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# Analysis of Indoor Air Pollution by CO and VOC in a Smart Building

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**Abstract:** The article analyses the changes over time of two parameters (CO and VOC) measured by a new indoor air pollution sensor. For this research, measurement data gathered from a selected indoor room over a four-week period were used. The measurements were divided into four different stages. Stage 1: The ventilation system in the investigated room was operational, while the complex air treatment device was not. Stage 2: Neither the ventilation system nor the complex air treatment device was functioning in the room. Stage 3: The complex air treatment device was operational, and the ventilation system was also working. Stage 4: Both the complex air treatment device and the ventilation system were operational in the room. Additionally, due to the quarantine announced in Lithuania during the COVID-19 pandemic, employees were not present in the workplace. The study determines the interdependence of the parameters recorded by the air pollution sensor and how they change over time.

**Keywords:** indoor air pollutants, CO, VOC, COVID-19, complex air treatment device

## 1. Introduction

The work environment significantly influences the health and well-being of employees, so it is essential to pay careful attention to it. Indoor air quality is influenced by both outdoor pollution and the activities of equipment and individuals within the space. The impact of air pollutants on human health varies based on their nature, concentration, and duration of exposure. To minimize the negative effects of these pollutants, it is important to ventilate indoor spaces and use air treatment devices. Key indoor air pollutants to monitor include carbon monoxide (CO) and volatile organic compounds (VOCs). Researchers around the world are studying the concentrations of various pollutants in workplace air, including CO, VOCs, and individual organic compounds (Ali et al. 2021, Gandolfo et al. 2017, Harb et al. 2018, Kumar et al. 2023, Demanega et al. 2021, Mumtaz et al. 2021, Mata et al. 2022, Maung et al. 2022, Yue et al. 2021, Agarwal et al. 2021, Montaluisa-Mantilla et al. 2023, Rosário Filho et al. 2021, Hwang & Park 2019, Hwang & Park 2020, Thevenet et al. 2018, Villanueva et al. 2018, Li & Ma 2021).

The principles of digital building modelling (BIM) have been implemented in a smart office building in Vilnius to monitor air quality using the smart sensor. This sensor transmits data on the concentrations of air pollutants—specifically carbon monoxide (CO) and volatile organic compounds (VOCs)—to a server at regular intervals (every minute). The concentrations of the two air pollutants are measured in parts per billion (ppb).

Carbon monoxide in office environments can originate from various sources of environmental air pollution, including transportation, industrial activities, and energy facilities. In the colder months, biofuel burning in homes can also contribute to CO levels. Pollutants can enter indoor spaces through leaky building structures or ventilation systems. Additionally, indoor air pollutants may arise from other sources, such as tobacco smoke and the preparation of food.

The primary source of carbon monoxide (CO) in the office under consideration is road transport.

Volatile organic compounds (VOCs) are organic compounds that originate from both anthropogenic (human-made) and biogenic (natural) sources, excluding methane. These compounds can form photochemical oxidants when they react with nitrogen oxides in the presence of sunlight, as outlined in Directive 2008/50/EC. In the office environment, the sources of VOCs often include environmental air pollution from transportation, industrial activities, and, to some extent, energy facilities and residential buildings that burn biofuels, particularly during the colder months. These pollutants can infiltrate the indoor space through leaks in building structures or ventilation systems. Additionally, indoor VOCs can originate from materials and products such as synthetic carpets, floor coverings, office furniture, copying and printing equipment, cleaning agents, cosmetics, and tobacco smoke. Within the office, the primary contributors to VOC levels are road transport and the use of copying and printing equipment.

This work aims to evaluate indoor air pollution by CO and VOCs, focusing on the impact of various ventilation modes and the effectiveness of a comprehensive air treatment device.

## 2. Materials and Methods

The research was conducted at T. Narbuto Street 5 in Vilnius, specifically in the office of a smart building. The coordinates of the research point (in the WGS system) are 54°41'54.55" N, 25°15'34.29" E. Located near the office is T. Narbuto Street, which is a busy thoroughfare frequented by cars, heavy vehicles, and city public transport. The average daily traffic flow in one direction on T. Narbuto Street is approximately 17 500 vehicles (Traffic flow...). Road transport contributes to air pollution by emitting various pollutants, including carbon monoxide (CO) and volatile organic compounds (VOCs). Several factors influence the concentration of pollutants in the office environment adjacent to the street: the number of vehicles, their speed, the type of fuel used, fuel consumption, the age of the vehicles (which determines compliance with different Euro emissions standards), the technical condition of the vehicles, the quality of the road surface, the degree of surrounding vegetation, and atmospheric conditions such as temperature, relative humidity, wind speed and direction, and atmospheric pressure.

