoor environment in office buildings is addressed by a number of studies around the world [4-8]. One of the significant symptoms of SBS is volatile organic compounds that have been emitted into the interior air for a long time. Sources of volatile organic compounds in offices include furniture, wall and flooring, photocopiers, printers cleaning products, etc. Short-term exposure to the high level of TVOC could cause headaches, dizziness, drowsiness, nausea, eye and respiratory irritation or allergic reactions.

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The volatile organic compounds that are present in indoor air include carcinogenic, harmful and allergenic substances. Commonly occurring indoor VOCs are ethylbenzene, carbon tetrachloride, benzene, 1,1,1-Trichloroethane, xylenes, tetrachloroethylene, toluene, trichloroethylene, styrene, 1,4-Dichlorobenzene. Previously, the typical representative was formaldehyde. According to Lars Mølhave [9], if the TVOC concentration is less than 0.2 mg/m^3 then users are not exposed to irritation and negative effects. Most users experience a feeling of discomfort when the limit value of 3 mg/m^3 is exceeded. Headache and other neurotoxic effects occur when the TVOC concentration is higher than 25 mg/m^3.

2. Basic requirements for office buildings and office rooms

The basic requirements for offices are given in CSN 73 5305 Administrative buildings and rooms. This standard specifies principles for the design of office buildings and premises, building complexes or parts thereof that contain premises for administrative, conceptual and managerial activities. Workplaces in office buildings can be organized as cellular or open space system. Minimum spaces are set in dependence on the activities and equipment of the office. Minimum office space without meeting space and storage space is 5 m^2 (8 m^2 recommended). The minimum office area without space for dealing with the shelf is 8 m^2 (10 m^2 recommended). Minimum office space with meeting space, without shelf, is 10 m^2 (12 m^2 recommended). Minimum office space with meeting space and shelf space is 12 m^2 (16 m^2 recommended). The minimum ceiling height is 2700 mm. The recommended height is 3000 mm.

The minimum working surface of the table should be at least 750 x 600 mm. The latest trend is a height-adjustable desk table that allows both sitting and standing work. The depth of the table is 800 mm, in some situations 600 mm is accepted. The height of fixed office desks for sitting should be 740 ± 20 mm.

Most offices are currently mechanically ventilated using an air conditioner. Table 1 shows the optimum value of ventilation intensity rate according to Ashrae and EN 15251 for the office room with the floor are 10.0 m^2. The minimum supply air must be increased at additional loads such as heat or odors.

Table 1. Ventilation intensity rate according to ASHRAE and EN 15251.

		l/s per person	l/s per m^2	l/s	m^3/h per person	m^3/h per m^2
ASHRAE		2.50	0.30	5.50	19.80	1.98
EN 15251	**I**	10.00	1.00	20.00	72.00	7.20
	II	7.00	0.70	17.00	61.20	6.12
	III	4.00	0.40	8.00	28.80	2.88

Noise from office and related activities should not exceed 35 - 45 dB. For open offices, the noise limit is 50 dB. For undemanding work, the limit can be increased to 60 dB. Daylight and artificial lighting should be combined. Daylight should prevail. The office room should be illuminated evenly. The light intensity should be about 500 lx.

3. Research Methods

According to the information above, the standardized optimum size of the single cellular office with 1 workplace, put off area and cabinets is 10.0 m^2. The ground plan dimensions are 3.200 x 3.125 meters. The clear height of the room is 3.0 meters. The floor plan of the experimental single cellular office is shown in Figure 1. The air volume is 30 m^3 without taking into account the equipment and furnishing. The window is solid, non-opening, 4.5 m^2. Ventilation is forced.

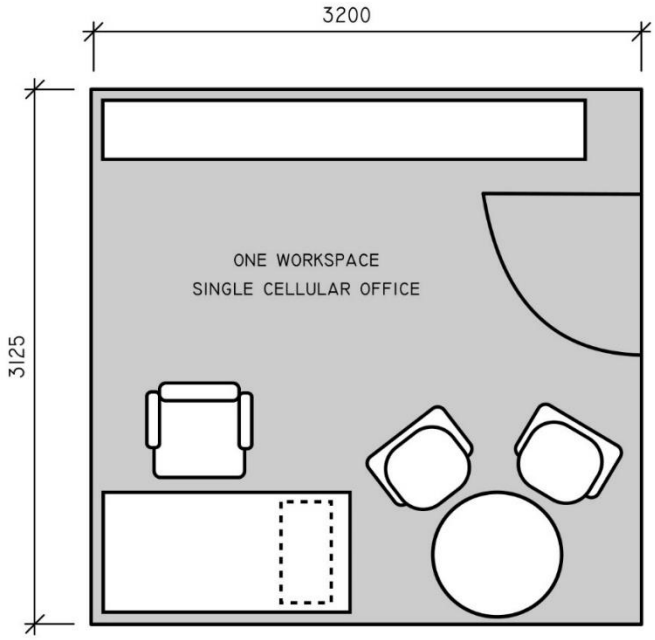

Figure 1. Floor plan of the observed single cellular office.

