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Investigation of indoor and outdoor air quality in a university campus during COVID-19 lock down period

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A B S T R A C T

The pandemic of COVID-19 currently shadows the world; the whole earth has been on an unprecedented lockdown. Social distancing among people interrupted domestic and international air traffic, suspended industrial productions and economic activities, and had various far-reaching and undetermined implications on air quality. Improvement in air quality has been reported in many cities during the lockdown. On March 22, 2020, the Turkish government enforced strict lockdown measures to reduce coronavirus disease transmission. This lockdown had a significant impact on the movement of people within the country, which resulted in a major drop in worldwide commercial activities. During this period, university campuses were emptied due to the transition to distance education. In this study, various air pollutants sulfur dioxide (SO2), nitrogen dioxide (NO2), ozone (O3), fine particulate matter (PM2.5), total bacteria, and total fungi were measured in different indoor environments at Eskisehir Technical University Campus in Eskisehir, Turkey during COVID-19 lock down period. Also, to calculate the indoor and outdoor ratios (I/O) of the pollutants, simultaneous outdoor measurements were also carried out. The average indoor SO2, NO2, O3, and PM2.5 concentrations in different indoor environments ranged between 2.10 and 54.58, 1.36–30.89, 12.01–39.05, and 21–94 μg/m3, respectively. The total number of bacteria and fungi ranged between 21.83–514.15 and 13.10–83.36 CFU/m3, respectively. Our study intends to give a glimpse to quantify the impact of a pandemic on air quality in different indoor environments in a university campus in Eskisehir, Turkey and calls for follow-up studies. Indoor concentrations were evaluated together with outdoor concentrations. In general, it can be said that the calculated I/O ratios for SO2, NO2, O3, bacteria, and fungi were less than 1 in most indoor environments.

1. Introduction

On March 11, 2020, the Ministry of Health of Turkey confirmed the first imported case of coronavirus disease (COVID-19) [1], caused by SARS-CoV-2 (Severe Acute Respiratory Syndrome causing Coronavirus) [2,3]. COVID-19 was initially reported in December 2019 in a small cluster in Wuhan (Province of Hubei, China) and subsequently spread worldwide [4]. The lockdown response to coronavirus disease in 2019 (COVID-19) led to a significant decline in global economic and transport activity [5]. Lockdown steps also included partial or full closure of international borders, schools, and non-essential industries and, in some cases, limited movement of people. In some places, the outdoor air we were exposed to was fresher than before the pandemic. Hypothesized that shutdowns resulted in much lower emissions of travel-related and commercial-related air contaminants, while other sources of air pollution remained constant or even increased [6]. The pollutants derived from the excess use of electricity due to our new intensely domestic lifestyle tend to be increased. Generally, the reduction in traffic and industry from the pandemic has socioeconomic and environmental impacts that still need to be quantified.

Indoor and outdoor air quality are the most significant factors affecting the quality of our life in general. We breathe 10 m3 of air every
day and spend 80–95% of our lives indoors [7]. Indoor air pollution can lead to health problems, odors, discomforts and irritation, diseases, cancer, and even increased human mortality [8,9]. Also, some air pollutants affect the construction materials and the structure of the building itself [9]. It was reported that long-term exposure to air pollution, including PM₁₀ and O₃, is estimated to cause more than 8.8 million deaths per year [10,11]. At the same time, NO₂ exposure results in 4 million new cases of pediatric asthma per year [12]. SO₂ is associated with damage to respiratory symptoms and premature death. SO₂ and NO₂ are classified as primary pollutants, whereas O₃ is a secondary pollutant in the troposphere due to the photochemical reactions between NO₃ and VOCs [13,14]. High atmospheric SO₂ concentrations are primarily due to sulfur-containing fuels such as coal for domestic heating purposes in urban areas [14,15]. PM₂.₅ is emitted from anthropogenic sources such as the combustion of fossil fuels, manufacturing, domestic heating, and exhausts of automobiles (e.g., elemental carbon) [16,17]. Air contains many microorganisms, which act as a transmission or dispersal medium. Biological agents may be released into the air as single unattached microbial cells (viruses, bacteria, fungi), as clumps consisting of several microorganisms, or intact cells or cell fragments may be attached to other suspended particles. Biological agents are fungi and other organic compounds discovered indoors have attracted scientific interest [22]. In general, indoor air contaminants cause two forms of health effects such as short-term (acute) effects and long-term (chronic) effects. Short-term health effects such as eye, nose, mouth, and skin irritation, headache, dizziness, and fatigue occur after a single or prolonged exposure which is the same as the common cold or other viral diseases [20,23]. Long-term or chronic health effects can be as worst as chronic bronchitis, adverse reproductive outcomes, and pregnancy-related problems, such as stillbirths and low birth weight, and lung cancer [24].

Airborne microorganisms are commonly present in the atmosphere and metabolically active, comprising a large portion of airborne particles [25]. The air disperses various pathogenic bacteria and allergenic fungi that affect human health, wildlife, and plants, which can be transported with the airflow, thus influencing the entire ecosystem [26, 27]. Many previous researchers investigated microorganisms distribution in the outdoor and indoor environments in the urban and rural atmospheres [28]. For example, Lighthart & Shaffer [29] and Després et al. [28] investigated the airborne cultivable bacteria in the outdoor urban and rural sites. It was noticed that most of the studies pay attention to the indoor cultivable microorganisms [30–32]. Griffin [34] and Montell et al. [35] showed that microorganisms could attach and transmit airborne particles over a long-range, in the downwind areas, which airflows capable of carrying particulates and microorganisms have contributed to an increase in the abundance and diversity of microorganisms. The aerodynamic diameter of most airborne bacteria and fungi ranges 1–3 μm and 2–4 μm, respectively [35]. Accordingly, it can be said that bacteria and fungi have almost similar dimensions to PM₂.₅ and PM₁₀ [36] so that they can occupy and transmit airborne particles easily. It was recognized that the levels of microorganisms dispersed throughout the atmosphere were strongly correlated with air pollutant concentrations [37]. In the studies of Griffin [34] and Montell et al. [33], it was found that the levels of PM₂.₅ and PM₁₀ were positively correlated with airborne microbial concentrations, and also Ho et al. [38] found a positive correlation between NO₂, SO₂, and CO concentrations and microbial concentrations. In addition, the effect of temperature in the atmosphere and air movement on indoor microbial and other pollutants was investigated [13,39,40]. While atmospheric air movements are among the most critical factors in pollutant transport, outdoor air is also mentioned among indoor pollutants and ventilation sources. The relationship between ventilation and indoor pollutant concentrations is discussed in detail in section 3.4. It was also reported that positive correlations were observed between the amount of sunlight and the indoor air of culturable bacteria [41]. Together with temperature, intensity of solar radiation can have a significant influence on the viability of microorganisms and gram positive bacteria are more resistant to higher solar radiation as compared to gram negative ones [42,43].