A smart meter, produced by Ecomesure in France, measures indoor air parameters and transmits data to a server via a Wi-Fi connection at one-minute intervals. This device can be integrated into a "smart home" system.

In the experiments, an air quality analyzer (Ecomesure, France) was used. Air quality and environmental parameters: air temperature, air pressure, humidity, CO, VOC, etc.
VOC: from 100 to 1000 ppb; accuracy 10% at full scale,
CO: 200-1000 000 ppb, accuracy 2%,
temperature: -40 to +85°C, accuracy 0.5°C,
humidity: 0 to 100%, accuracy 3%,
pressure: 300 to 1100 hPa, accuracy 0.12 hPa.

Such technologies are designed to alert users to deteriorating air quality and help maintain acceptable levels of air quality. The comfort of office workers is closely tied to indoor air quality; inadequate air quality can negatively affect employee health and productivity. To ensure good air quality, the smart meter monitors indoor air parameters, while an air treatment system is in place. By analyzing the data from the smart meter, steps can be taken to enhance employee comfort. An effective working environment in an office can be supported by a system that combines a smart indoor parameter meter with a comprehensive air cleaning device. This may include an electrostatic filter with a pre-filter, a cassette filter, and an adsorptive filter. Such solutions are essential in settings where air quality is critical, such as in high-tech manufacturing companies, educational institutions, medical facilities, and office spaces.

The data collected during a research study on new indoor air pollution parameters were used for this analysis. The study took place over four weeks in a smart building from February 24 to March 22, 2020, and it was divided into four different stages:

- Stage 1: From February 24 to March 1, 2020, the ventilation system in the investigated room was operational, but the complex air treatment device was not functioning.
- Stage 2: From March 2 to March 8, 2020, neither the ventilation system nor the complex air treatment device worked in the examined room.
- Stage 3: From March 9 to March 15, 2020, both the complex air treatment device and the ventilation system were operational in the investigated room.
- Stage 4: From March 16 to March 22, 2020, the complex air treatment device continued to operate alongside the ventilation system in the room.

This period coincided with the quarantine implemented in Lithuania due to the COVID-19 pandemic. Measurements were taken weekly, starting from Monday at 00:01 and ending on Sunday at 23:59. The device for recording air pollutant concentrations was installed in a room on the 4th floor, which has south-facing windows, while the primary traffic flow is directed to the north side of the smart building. Additionally, on the 3rd floor of the analyzed smart building, a complex air treatment device is located, designed to filter indoor air pollutants, specifically carbon monoxide (CO) and volatile organic compounds (VOCs). The specifications of the complex air treatment device are detailed in Table 1.

The location of the complex air treatment device has been designated to a technical room to minimize noise disturbance for office workers and to prevent additional air pollution during its operation, due to small emision of ozone.

**Table 1.** Technical specifications of the advanced air treatment device

| No | Parameter | Value |
|---|---|---|
| 1 | Height | 540 mm |
| 2 | Length | 2180 mm |
| 3 | Width | 470 mm |
| 4 | Yield | 850 $m^3/h$ |
| 5 | Aerodynamic resistance till | 300 Pa |
| 6 | Ambient temperature | +5÷+45°C |
| 7 | Cleaned air temperature till | 60°C |
| 8 | Relative humidity till | 85% |
| 9 | Power supply voltage | 220 V |
| 10 | Power consumed by the power supply | till 120W |
| 11 | Ionization voltage regulation limits | (4000-8000) V |
| 12 | Limits for regulating the deposition voltage | (2000-4000) V |
| 13 | CO removal efficiency till | 70% |
| 14 | Ozone removal efficiency till | 50% |
| 15 | VOC removal efficiency till | 44% |

Air is drawn from the 3rd floor, cleaned, and then circulated to the 4th floor, where an intelligent interactive indoor quality control and air pollution reduction system is located, as this is where the office workers are situated. The cleaned air, which has had gaseous pollutants removed, is then returned to the technical room on the 3rd floor, where the air cleaning cycle repeats. Maintaining good indoor air quality is crucial for human comfort, productivity, and overall health; therefore, indoor spaces require adequate ventilation. In Norway and Germany, the recommended air supply for ventilating low-energy buildings is at least 1.2 $m^3/(h \cdot m^2)$, while in Denmark, it is 1.08 $m^3/(h \cdot m^2)$, and in Lithuania, it is 0.7 $m^3/(h \cdot m^2)$, according to STR 2.01.02:2016. The complex air treatment device used in this research is shown in Fig. 1.