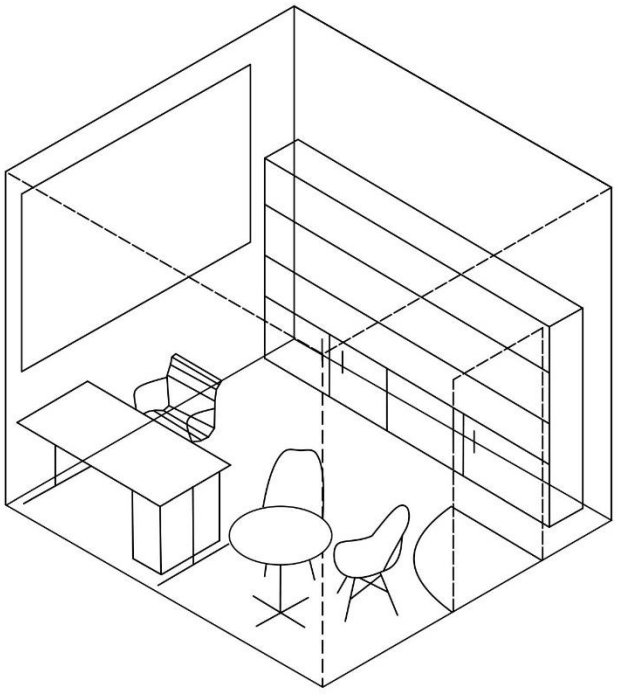

Figure 2. Simple axonometry of the observed single cellular office.

A commercial nylon carpet suitable for office use is chosen as flooring. The ceiling is made of gypsum wallboards (15.9 mm) with fire protection. The walls are treated with interior painting. The basic material characteristics of the experimental single cellular office room without equipment are given in Table 2. The table contains information about the material, emissions surface, surface area and range emission factor.

Table 2. Material characteristics of the experimental office room without furnishing.

Structural unit	Material	Emission surface [m^2]	Range emission factor [$l/s.m^2$]
Floor	Commercial nylon carpet	10.00	1.103
Ceiling	Gypsum wallboard, fire-code	10.00	3.866 – 5.232
Walls	Interior paint	31,85	55.287 – 154.450
Door	Particle board	1.60	3.866 – 5.232
Windows	Glass	4.50	-

Basic office equipment and furnishing include 1600 mm x 800 mm desk, 1x pedestal under the desk, 1x task chair, coffee table, 2x chairs, and cabinet (3000 x 2000 x 500 mm). The basic material characteristics of the experimental single cellular office room including equipment and furnishing are defined in Table 3.

Table 3. Material characteristics of the experimental office room including furnishing.

Structural unit	Material	Emission surface [m^2]	Range emission factor [$l/s.m^2$]
Floor	Commercial nylon carpet	10.00	1.103
Ceiling	Gypsum wallboard, fire-code	10.00	3.866 – 5.232
Walls	Interior paint	31,85	55.287 – 154.450
Door	Particle board	1.60	3.866 – 5.232
Windows	Glass	4.50	-
Furnishing	Particle board	22,75	3.866 – 5.232

Ventilation rate time schedule is illustrating in Table 4. Category II according to EN 15 251 is considered. According to Table 1, the ventilation rate is 61.20 m^3/h during working hours, i.e. from Monday to Friday from 06:00 to 18:00. The minimum allowable air exchange, 0.10 m^3/h, is maintained between 18:00 and 06:00 on weekdays. Minimum air exchange is also considered on weekends and public holidays.

Table 4. Ventilation rate time schedule.

	06:00 – 18:00	18:00 – 06:00
Working days (Monday – Friday)	61.20 m^3/h	0.10 m^3/h
Weekend (Saturday – Sunday)	0.10 m^3/h	0.10 m^3/h

The Indoor Air Quality Emission Simulation Tool calculates indoor air concentrations using a mass balance approach as shown in the following equation:

$$V \cdot \frac{dC}{dt} = Q \cdot C - Q \cdot C_{in} + \sum^{n} EF_i \cdot A_i \quad (1)$$

where C is VOCs concentration [mg/m^3], V is air volume [m^3], Q is ventilation rate [m^3/h], C_{in} is VOCs concentration in ventilation air [mg/m^3], A_i is surface area of the i_{th} source [m^2], EF_i is the emission factor of the i_{th} source [m^2], and n is the number of sources [3, 10].