Natural and man-made disasters degrade the quality of life for humans and the environment. These events generate new knowledge and technologies that can be used to prevent and mitigate future disasters, improve people’s quality of life, and ensure their safety. The COVID-19 pandemic has reduced global city traffic several times, accompanied by a noticeable economic recession, a decrease in industrial emissions that pollute city air, and a decrease in greenhouse gas emissions that may have climatic effects [44]. Le et al. [45] stated that during the COVID-19 pandemic in China, motor vehicle traffic was suspended, and manufacturing was halted. Satellite and ground-based observations indicated that certain emissions were reduced by up to 90% during the city-lockdown period. Ginzburg et al. [46] present the findings of an analysis of changes in Moscow’s atmospheric air quality during the lockdown period and the subsequent decline in business activity caused by the COVID-19 coronavirus pandemic. The concentrations of the major pollutants in the atmosphere decreased by 30%–50% during the lockdown period. Moreover, Shi et al. [47] quantify changes in ambient NO₂, O₃, and PM₂.₅ levels in 11 cities worldwide by utilizing a weathering machine learning technique. They observed a sudden decrease in weathered NO₂ concentrations attributable to the lockdowns at (10–50%), increases in O₃ in almost all cities by (2–30%), and a decrease in PM₂.₅ concentrations in most cities studied but an increase in London and Paris. Furthermore, Huang et al. [48] air quality data collected during the COVID-19 lockdown in Hong Kong, China, in January–April 2020 was compared to data collected during the same period in 2017–2019. The roadside and ambient NO₂, PM₁₀, PM₂.₅, CO, and SO₂ concentrations were found to be lower in 2020 when compared to the previous years’ data (2017–2019), whereas the concentration of O₃ was higher.

Indoor air quality in workplaces, schools, universities, and residential environments caught the attention of scientists and the public in recent years [51,49,66]. The condition of the university campus buildings and the furnishings and fittings of the classrooms, offices, laboratories, canteens, corridors, etc., are highly variable. Since students, academicians, and the other administrative support staff spend on average 7–9 h per weekday at the university campus, mostly indoors, the indoor and outdoor air quality in university buildings are expected to be key role players in the assessment of the effects of their personal exposure to air pollution. This article aimed to determine indoor air quality in a University campus during pandemic period. COVID-19 pandemic lockdown events between March and the middle of June 2020 are associated with reductions in some air pollutants concentrations. With the onset of the pandemic, distance education started in universities in Turkey, and therefore human, and vehicle density in the university campuses decreased considerably. To examine the impact of the mentioned reduction on indoor and outdoor air pollution in the university campuses, the levels of NO₂, SO₂, O₃, and PM₂.₅ and also microbial pollutants such as total bacteria and total fungi were measured in various indoor and outdoor environments in a university campus in Eskişehir, Turkey. Using simultaneous indoor and outdoor sampling
results, Indoor/Outdoor concentration ratios (I/O) for all pollutants were calculated. Also, the contribution rates of each pollutant to indoor air pollution were investigated for all buildings where the sampling studies were carried out.

2. Material and method

2.1. Sampling locations and sampling program

In this study, gaseous (NO$_2$, SO$_2$, and O$_3$), particulate (PM$_{2.5}$), and microbial (total bacteria and fungi) pollutant levels were measured in various indoor and outdoor environments in Eskişehir Technical University Campus in Eskişehir, Turkey. The campus is located in the north of the city. The locations of the buildings where indoor and outdoor sampling points are located are shown in Fig. 1. The campus has a school of foreign languages, earth and space sciences institute, institute of graduate program, aeronautics and astronautics, engineering faculty, faculty of sport science, environmental research center, seismic research center, mess hall, deanery, and rectorate building. The university has active registered 8035 students (according to May 2019 data). 49 indoor and 9 outdoor points were selected for the pollutant measurements. Among the 49 indoor sampling points, there are 8 offices, 8 laboratories, 5 classrooms, 10 various places (storage areas, workshops, etc.), 5 points in different cafeterias (student’s and teacher’s cafeterias), 3 points from the different departmental canteens, 10 points in a multi-purpose sports hall. Detailed information about the properties of the sampling points and the numbers of the collected samples are presented in Table S1. The sampling studies were conducted between June 8 and 18, 2020, and the passive samples for NO$_2$, SO$_2$, and O$_3$ were collected for 10-day concurrently. The university campus was empty for both students and employees during the sampling period in the summer. As in many parts of the world, education was carried out remotely for almost 2 years during the pandemic period. During those months, the vacancy situation on the campus was always the same. While the microbial samples were collected by passive sampling for 1 h, 15-min online PM$_{2.5}$ measurements were performed at each point. PM$_{2.5}$ sampling checked the instant concentrations as departments were empty due to the COVID-19 pandemic lockdown. Only two instruments were available to measure the concentration of PM$_{2.5}$. Microbial contaminant samples were collected on the first day of passive sampling. They were placed simultaneously with the passive samplers and collected 1 h later. PM$_{2.5}$ measurements were also completed in the first two days of passive sampling.