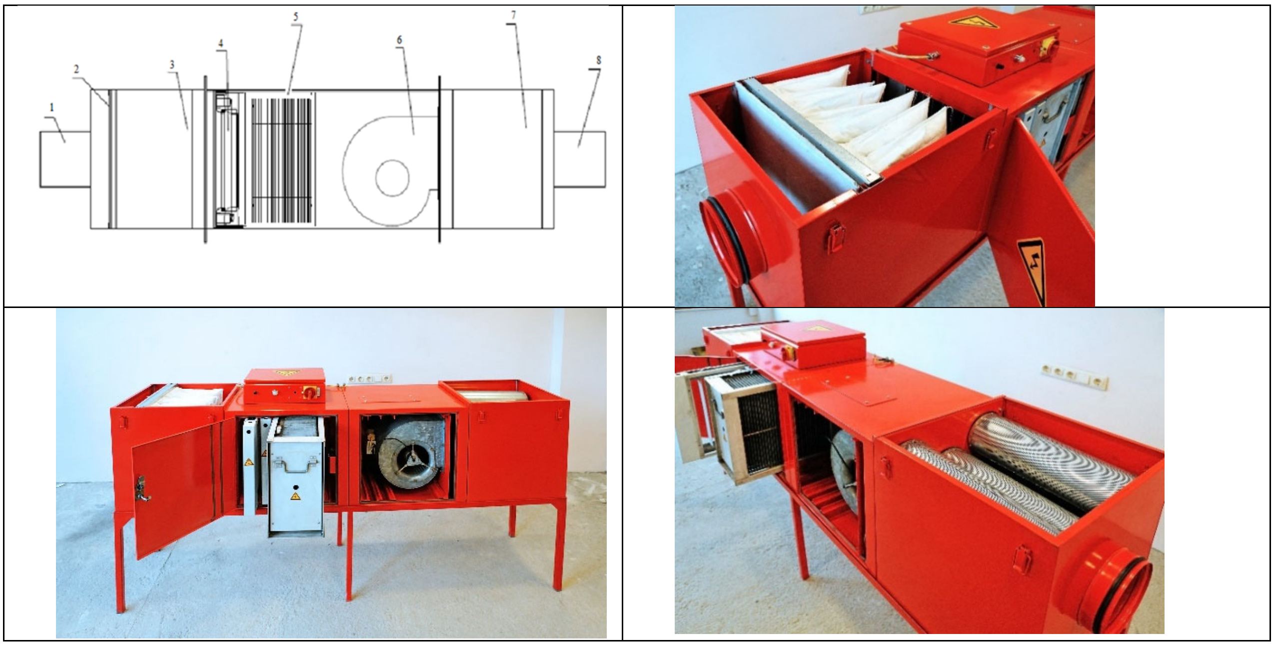


**Fig. 1.** Complex air treatment device: 1. inlet duct, 2. pre-filter, 3. cartridge filter, 4. electrostatic filter ionization cartridge, 5. electrostatic filter collector cartridge, 6. fan, 7. activated carbon filter, 8. outlet duct

The complex recirculating air device is stationary and designed for use in smart building offices. It consists of four filters: a pre-filter, a cartridge filter, an electrostatic filter, and an adsorption filter.

The pre-filter is responsible for preventing larger objects from entering the system, which can cause short-circuiting between the electrodes. It ensures even airflow distribution at the inlet of the cartridge and electrostatic filters. This filter is made of a dense fabric embedded in a frame and achieves a G4 air cleaning efficiency rating for PM10 particles, as per the ISO 16890-1:2016 standard.

**The cartridge air cleaning filter** achieves F9 class air cleaning efficiency, as specified in the ISO 16890-1:2016 standard, effectively treating air for PM2.5 and PM10 particles.

**The electrostatic air cleaning filter** consists of two ionizer cartridges and a settling manifold cartridge (collectors). It cleans the air from PM1.0, PM2.5, and PM10. During the corona discharge process, the ionizer unit charges aerosol particles, which then adhere to the surface of the collector. As aerosol particles accumulate, they reduce the strength of the ionizing electric field, leading to decreased filter cleaning efficiency. To maintain performance, the filter must be periodically regenerated by removing the mesh, ionizer, and collector from the housing, followed by a thorough rinse with hot water. The frequency of washing depends on the filter's operating time and the concentration of aerosols in the air. Additionally, ozone is produced as a byproduct during the corona discharge in the ionizer unit.