4. Results and discussions

The estimated TVOC emission rate using Indoor Air Quality Emission Simulation Tool (IA-QUEST) are illustrated in Figure 3 and Figure 4. Figure 3 shows the expected long-term TVOC concentration over a period of 1 year (8 760 hours) for the ventilation rate time schedule as is defined above (Table 4). In the first phase, only building materials are considered without the influence of equipment and furniture. Basic statistical analysis is shown in Table 5. The mean value is 11.16 mg/m^3 with the standard error of 0.457. The median of TVOC concentration is 2.06 mg/m^3. The minimum value is 0.09 mg/m^3 and the maximum value is 874.37 mg/m^3. The rest of the basic statistics are shown in Table 5.

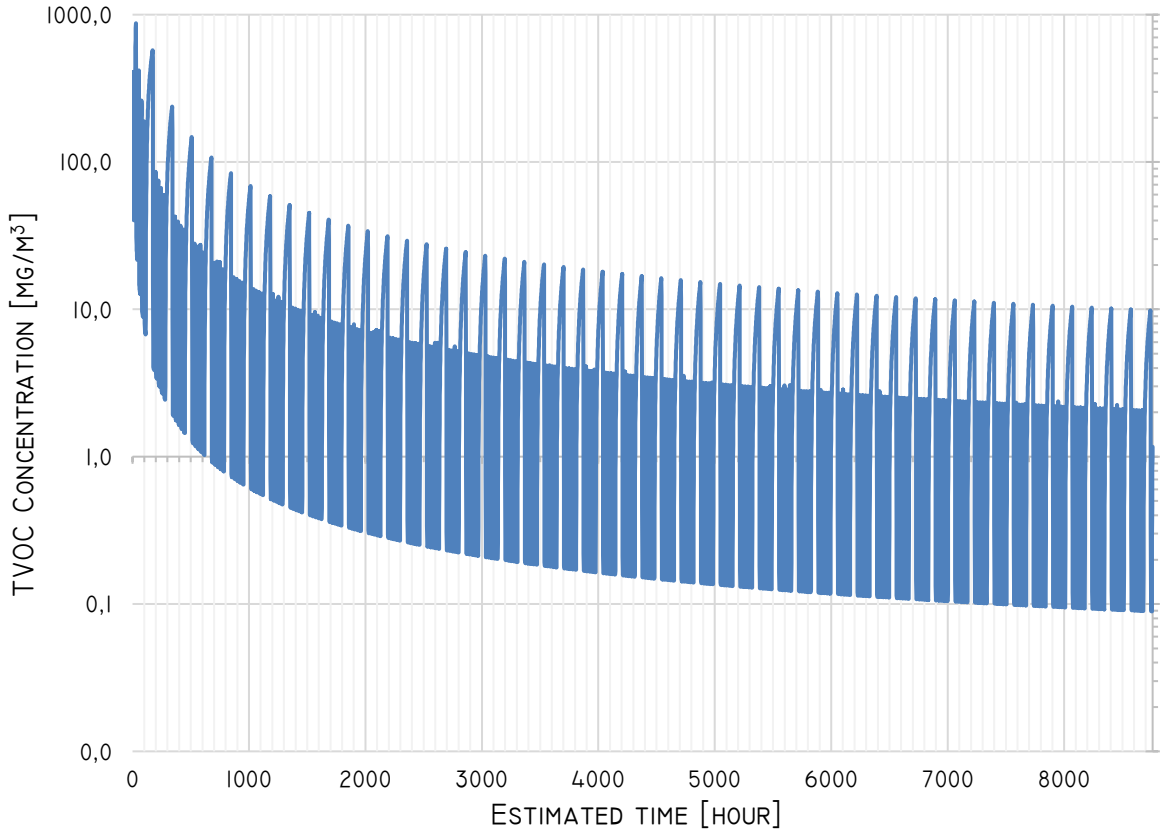

Figure 3. Long-term TVOC concentration in the single cellular office without furnishing.

Figure 4 illustrates long-term TVOC concentration in the single cellular office with the impact of the furnishing. The influence of electrical appliances is not considered. The study [11] deals with the influence of electrical appliances on indoor quality and TVOC emissions. The mean value is 12.65 mg/m^3 with standard error of 0.504. The median of TVOC concentration is 2.30 mg/m^3. The minimum value is 0.10 mg/m^3 and the maximum value is 908.58 mg/m^3.