2.2. Preparation and analyses of gas-phase samples and PM$_{2.5}$ measurements

The concentrations of the inorganic gaseous pollutants (NO$_2$, SO$_2$, O$_3$) were determined using passive samplers developed by Air Quality Research Group in Eskişehir Technical University Environmental Engineering Department, and the samplers have been used in several studies [51-56]. Passive air sampling is more desirable than other sampling techniques because it enables simultaneous sampling of spatial variability and exposure levels at multiple locations [13,57]. In this study, two different passive samplers were used for the inorganic pollutant samplings. The dimensions (2.5 cm length and 2 cm inner diameter) and main parts (plastic body, plastic ring, and stainless steel mesh barrier and close cap) of all the passive samplers were the same. Still, the materials of the samplers and collecting mediums were different [51]. O$_3$ sampler was made from Delrin, while NO$_2$–SO$_2$ passive sampler was made from Teflon [52]. NO$_2$ and SO$_2$ can be sampled in the same collecting medium in the same sampler. Whatman GF/A fiberglass filter paper impregnated with 20% TEA aqueous solution for NO$_2$–SO$_2$ and 1% NaNO$_2$ + 2% Na$_2$CO$_3$ + 2% aqueous glycerol solution for O$_3$ were used [52,54,56,40]. The impregnated filter papers were dried, placed in the samplers, and secured with a fixing ring. 120 passive samplers for inorganic pollutants (including four blank samplers) were collected during 10 days. After sampling, filter papers in NO$_2$–SO$_2$ passive samplers (Whatman GF/A, Sigma-Aldrich Co., Taufkirchen, Germany) were extracted with 10 mL of ultrapure water (Milli Q) and 0.02 mL of 35% H$_2$O$_2$ for 15 min. Also, filter papers of the O$_3$ sampler were extracted with 10 mL Milli Q ultrapure water (Millipore, USA) for 15 min [53,54]. The solution for each sample was then placed in vials and analyzed by using a Dionex-1100 ion chromatograph. Inorganic pollutant concentrations were determined based on Fick’s first law of diffusion. PM$_{2.5}$ concentrations were measured using two DustTrak aerosol monitors (Model 8530, TSI Inc.). The aerosol monitors calibrated by the manufacturing company were tested by comparing them with each other before starting the measurement studies. Previously calibrated monitors are set to a 1-min measurement interval, so each monitor recorded 15 data for a 15-min measurement for each sampling point. Zero calibration was also conducted on the aerosol monitors before each measurement [58].

2.3. Preparation and analyses of microbial samples

Microbiological samples were collected by a passive method based on the 1/1/1 scheme (for 1 h, 1 m from the floor, at least 1 m away from
walls or any obstacle) [59]. Accordingly, petri dishes containing sterile media were placed 1 m above the ground and 1 m away from any structure such as walls, windows, and doors. Two petri dishes, one for bacteria and one for fungi, were placed at each sampling point. Tryticase Soy Agar was used for total bacteria, and chloramphenicol added Sabaroud Dextrose Agar (SDA) was used for total fungi. The growth media were exposed to indoor air, then transferred to the laboratory under suitable conditions, and incubated at 37 °C for 24 h for bacteria and at 28 °C for 7 days for fungi. Naked eye count quantified bacteria and fungi levels according to the methodologies expressed in ISO 4833:2013 [60] and EN 13098:2000 [61]. Once colony forming units (CFU) were counted, colony-forming units per cubic meter (CFU/m³) were calculated considering equation (1) explained below described by Fekadu and Getachewu [62].

\[ N = 5a \times 10^y (bt)^{-1} \]  

(1)

where \( N \) is microbial CFU/m³ of indoor air, \( a \) is the number of colonies per Petri dish, \( b \) is Petri dish surface area (cm²), \( t \) is the exposure time (minutes). Moreover, IMA was estimated as colonies per sampling time and petri dishes’ surface area (CFU/m³).

3. Results and discussion

3.1. Concentrations of inorganic gas pollutants (SO₂, NO₂, and O₃)

In this study, concentrations of SO₂, NO₂, O₃, PM₂.5, total bacteria, and total fungi were determined in different indoor and outdoor environments of a university campus in Eskişehir, Turkey. The indoor and outdoor concentrations of the inorganic gas pollutants such as SO₂, NO₂, and O₃ measured at each sampling point selected from the various buildings in the university campus are shown in Table 1, while the indoor and outdoor concentration ratios of these measured pollutants are shown in Table S2.

The average indoor SO₂ concentrations obtained from various departments ranged between 2.10 ± 0.90–54.58 ± 31.97 μg/m³ (Table S2). Among all indoor environments, the minimum average indoor SO₂ concentration (2.10 ± 0.90 μg/m³) was measured in the faculty of sports science. At the same time, the earth and space science institute had the highest average indoor SO₂ concentration (54.58 ± 31.97 μg/m³). The lowest indoor SO₂ concentration (0.91 μg/m³) was measured in the classroom of the faculty of engineering, while the office in the earth and space sciences institute had the highest indoor SO₂ concentration (77.18 μg/m³) among all the sampling points within the departments of the university. The average indoor concentrations of SO₂ in the rector building 6.70 ± 1.16 μg/m³, faculty of engineering 9.26 ± 8.80 μg/m³, environmental research center 10.78 ± 13.08 μg/m³, faculty of sports science 2.10 ± 0.90 and cafeterias 7.96 ± 4.96 μg/m³ were lower than their outdoor concentrations of 15.91 ± 55.09, 22.06 ± 13.42, 18.17 ± 16.42 μg/m³, respectively. In contrast, the average indoor concentrations of SO₂ in the faculty of aeronautics and astronautics/civil aviation (17.46 ± 13.31 μg/m³) and seismic research center (21.45 ± 1.66 μg/m³) were higher than the outdoor concentrations (17.19 μg/m³, 15.91 μg/m³, respectively). This finding can be explained by the proximity of the sampled indoor environment to the pollution sources. However, in the engineering dean building, the school of foreign languages, earth and space sciences institute, seismic research center, institute of the graduate program, the average indoor concentrations of SO₂ were compared with the outdoor concentrations measured in the closest outdoor environments since direct outdoor SO₂ samples were not taken from these departments. Because these departments were close to other buildings from which the outdoor samples were generally taken. The indoor average SO₂ concentrations measured in engineering dean building, school of foreign languages, earth and space sciences institute, and institute of graduate program buildings were 3.11 ± 1.16, 2.84, 38.09 ± 31.97, and 2.43 ± 1.17 μg/m³ (Table S2), respectively, which