The adsorption air cleaning filter is composed of eight cartridges, each consisting of two concentric perforated metal cylinders. The space between these cylinders is filled with a mixture of activated carbon granules and a catalyst. The activated carbon granules in the filter absorb nitrogen dioxide, volatile organic compounds (VOCs), and ozone from the air. The catalyst is composed of a mixture of copper oxide powder and manganese dioxide granules in a 1:3 weight ratio. The active surface of the catalyst oxidizes carbon monoxide into carbon dioxide, which poses a lower risk to human health.

This complex air cleaning device aims to eliminate harmful air contaminants in the indoor environments of smart buildings. Smart buildings are modern structures that utilize digital technologies and electronic tools to enhance employee convenience. They allow for control and regulation of indoor parameters via wireless internet access, creating optimal and comfortable working conditions.

Additionally, a smart indoor air quality measurement system evaluates the air quality within these offices.

### Statistical Analysis

Descriptive statistical analysis was employed, and statistical variables, including the mean, standard deviation, confidence interval, and Pearson coefficient, were calculated. The study results were considered statistically significant with a p-value of less than 0.05. The research data were processed using Excel 2016.

## 3. Results and Discussion

The measured CO concentrations in the office room during stages 1-4 are shown in Fig. 2.

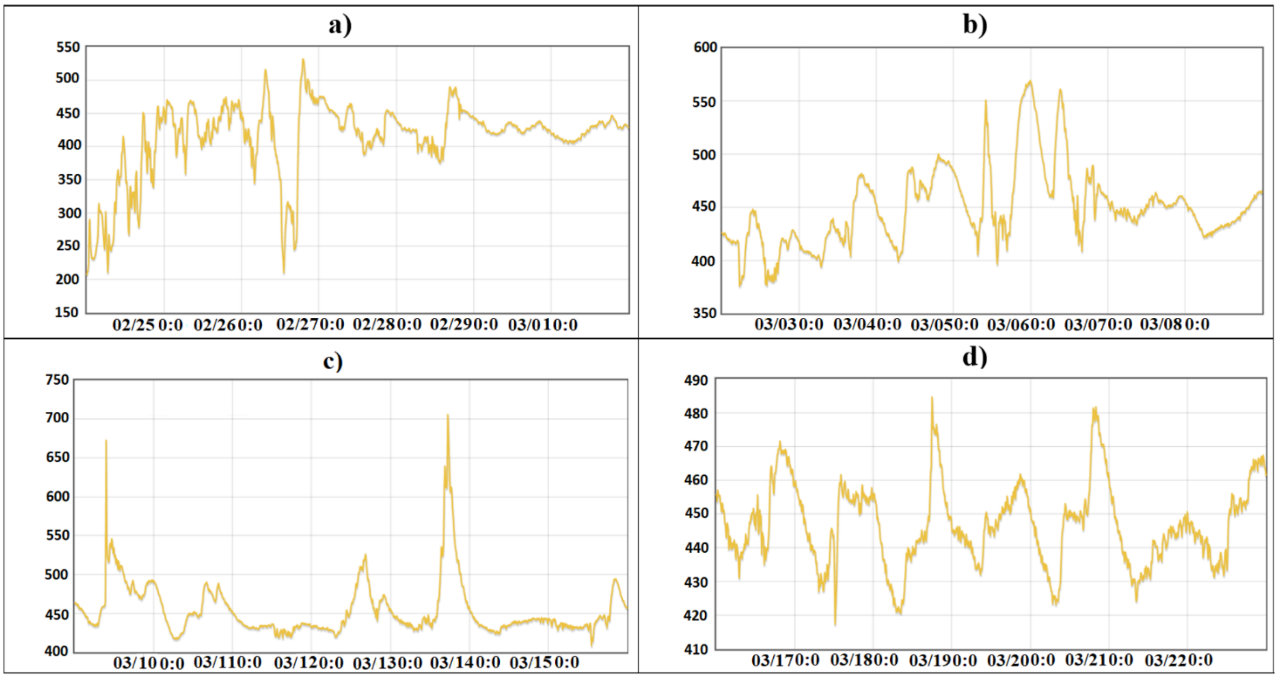


**Fig. 2.** Variation of CO concentration (ppb) in office room: a) February 24-March 1. b) March 2-8. c) March 9-15. d) March 16-22 (ppb)

The analysis of gaseous pollutant concentrations in the office room was conducted on weekdays during working hours (from 8 a.m. to 6 p.m., Monday to Friday) and on weekends (from Friday at 6 p.m. until Sunday at 11:59 a.m.).