The long-term effect of furniture is relatively low. The average addition of furniture to TVOC concentrations is about 13%. In the case of offices without furniture, TVOC concentration of less than 3.0 mg/m^3 is achieved for the first time in 233 hours (9 days). A concentration of less than 0.2 mg/m^3 is first achieved in 3203 hours (133,45 days). In the second case (with furniture), TVOC concentration of less than 3.0 mg/m^3 is achieved for the first time in 274 hours (11,4 days). A concentration of less than 0.2 mg/m^3 is first achieved in 3709 hours (154,54 days).

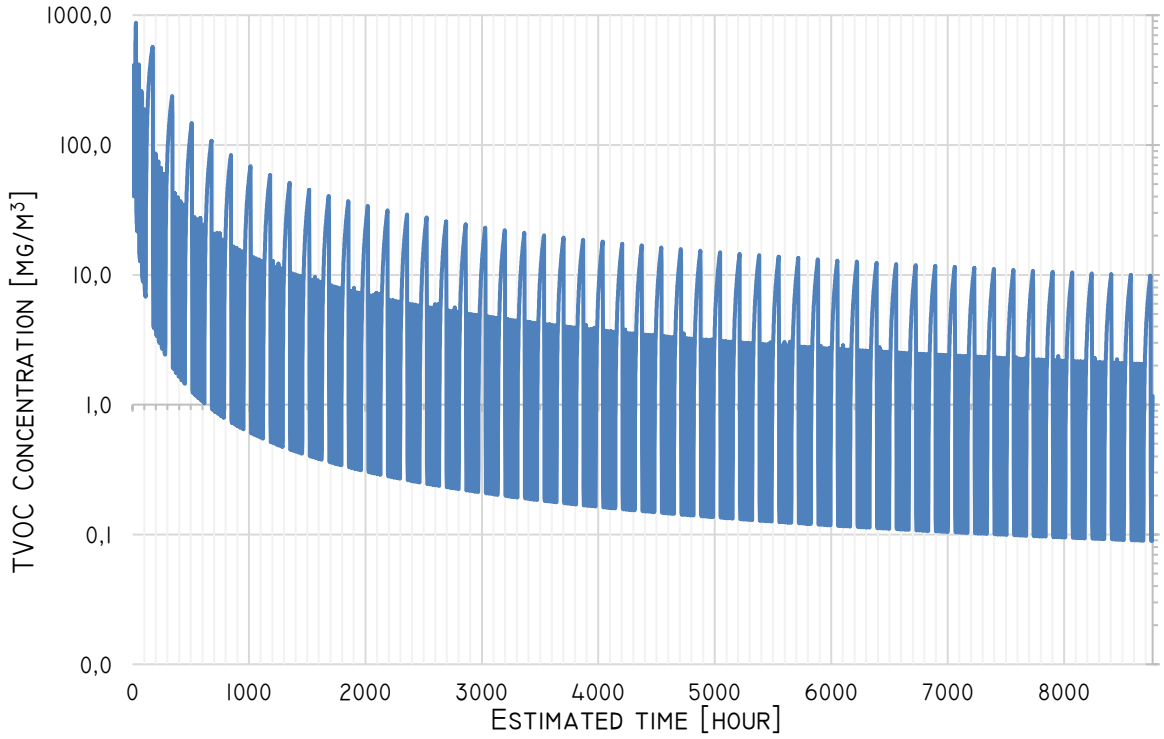

Figure 4. Long-term TVOC concentration of the single cellular office with furnishing.

Table 5. TVOC concentration without/with furnishing.

	TVOC concentration without furnishing	TVOC concentration with furnishing
Mean	11.1558	12.6516
Std. Error of Mean	0.45708	0.50377
Median	2.0600	2.3100
Mode	0.10	0.11
Std. Deviation	42.77997	47.15025
Variance	1830.126	2223.146
Skewness	9.795	9.430
Std. Error of Skewness	0.026	0.026
Kurtosis	119.667	110.139
Std. Error of Kurtosis	0.052	0.052
Range	874.28	908.48
Minimum	0.09	0.10
Maximum	874.37	908.58

5. Conclusions

Ensuring satisfactory indoor air quality (IAQ) and indoor environmental quality (IEQ) is one of the basic principles of sustainable development because people spend a major part of lifetime indoor. The level of TVOC concentration for one year in the single cellular office is demonstrated in the contribution. Based on the prediction, it is clear that the values of concentrations of volatile organic compounds exceed the permitted limits. Acceptable TVOC concentrations will be achieved approximately one-third of the year after commissioning the building. Office equipment increases concentration of VOCs about 10%. Reduction of TVOC concentration is necessary to prevent Sick Building Syndrome (SBS). The

main aim of sustainable development is to ensure the optimum and suitable quality of the internal environment with minimum operational and investment costs.

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