| Sampling points | SO₂ (μg/m³) | NO₂ (μg/m³) | O₃ (μg/m³) | PM₂.5 (μg/m³) | Bacteria (CFU/m³) | Fungi (CFU/m³) |
|-----------------|-------------|-------------|------------|---------------|------------------|----------------|
| Office          | 1.59        | 4.63        | 26.61      | 56            | 65.50            | 157.19         |
| Office          | 2.97        | 4.87        | 42.07      | 37            | 65.50            | 130.99         |
| Classroom 1     | 3.76        | 0.04        | 8.06       | 32            | 52.40            | 144.09         |
| Classroom 2     | 23.79       | 2.62        | 11.22      | 72            | 26.20            | 78.60          |
| Canteen         | 27.77       | 3.87        | 12.06      | 31            | 26.20            | 288.18         |
| Canteen         | 23.40       | 4.70        | 19.71      | 61            | 39.30            | 157.19         |
| Office          | 5.75        | 2.32        | 23.03      | 70            | 78.60            | 183.39         |
| Workshop lab.   | 1.46        | 3.70        | 16.47      | 42            | 13.10            | 39.30          |
| Classroom 1     | 3.76        | 0.04        | 8.06       | 32            | 52.40            | 144.09         |
| Classroom 2     | 23.79       | 2.62        | 11.22      | 72            | 26.20            | 78.60          |
| Canteen         | 27.77       | 3.87        | 12.06      | 31            | 26.20            | 288.18         |
| Canteen         | 17.19       | 5.21        | 9.75       | 35            | 26.20            | 288.18         |
| Corridor        | 13.40       | 4.70        | 19.71      | 61            | 39.30            | 157.19         |
| Outdoor         | 55.09       | 7.60        | 70.01      | 50            | 1244.42          | 117.89         |
| Aerodynamics    | 10.77       | 3.57        | 8.63       | 46            | 26.20            | 78.60          |
| Material testing lab. | 10.98 | 3.63       | 16.63      | 28            | 13.10            | 0              |
| Hydraulic system lab. | 44.17 | 3.98       | 9.84       | 47            | 26.20            | 52.40          |

(continued on next page)
were lower than their outdoor concentrations such as 15.56 μg/m³ (campus entry outdoor), 16.42 μg/m³ (cafeterias outdoor), 55.09 μg/m³ (faculty of aeronautics and astronautics/civil aviation outdoor) and 16.42 μg/m³ (cafeterias outdoor), respectively while SO₂ concentration (21.45 ± 1.66 μg/m³) measured in seismic research center was higher than its outdoor concentration (15.91 μg/m³) (rector building parking area). The outdoor SO₂ concentrations measured at the few sites were 15.91 μg/m³ in rector building parking, 17.17 μg/m³ and 55.09 μg/m³ in the outdoors of the faculty of aeronautics and astronautics/civil aviation department (there are two outdoor points), 22.06 μg/m³ in engineering faculty parking area, 18.17 μg/m³ in (faculty of sports science indoor sports hall parking area), 13.42 μg/m³ (environmental research center), 16.42 μg/m³ (cafeterias), 15.56 μg/m³ (campus entry outdoor) and 34.50 μg/m³ (campus exit) (Table 1). SO₂ is the main oxide of sulfur found in indoor air; however, the indoor concentrations determined inside school buildings are generally lower than those [21].

World Health Organization [63] proposed a guideline value for indoor SO₂ as 20 μg/m³ for the 24-h mean. Although the sampling times in our study are not the same as the time intervals in the WHO values, they were compared with the WHO guideline values. In this study, it was seen that the average indoor concentrations of SO₂ in most of the departments were below the guideline value of 20 μg/m³ for the 24-h mean. However, in three departments like earth and space sciences institute, seismic research center, and faculty of sports science, the average indoor concentrations of SO₂ which were 54.58, 21.45, and 26.58 μg/m³, respectively, exceeded the guideline value of 20 μg/m³ for the 24-h mean (Table S2). The average indoor concentrations of SO₂ found in this study (2.84–54.58 μg/m³) were higher than the concentrations of SO₂ measured in various studies like 5–16 μg/m³ by Lee and Chang [64] in 5 schools in Hong Kong, 0.1–2.4 μg/m³ by Strange et al. [65] in 27 schools of Antwerp, Belgium and 2.7–4 μg/m³ by Bozkurt et al. [66] in 3 schools of Kocaeli, Turkey, while as they were lower than the concentrations of SO₂ (60–641 μg/m³) calculated by Zhao et al. [67] in 10 schools of Taiyuan, China. This reduction in the average indoor SO₂ concentrations in this study compared with the review literature can be due to the less movement in the university departments as the work was conducted during the COVID-19 pandemic lockdown. In contrast, the works mentioned above were performed before the COVID-19 pandemic lockdown period. A more detailed comparison of SO₂ concentrations found in university campus during the COVID-19 pandemic lockdown period compared with review literature done before the COVID-19 pandemic lockdown period can be seen in Table 4.

Average indoor NO₂ concentrations measured in various indoor environments in the university campus ranged between 1.36 ± 1.82–30.89 ± 39.09 μg/m³ (Table S2). Among all departments, the campus earth and space sciences institute had the minimum average indoor NO₂ concentration (1.36 ± 1.82 μg/m³), while the seismic research center had the highest average indoor NO₂ concentration (30.89 ± 39.09 μg/m³). Classroom 1 in the faculty of aeronautics and astronautics/civil aviation had the lowest indoor NO₂ concentration (0.04 μg/m³), while the seismic research control center in the seismic research center had the highest indoor NO₂ concentration (58.53 μg/m³) among all sampling points within the department (Table 1). The average indoor concentrations of NO₂ in the rector building (2.18 ± 1.90 μg/m³), faculty of aeronautics and astronautics/civil aviation (3.09 ± 1.45 μg/m³), faculty of sports science (3.81 ± 1.53 μg/m³), environmental research center (3.71 ± 0.93 μg/m³) and cafeterias (4.54 ± 0.63 μg/m³) were lower than their outdoor concentrations (4.86, 7.60, 26.96, 5.28 and 5.48 μg/m³, respectively). Moreover, the average indoor concentration of NO₂ in the faculty of engineering (6.99 ± 6.44 μg/m³) was higher than the outdoor concentration (4.80 μg/m³). In-office and school environments, the outdoor air is a possible source of NO₂ [68,69]. However, in the engineering dean building, school of foreign languages, earth and space sciences institute, seismic research center, and institute of the graduate program, the average indoor concentrations of NO₂ were compared with the closest outdoor NO₂ concentrations similar to SO₂ evaluation. The average indoor NO₂ concentrations in engineering dean building, school of foreign languages, earth and space sciences institute, and institute of the graduate program were 1.72 ± 1.38, 2.82, 1.36 ± 1.82, and 2.74 ± 2.66 μg/m³, respectively, which were lower than their outdoor concentrations that are 6.67 μg/m³ (campus entry outdoor), 7.06 μg/m³ (Faculty of aeronautics and astronautics/civil aviation outdoor) and 5.48 μg/m³ (cafeterias outdoor). Moreover, the average indoor NO₂ concentration in the seismic research center (30.89 ± 39.09 μg/m³) was higher than its outdoor concentration (4.86 μg/m³) (rector building parking area). The outdoor NO₂ concentrations measured at the few sites were 4.86 μg/m³ (rector building parking area), 5.21 μg/m³ and 7.60 μg/m³ (two outdoor samples of faculty of aeronautics and astronautics/civil aviation department), 4.80 μg/m³ (engineering faculty parking area), 12.84 μg/m³ (faculty of sports science indoor sports hall parking area), 5.28 μg/m³ (environmental research center), 5.48 μg/m³ (cafeterias entry outdoor), 6.67 μg/m³ (campus entry outdoor) and 7.98 μg/m³ (campus exit outdoor) (Table 1). NO₂ is usually formed from combustion processes in furnaces, gas appliances, and smoke from cigarettes [70].