**Stage 1**: during the first week of research (February 24 - March 1, 2020), carbon monoxide (CO) concentrations on weekdays during working hours ranged from 210.29 to 494.19 ppb. The highest recorded CO concentration was 533.92 ppb, which occurred after working hours. The second-highest carbon monoxide (CO) concentration was recorded on Wednesday at around 8 a.m., reaching 494.19 ppb. Lesser peaks in concentration were observed on Friday at approximately 4:30 p.m. (490.4 ppb) and on Tuesday at around 8 a.m. (469.44 ppb). Over the weekend, CO concentrations varied from 375.09 to 489.33 ppb, with an average of 427.13 ppb (Fig. 2a).

**In the second week** of research (March 2-8, 2020), CO concentrations during working hours on weekdays ranged from 376.59 to 561.28 ppb. The highest recorded CO concentration was 569.6 ppb, which occurred after working hours. The second highest CO concentration during this week was recorded on Friday at around 9 a.m., reaching 561.28 ppb. Other notable peaks occurred on Wednesday at 11 a.m. (487.84 ppb) and Thursday at 10 a.m. (550.99 ppb). Over the weekend, CO concentrations ranged from 421.76 to 489.87 ppb, with an average of 447.34 ppb (Fig. 2b).

**During the third week** of research (March 9-15, 2020), CO concentrations during working hours on weekdays fluctuated between 408.64 and 709.87 ppb. The highest recorded CO concentration was 709.87 ppb after working hours. The second-highest concentration of CO, reaching 484.91 ppb, was recorded on Wednesday around 6:00 p.m. Lower peaks were noted on Monday at around 5:00 p.m. (464.32 ppb) and on Tuesday at 2:00 p.m. (461.6 ppb). Over the weekend, CO concentrations ranged from 424.16 to 481.71 ppb, with an average of 448.20 ppb (Fig. 2c). Over the weekend, CO concentrations ranged from 408.64 to 616.48 ppb, with an average of 449.14 ppb (Fig. 2c).

**During the fourth research week**, from March 16 to March 22, 2020, carbon monoxide (CO) concentrations ranged from 417.39 to 484.91 ppb. The highest CO concentration was recorded on Wednesday at around 6 p.m. and reached 484.91 ppb. Smaller peaks were recorded on Monday at around 5 p.m. (464.32 ppb) and on Tuesday at around 2 p.m. (461.6 ppb). Over the weekend, CO concentrations ranged from 424.16 to 481.71 ppb, with an average of 448.20 ppb (Fig. 2d).

Volatile organic compound (VOC) concentrations measured in the office during stages 1-4 are presented in Fig. 3.

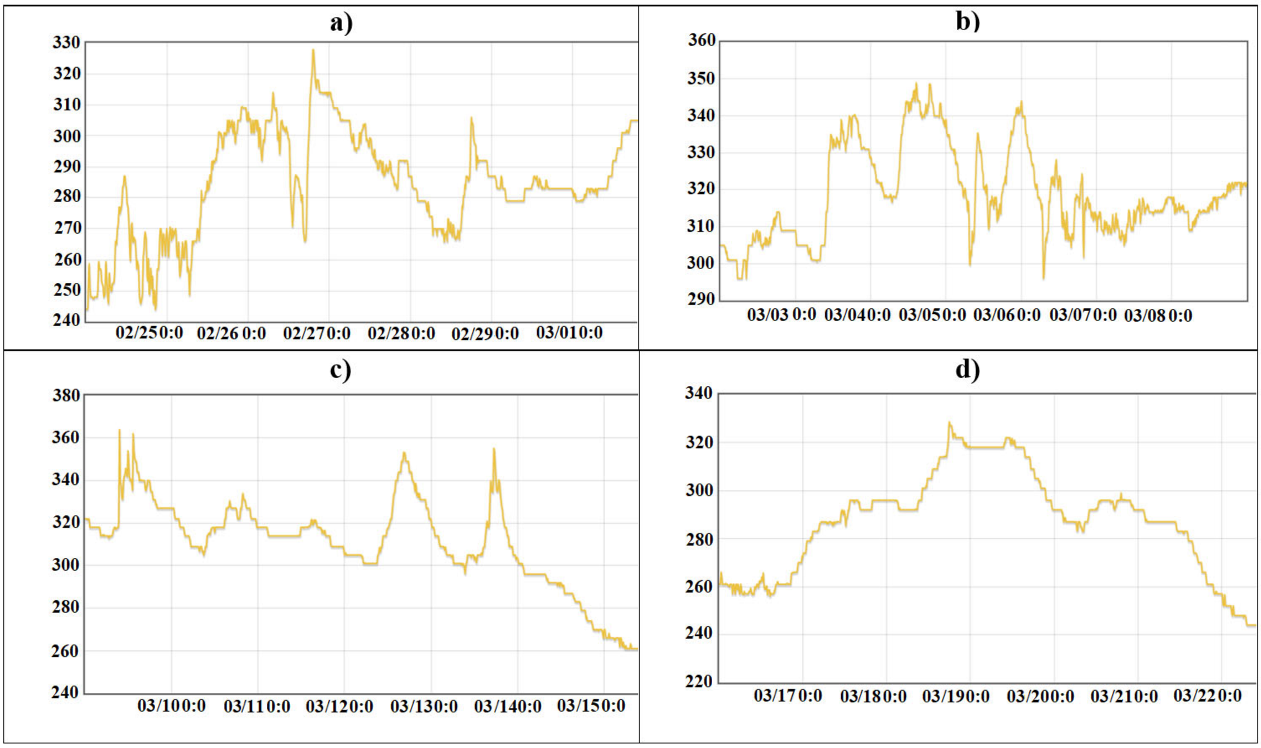


**Fig. 3.** Variation in VOC concentrations (ppb) in office room: a) February 24-March 1, b) March 2-8, c) March 9-15, d) March 16-22

**Stage 1**: In the first week of research (February 24 - March 1, 2020), the VOC concentration during working hours on weekdays ranged from 245.87 to 309 ppb. The highest recorded VOC concentration was 327.80 ppb, which occurred after working hours. The highest VOC concentration was recorded on Wednesday around 8 a.m., reaching 309 ppb. Smaller peaks were observed on Tuesday at 6 p.m. (305 ppb) and Friday at 6 p.m. (305.33 ppb). Over the weekend, VOC concentrations varied from 279 to 306 ppb, with an average concentration of 289.70 ppb (Figure 3a).

**Stage 2**: In the second week of research (March 2 - March 8, 2020), VOC concentrations during working hours on weekdays ranged from 296 to 348.67 ppb. The peak concentration occurred on Wednesday around 2:30 p.m., reaching 348 ppb. Smaller peaks were recorded on Tuesday at 5 p.m. (340 ppb) and Thursday at 10 a.m. (335.33 ppb). Over the weekend, VOC concentrations ranged from 301.80 to 324.33 ppb, averaging 314.89 ppb (Figure 3b).

**Stage 3**: During the third week of research (March 9 - March 15, 2020), VOC concentrations during working hours on weekdays ranged from 296.33 to 363.93 ppb. The highest concentration was recorded on Monday at 9:30 a.m., reaching a peak of 363.93 ppb. Lower peaks occurred on Thursday at 4:30 p.m. (353.27 ppb) and Friday at 5:30 p.m. (356.60 ppb). Over the weekend, VOC concentrations ranged from 258.33 to 340.27 ppb, with an average of 280.85 ppb (Figure 3c).

**Stage 4**: In the fourth week of research (March 16 - March 22, 2020), VOC concentrations during working hours on weekdays varied from 283 to 328.87 ppb. The highest concentration was noted on Wednesday at 6 p.m., reaching 328.87 ppb. Lower peaks were observed on Thursday at 10 a.m. (322 ppb) and Friday at 1:30 p.m. (296 ppb). Over the weekend, VOC concentrations ranged from 235.00 to 299.00 ppb, averaging 260.63 ppb (Figure 3d).

The maximum concentrations of air pollutants in the room can be attributed to various obvious and accidental reasons. To objectively compare the concentrations of air pollutants, the average concentrations of each pollutant for each week were calculated.

Table 2 displays the matrix of Pearson correlation coefficients.

**Table 2.** Pearson coefficients matrix

| | VOC | Stage |
|---|---|---|
| CO | 0.65 | 1 stage |
| CO | 0.64 | 2 stage |
| CO | 0.51 | 3 stage |
| CO | -0.01 | 4 stage |

During the first stage of the study, an examination of the inter-correlation among pollutant concentrations revealed a moderate correlation between carbon monoxide (CO) and volatile organic compounds (VOCs), with a correlation coefficient of 0.65.

In the second stage, the correlation was slightly lower, equal to 0.64.

By the third stage, this correlation further decreased to 0.51.

However, in the fourth stage, a very weak negative correlation was established between CO and VOCs, with a correlation coefficient of -0.01.

Fig. 4 depicts an example of VOC concentration dependence on CO concentration during stage 1 (February 24-March 1).

It can be observed that as the CO concentration increases, a trend of increasing VOC concentration is evident; however, the correlation between the two parameters is not very strong, as indicated by an $r^2$ value of 0.43 (Fig. 4).