Table 1 (continued)

| Sampling points | SO₂ (μg/m³) | NO₂ (μg/m³) | O₃ (μg/m³) | PM₁₀ (μg/m³) | Bacteria (CFU/m³) | Fungi (CFU/m³) |
|----------------|------------|------------|------------|--------------|-----------------|----------------|
| Indoor sport hall | 7.32 | 6.34 | 21.51 | 65 | 26.20 | 0 |
| Outdoor sport hall | 17.48 | 4.06 | 26.33 | 48 | 13.10 | 65.50 |
| Indoor sport hall parking (outdoor) | 18.17 | 12.84 | 60.34 | 32 | 785.95 | 261.98 |
| Multi-purpose sport hall | 36.65 | 4.75 | 22.64 | 46 | 52.40 | 785.95 |
| Indoor sport hall parking (outdoor) | 36.76 | 2.28 | 5.81 | 41 | 13.10 | 104.79 |
| Indoor sport hall parking (outdoor) | 14.26 | 4.75 | 19.92 | 48 | 0 | 13.10 |
| Indoor sport hall parking (outdoor) | 27.31 | 2.85 | 4.69 | 40 | 39.30 | 681.16 |
| Environmental Research Center | 5.20 | 2.63 | 13.04 | 45 | 26.20 | 78.60 |
| Office (2. floor) | 3.97 | 4.27 | 22.73 | 50 | 52.40 | 52.40 |
| Corridor (2. floor) | 25.86 | 4.21 | 10.72 | 66 | 13.10 | 157.19 |
| Laboratory | 13.42 | 5.28 | 21.93 | 54 | 576.36 | 615.66 |
| Cafeterias | 16.42 | 5.48 | 67.20 | 52 | 654.96 | 1047.93 |
| Student cafeteria | 3.72 | 3.76 | 24.78 | 61 | 65.50 | 39.30 |
| Student cafeteria (sitting area) | 9.72 | 4.28 | 16.55 | 87 | 235.79 | 26.20 |
| Teacher’s cafeteria (kitchen) | 14.18 | 5.10 | 6.48 | 154 | 1729.09 | 484.67 |
| Teacher’s cafeteria (kitchen) | 4.19 | 4.99 | 27.57 | 72 | 26.20 | 39.30 |
| Teacher’s cafeteria (sitting area) | 15.56 | 6.67 | 53.18 | 52 | 1663.59 | 314.38 |
| Campus (entry) outdoor | 34.50 | 7.98 | 174.85 | – | – | – |
| Campus (exit) outdoor | 2.30 | 2.66 | 13.04 | 45 | 26.20 | 78.60 |

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different environments within the university campus in this study were close to the indoor NO$_2$ concentrations measured in other studies carried out by Demirel et al. [55] (8.2–27.06 μg/m$^3$) in 2 schools of Eskişehir, Turkey, by Bozkurt et al. [66] in 3 schools of Koçaeli, Turkey (22.2–26.6 μg/m$^3$) and were lower than the values found by Can et al. [51] in painting and printmaking departments (13.47–89.77 μg/m$^3$). This reduction in the average indoor NO$_2$ concentrations in this study compared with the review literature can be due to the less movement in the university departments as the work was conducted during the COVID-19 pandemic lockdown while as the above mentioned works were conducted before the COVID-19 pandemic lockdown period. The more detailed comparison of NO$_2$ concentrations found in university campus during the COVID-19 pandemic lockdown period compared with other studies done before the COVID-19 pandemic lockdown period can be seen in Table 4.