After analyzing the research data over four weeks, it was observed that peaks in air pollutant concentrations typically occurred between 8 and 10 a.m. and again in the evening, around 4 and 6 p.m., which aligns with the end of the working day. During other hours, pollutant concentration peaks were less frequently recorded. This pattern likely results from the accumulation of pollutants indoors and the increased road traffic during the morning and evening. The concentrations of the studied air pollutants in indoor air are influenced by both ambient air concentrations and the activities of people and equipment.

Carbon monoxide is an inert pollutant, and its concentration indoors is primarily affected by ambient air levels.

VOC concentrations in indoor environments are primarily determined by their prevalence in outdoor air, but can be influenced to some extent by the activities of people and equipment within the room.

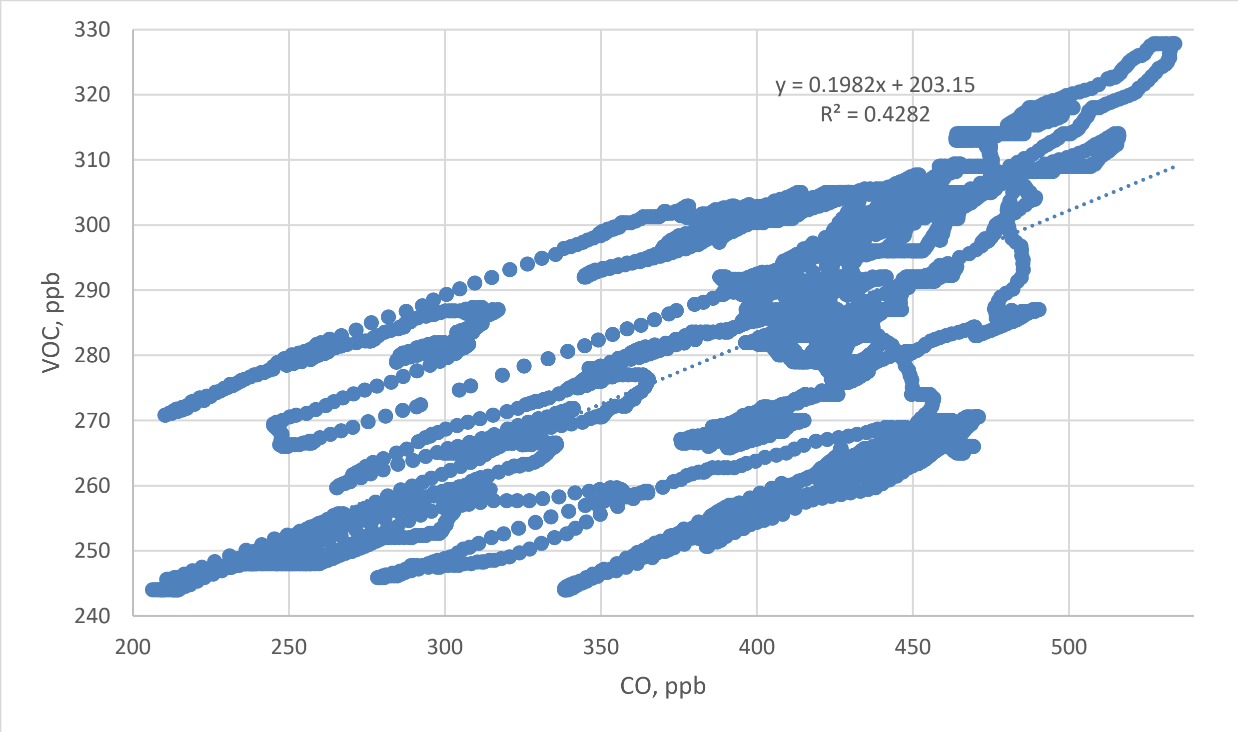


**Fig. 4.** An example of VOC concentration dependence on CO concentration during stage 1 (February 24 - March 1)

In Table 3, concentrations of air pollutants are compared with values set in different standards - Lithuanian hygiene standard HN 23:2011, WHO (World Health Organization), and NAAQS (National Ambient Air Quality Standards) (HN 23:2011; Information on limits,...; NAAQS Table).