The average indoor O$_3$ concentrations in different departments ranged between 12.01 ± 4.68–39.05 ± 28.73 μg/m$^3$ (Table S2). Among all departments in the university campus, the faculty of aeronautics and astronautics/civil aviation had the minimum average indoor O$_3$ concentration (12.01 ± 4.68 μg/m$^3$), while the seismic research center had the highest average indoor concentration (39.05 ± 28.73 μg/m$^3$). The office in the faculty of aeronautics and astronautics/civil aviation had the lowest indoor O$_3$ concentration (5.47 μg/m$^3$). In contrast, the seismic research center control center in the seismic research center had the highest indoor O$_3$ concentration (59.53 μg/m$^3$) among all sampling points within the departments. The average indoor concentrations of O$_3$ in rector building (15.68 ± 12.04 μg/m$^3$), faculty of aeronautics and astronautics/civil aviation (12.01 ± 4.68 μg/m$^3$), faculty of engineering (13.07 ± 7.40 μg/m$^3$), faculty of sports science (15.25 ± 6.55 μg/m$^3$), environmental research center (15.50 ± 6.36 μg/m$^3$) and cafeterias (18.85 ± 9.48 μg/m$^3$) were lower than their outdoor concentrations (95.78, 70.01, 144.26, 60.34, 21.93 and 67.20 μg/m$^3$, respectively). Reduced ventilation may cause lower O$_3$ levels in various indoor environments since outdoor O$_3$ concentrations are higher than indoor concentrations. Indoor O$_3$ concentrations are also reduced due to the deposition of O$_3$ on various surfaces, and chemical reactions have also been reported in the literature [71,72]. However, in the engineering dean building, school of foreign languages, earth and space sciences institute, seismic research center, and institute of the graduate program, the average indoor O$_3$ concentrations were compared with the closest outdoor O$_3$ concentrations. The average indoor O$_3$ concentrations in the engineering dean building, school of foreign languages, earth and space sciences institute, seismic research center, and institute of the graduate program were (13.66 ± 2.53 μg/m$^3$) lower than the outdoor O$_3$ concentrations that were 53.18 μg/m$^3$ (campus entry outdoor), 21.93 μg/m$^3$ (rector building parking area) and 67.20 μg/m$^3$ (cafeterias outdoor). The outdoor O$_3$ concentrations measured at the few sites were 95.78 μg/m$^3$ (rector building parking area), 97.15 μg/m$^3$ and 70.01 μg/m$^3$ (two outdoor sampling points in the faculty of aeronautics and astronautics/civil aviation department) of 144.26 μg/m$^3$ (engineering faculty parking area), 60.34 μg/m$^3$ (faculty of sports science indoor sports hall parking area), 21.93 μg/m$^3$ (environmental research center), 67.20 μg/m$^3$ (cafeterias), 53.18 μg/m$^3$ (campus entry outdoor) and 174.85 μg/m$^3$ (campus exit outdoor). In general, indoor O$_3$ concentrations are substantially lower than outdoor concentrations unless there is critical O$_3$ sources such as O$_3$ generators, electrostatic air cleaners, photocopiers, and laser printers [71,73]. Among various gaseous air pollutants, an association of O$_3$ with adverse respiratory health effects is well reported [74,75]. Exposure to O$_3$ may increase the allergic reaction to aeroallergens by increasing the airways’ permeability and altering the immune response to allergens [76]. In the upper layer of the sky, O$_3$ protects from the harmful effects of the sun. In the lower layer, close to the earth, inhalation can be harmful in an outdoor and indoor environment. When inhaled, it can damage the lungs and irritate the throat. It results from a swift reaction between the gas and the indoor surfaces [77].

World Health Organization [63] published a new indoor guideline value for O$_3$ which is 100 μg/m$^3$ for 4-h mean; the previous guideline value was 120 μg/m$^3$ for 8-h mean published in 2000 [63]. The average indoor concentrations of O$_3$ in all the indoor environments (Table S2) were below the indoor guideline value for O$_3$ which is 100 μg/m$^3$ for 4-h mean. The average indoor concentrations of O$_3$ (12.01–39.05 μg/m$^3$) obtained from different departments within the university campus (Table S2) were lower than the indoor concentrations of O$_3$ found by Can et al. [51] (3.89–51.82 μg/m$^3$) in painting and printmaking department of Anadolu University, Eskişehir, Turkey. Also, it was lower than the value evaluated by Zhao et al. [67] in 10 schools in Taiyuan, China (3–61.2 μg/m$^3$), and was higher than the concentrations of O$_3$ found by Demirel et al. [55] in 2 schools of Eskişehir, Turkey (16.93–23.76 μg/m$^3$) and the concentrations found by Bozkurt et al. [66] in 3 schools of Koçaeli, Turkey (7–12 μg/m$^3$). This reduction in the average indoor O$_3$ concentrations in this study compared with the review literature can be due to the less movement in the university departments as the work was conducted during the COVID-19 pandemic lockdown. In contrast, the works mentioned above were performed before the COVID-19 pandemic lockdown period. A more detailed comparison of O$_3$ concentrations found in university campus during the COVID-19 pandemic lockdown period compared with other studies done before the COVID-19 pandemic lockdown period can be seen in Table 4.

### 3.2. PM$_{2.5}$ mass concentrations

The measured indoor PM$_{2.5}$ concentrations at each sampling point in different departments of the university campus are shown in Table 1. The average indoor PM$_{2.5}$ concentrations in various departments ranged between 21.00 ± 5.65–94.00 ± 41.71 μg/m$^3$ (Table S2). Among all departments, the earth and space sciences institute had the minimum average indoor PM$_{2.5}$ concentration (21 ± 5.65 μg/m$^3$), while the cafeterias had the highest average indoor PM$_{2.5}$ concentration (94.00 ± 41.71 μg/m$^3$). The corridor in the earth and space sciences institute had the lowest indoor PM$_{2.5}$ concentration (17 μg/m$^3$), while the kitchen in the cafeteria had the highest indoor PM$_{2.5}$ concentration (154 μg/m$^3$) among all sampling points within the departments. Several mostly small investigations on PM concentrations have been conducted in different countries such as Turkey [66], Hong Kong [64], Belgium [65], Netherlands [68,69], U.S [81–84,90] due to the high variability between classrooms, these studies are only of limited value for estimating typical exposure levels.