**Table 3.** Comparison of air pollutant concentrations with standards

| Pollutant | Stage | Average value, ppb | Maximum value, ppb | HN 23:2011, 8 hours, ppb | WHO, 8 hours, ppb | WHO hygienically safe, ppb | WHO hygienically conspicuous, ppb | NAAQS 8 hours, ppb |
|---|---|---|---|---|---|---|---|---|
| CO | 1 | 413.10 | 533.92 | 20 000 | 8 000 | - | - | 9 000 |
| CO | 2 | 449.91 | 569.60 | 20 000 | 8 000 | - | - | 9 000 |
| CO | 3 | 454.74 | 709.87 | 20 000 | 8 000 | - | - | 9 000 |
| CO | 4 | 446.80 | 484.91 | 20 000 | 8 000 | - | - | 9 000 |
| VOC | 1 | 285.01 | 327.80 | - | - | 150 to 400 ppb | 400 to 1200 ppb | - |
| VOC | 2 | 318.81 | 349.00 | - | - | 150 to 400 ppb | 400 to 1200 ppb | - |
| VOC | 3 | 306.92 | 363.93 | - | - | 150 to 400 ppb | 400 to 1200 ppb | - |
| VOC | 4 | 283.21 | 328.87 | - | - | 150 to 400 ppb | 400 to 1200 ppb | - |

In the first stage, when the room was ventilated, the average concentrations of pollutants were as follows: CO at 413.10 ppb and VOC at 285.01 ppb.

In the second stage, when ventilation and the air treatment system were not functioning, the average concentrations of the tested pollutants increased compared to the first stage. The average pollutant concentrations recorded were: CO at 449.91 ppb and VOC at 318.81 ppb.

During stage 3, the room's ventilation system was not operational, but a complex air treatment device that removes carbon monoxide (CO) from the air was functioning. The average pollutant concentrations recorded during this stage were as follows: CO at 454.74 ppb and volatile organic compounds (VOCs) at 306.92 ppb.

In stage 4, the ventilation system remained nonfunctional, yet the air treatment device continued to operate. Additionally, since people were not working due to quarantine, the average concentrations of pollutants measured were 446.80 ppb for CO and 283.21 ppb for VOCs (Table 3).

The highest and average concentrations of CO in indoor air were compared with the limit values.

It was determined that the highest concentration of CO measured during stages 1-4 was 11.3 times lower than the WHO limit value of 8 hours. The average concentration of stages 1-4 was 17.9-19.4 times lower than the WHO limit value of 8 hours. It can be seen from Table 3 that the strictest limit value for CO is 8000 ppb according to the WHO (8-hour averaging period). This is followed by the limit value set in NAAQS (9000 ppb, 8-hour averaging period) and HN 23:2011 (20000 ppb, 8-hour averaging period).

It was determined that the highest and average concentrations of VOC measured during stages 1-4 meet the requirements of the WHO (hygienically safe). There are no limit values of VOC set in HN 23:2011 and NAAQS standards.

The WHO generally recommends keeping concentrations of VOCs below 200 µg/m³ to protect public health (WHO Guidelines….). After comparing measured VOC concentrations in indoor air with the strictest recommendations of the WHO (below 200 µg/m³), it was determined that the average concentrations of VOC exceeded the permissible value by 1.41-1.49 times, and the highest VOC concentrations exceeded it by 1.64-1.82 times accordingly.

CO concentrations measured in schools in China were between 17.5 and 1410 ppb (Zhu et al. 2021). The measured concentration of CO in the selected smart building's indoor air was within this range.

The concentrations of TVOCs (total volatile organic compounds, according to toluene) ranged from 219.2 to 14,546 µg/m³ in private homes, and they approximately equal 57.4-3,811 ppb (Mai et al. 2024). The measured concentration of VOC in the selected smart building's indoor air was in the same range.

The effectiveness of the complex air treatment device increases when pollutant concentrations are closer to or exceed permissible levels. The research results indicate that the average concentrations of the air pollutants measured were low; thus, the efficiency of the air cleaning device was also low. Compared to stage 2, where ventilation was not functioning, the average concentrations of tested air pollutants during stage 3 were lower. Throughout the research conducted during stages 1 to 4, the average meteorological parameters in the office were determined as follows: relative humidity at approximately 33.2%, air temperature at 23.8°C, and air pressure at 99.681 kPa.

## 4. Conclusions

After analyzing the data from the four stages, it was observed that the peaks (maximum values) of air pollutant concentrations typically occur between 8 and 10 a.m. and in the evening around 4-6 p.m., before the end of the workday. During other working hours, peaks in air pollutant concentrations were less frequent. This pattern may be attributed to the accumulation of pollutants in the room and/or the morning and evening increase in road traffic.

The measured highest and average VOC concentrations were following the limit values for indoor environments specified in the analyzed international standards, except for the strictest WHO standard, which recommends a VOC concentration below 200 µg/m³.

The measured maximum CO concentrations were in line with the limit values for indoor environments given in the analyzed international standards. They were more than 15 times lower than the strictest limit value.

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