The average indoor concentration of PM$_{2.5}$ in aeronautics and astronautics/civil aviation faculty (47 ± 15.71 μg/m$^3$) was lower than its outdoor concentration (50 μg/m$^3$). While as the average indoor concentrations of PM$_{2.5}$ in the rector building (48 ± 1.41 μg/m$^3$), faculty of engineering (52 ± 15.22 μg/m$^3$), faculty of sports science (54 ± 12.3 μg/m$^3$), and cafeterias (94 ± 41.71 μg/m$^3$) were higher than their outdoor concentrations that were 40, 43, 32 and 52 μg/m$^3$, respectively. The highest indoor levels of PM$_{2.5}$ can be explained by the proximity of the sampled indoor environment to the pollution sources. The average indoor concentration of PM$_{2.5}$ (54 ± 10.97 μg/m$^3$) was equal to its outdoor concentration (54 μg/m$^3$) in the environmental research center. However, as inorganic gaseous pollutants, the average indoor concentrations of PM$_{2.5}$ were compared with the closest outdoor concentrations in the engineering dean building, school of foreign languages, earth and space sciences institute, seismic research center, and institute of the graduate program. The indoor average PM$_{2.5}$ concentrations in the engineering dean building, school of foreign languages, earth and space sciences institute (38 ± 7.34 μg/m$^3$, 44.00 μg/m$^3$, and 39 ± 5.65 μg/m$^3$, respectively) were lower than their nearest outdoor concentrations that were 52.00 μg/m$^3$ (campus entry outdoor), 52.00 μg/m$^3$ (cafeterias outdoor) and 50 μg/m$^3$ (faculty of aeronautics and astronautics/civil aviation outdoor). At the same time, the average
indoor concentrations of PM$_{2.5}$ in the seismic research center (56.50 ± 3.53 μg/m$^3$) and institute of the graduate program (63 ± 9.89 μg/m$^3$) were higher than levels measured in the nearest outdoor environment that was 40 μg/m$^3$ in rector building parking area and 52 μg/m$^3$ in outdoor of cafeterias. The outdoor PM$_{2.5}$ concentrations measured at the few sites were 40 μg/m$^3$ (rector building parking area), 35 μg/m$^3$ and 50 μg/m$^3$ (two outdoors of faculty of aeronautics and astronautics/civil aviation department), 43 μg/m$^3$ (engineering faculty parking area), 32 μg/m$^3$ (faculties of sports science indoor sports hall parking area), 54 μg/m$^3$ (environmental research center), 52 μg/m$^3$ (cafeterias) and campus entry outdoor 52 μg/m$^3$. PM in general, and especially PM$_{10}$ and PM$_{2.5}$, are associated with respiratory allergic diseases, asthma [84], and mortality [85]. PM can act as a carrier of allergens [86,87]. The health effects of PM$_{2.5}$ depend not only on its biological composition but also on its chemical characteristics. In this context, considering only PM$_{2.5}$ mass concentration as a guideline in the current air quality assessment by particles would be a limited approach since it ignores its sources, constituents, seasonal variations, and biological activity.

The PM$_{2.5}$ concentrations were not compared with the World Health Organization indoor air quality guidelines. The PM$_{2.5}$ concentrations results were just the instant concentration results and were done for the screening purpose. The average indoor concentrations of PM$_{2.5}$ found within all the departments were lower (21 ± 5.65–94 ± 41.71 μg/m$^3$) than the indoor concentrations of PM$_{2.5}$ (11–166 μg/m$^3$) measured by Stranger et al. [65] in 27 schools in Antwerp, Belgium and the concentrations calculated by Gaidajis and Angelakoglou [88] in University classrooms in Xanthi, Greece (25–144 μg/m$^3$). This reduction in the average indoor PM$_{2.5}$ concentrations in this study compared with the review literature can be due to the less movement in the university departments as the work was conducted during the COVID-19 pandemic lockdown. In contrast, the works mentioned above were performed during the COVID-19 pandemic lockdown. In contrast, the works mentioned above were performed during the COVID-19 pandemic lockdown period. The more detailed comparison of PM$_{2.5}$ concentrations found in university campus during the COVID-19 pandemic lockdown period compared with other studies done before the COVID-19 pandemic lockdown period can be seen in Table 4. The results clearly show that exposure to PM$_{2.5}$ on a university campus was variable. The wide range of PM$_{2.5}$ concentrations indicates the considerable potential for reduction and the need to identify factors responsible for this variability. Our results align with and extend the findings of previous studies on PM$_{2.5}$ levels in the indoor air of school buildings. Only limited data on indoor PM$_{2.5}$ concentration in school buildings is available. Indoor sources such as tobacco smoke and other factors such as heating can generally contribute to indoor PM levels but are unlikely to be relevant in the classrooms, offices, and laboratories we examined. For example, since smoking is usually not allowed in university campus buildings, our study had no direct connection. Heating can also be excluded as a significant indoor source because all facilities use a central heating system on the campus. We did not register any other burning inside the classrooms, offices, and laboratories.

3.3. Biological pollutants (total bacteria and total fungi count)

The calculated indoor results of the biological pollutants such as bacteria and fungi at each sampling point in different university departments are shown in Table 1. The average indoor total bacteria count in various departments ranged between 21.83 ± 13.53 CFU/m$^3$. 514.15 ± 815.05 CFU/m$^3$ (Table S2). Among all departments in the university, the faculty of engineering had the minimum average indoor bacteria count (21.83 ± 13.53 CFU/m$^3$). In comparison, cafeterias had the highest average indoor bacteria count (514.15 ± 815.05 CFU/m$^3$). The aerodynamics laboratory in the faculty of aeronautics and astronautics/civil aviation department, canteen entry in the faculty of engineering, indoor sports hall, indoor sports hall (entry-right), and athletics in the faculty of sports science had zero indoor bacteria count, while as the cafeteria kitchen was having the highest indoor bacteria count (1729.09 CFU/m$^3$) among all sampling points within the departments.

Indoor average bacteria count in the rector building (32.75 ± 9.26 CFU/m$^3$), faculty of aeronautics and astronautics/civil aviation (24.74 ± 15.28 CFU/m$^3$), faculty of engineering (21.83 ± 13.53 CFU/m$^3$), faculty of sport science (31.81 ± 28.0 CFU/m$^3$), environmental research center (30.57 ± 20.01 CFU/m$^3$) and cafeterias (514.15 ± 815.05 CFU/m$^3$) were lower than outdoor bacteria count (550.17, 1244.42, 1663.59, 785.95, 576.36 and 654.94 CFU/m$^3$, respectively). However, in the engineering dean building, school of foreign languages, earth and space sciences institute, seismic research center, and institute of the graduate program, the average indoor bacteria count was compared with the closest outdoor bacteria counts similar to SO$_2$, NO$_2$, O$_3$ and PM$_{2.5}$ as direct outdoor bacteria samples were not taken from these departments. Because these departments were close to other departments from which the outdoor samples were generally taken. The average indoor bacteria counts in these departments were 55.68 ± 27.00, 39.30, 157.19 ± 37.05, 131 ± 74.09, and 72.05 ± 9.26 CFU/m$^3$, respectively, which were lower than their outdoor bacteria count, which was 1663.59 CFU/m$^3$ (campus entry outdoor), 654.96 CFU/m$^3$ (cafeterias outdoor), 1244.42 CFU/m$^3$ (faculty of aeronautics and astronautics/civil aviation outdoor), 550.17 CFU/m$^3$ (rector building parking area) and 654.96 CFU/m$^3$ (cafeterias outdoor), respectively. The total outdoor bacteria count measured at the few sites were 550.17 CFU/m$^3$ (rector building parking area), 26.20 CFU/m$^3$ and 1244.42 CFU/m$^3$ (two outdoor sampling environments in the faculty of aeronautics and astronautics/civil aviation department), 1663.59 CFU/m$^3$ (engineering faculty parking area), 785.95 CFU/m$^3$ (faculty of sports science indoor sports hall parking area), 576.36 CFU/m$^3$ (environmental research center), 654.96 CFU/m$^3$ (cafeterias), campus entry outdoor 1663.59 CFU/m$^3$ and campus exit outdoor 1624.30 CFU/m$^3$. The quantitative interpretation of the total bacterial count results describing the air quality in the university campus’s different departments was evaluated based on the indoor standards for non-industrial premises formulated by the European Collaborative Action [89]. According to this classification, most departments fell into the pollution degree from very low to intermediate, while the cafeterias had a high pollution degree in terms of average bacteria count (Table 2) so was not in hygienic conditions. This proves

### Table 2
Assessment of air quality in all departments for bacteria and fungi as per the standards for non-industrial premises.

| Biological pollutants | Range of values | Pollution degree | Sampling points in the different departments of the university |
|-----------------------|----------------|-----------------|---------------------------------------------------------------|
| Bacteria              | <50            | Very low        | Rector building, School of foreign languages, Faculty of aeronautics and astronautics/civil aviation department, Faculty of engineering, Faculty of sports science, and Environmental research center |
|                       | 50–100         | Low             | Engineering dean building and Institute of graduate program |
|                       | 101–500        | Intermediate    | Earth and space science institute and Seismic research center |
| Fungi                 | >2000          | High            | Cafeterias |
|                       | >25            | Very high       | School of foreign languages |
|                       | 25–100         | Low             | Faculty of aeronautics and astronautics/civil aviation department, Faculty of engineering, and Environmental research center |
|                       | 101–500        | Intermediate    | Engineering dean building, Rector building, Seismic research center, Institute of graduate program |
|                       | >2000          | Very high       | Cafeterias |

*None of the departments got classified.*
that the cafeterias’ indoor air environmental conditions favor the growth and development of the bacteria population (Table 2). The average bacterial count found in our study (21.83 ± 13.53–51.45 ± 815.05 CFU/m³) (Table S2) was lower than 577–946 CFU/m³ examined by Scheff et al. [80] in 1 school in Illinois, Chicago, < 1000 CFU/m³ calculated by Lee and Chang [64] in 5 schools in Hong Kong, <2220 CFU/m³ found by Lee et al. [49] in 10 schools and offices in Hong Kong and 934–1634 CFU/m³ evaluated by Pegas et al. [90] in 3 schools in Lisbon, Portugal. This reduction in the average indoor bacteria count in this study compared with the review literature may be due to the less movement in the university departments as the work was conducted during the COVID-19 pandemic lockdown. In contrast, the works mentioned above were performed before the COVID-19 pandemic lockdown period. A more detailed comparison of fungi counts found in university campus during the COVID-19 pandemic lockdown period compared with other studies done before the COVID-19 pandemic lockdown period can be seen in Table 4.

In many human activities, microorganisms in the environment represent a hidden but dangerous risk factor. The total microbial contamination obtained for all departments is shown in Table 3. Five classes of IMA have been devised: 0–5 very good; 6–25 good; 26–50 fair; 51–75 poor; >76 very poor [95]. Each class represents a different increasing level of contamination. In practice, this choice proved useful for the aim to which it was intended. As seen in Table 3, none of the university departments had a good performance in terms of the IMA. However, the only school of foreign languages had a good performance, while most of the departments fell between fair and poor performance. Earth and space sciences institute, seismic research center, and cafeterias had very poor performances in terms of total microbial contamination. No uniform international standard is available on levels and acceptable maximum bioaerosol loads [96]. Different countries have different standards for biological pollutants. The work conducted by a WHO expert group on an assessment of health risks of biological agents in indoor environments suggested that the total microbial load should not exceed 1000 CFU/m³. If the value is higher than this, the environment is considered contaminated [18]. In another study, it is considered that 300 CFU/m³ and 750 CFU/m³ should be the limit for fungi and bacteria, respectively [97].

### 3.4. Indoor/outdoor ratios (I/O)

Several studies [55,51,65,99,98] have investigated indoor air quality in different school environments. Indoor air quality is often discussed in terms of Indoor/Outdoor (I/O) ratios. I/O ratios were calculated using indoor and outdoor measurement results (Table S2). I/O ratios for SO2 obtained in engineering dean building, rector building, school of foreign languages, earth and space sciences institute, institute of the graduate program, faculty of engineering, environmental research center, and cafeterias were <1. In the seismic research center, the faculty of aeronautics and astronautics/civil aviation department, and the faculty of sports science, the ratios were greater than 1 (Table S2). In the case of NO2, I/O ratios were lower than 1 in all departments except the seismic research center and faculty of engineering, where it exceeded 1 (Table S2). However, I/O ratios for O3 were <1 in all departments (Table S2). In general, it can be said that I/O ratios for SO2, NO2 and O3 were less than 1 in most departments, which implies that indoor pollutant sources were not dominant and also there were outdoor sources for these pollutants. The tropospheric O3 is a photochemical

### Table 3

| IMA value | CFU/m³/h | Performance |
|-----------|----------|-------------|
| 0–5       | 0–9      | Very good   |
| 6–25      | 10–39    | Good        |
| 26–50     | 40–84    | Fair        |
| 51–75     | 85–124   | Poor        |
| ≥76       | ≥125     | Very poor   |

a None of the departments got classified.
reaction product, and the increased solar radiation during summer has a crucial role in its concentrations. The high outdoor concentration of NO₂ is attributed to increased NO₂ emissions from cars in winter and the photochemical conversion of NO to NO₂ in summer. However, I/O ratios for PM₂.₅ in most departments were greater than one, which explains that there were indoor sources of PM₂.₅ in these departments, while in a few departments like engineering dean building, school of foreign languages, earth and space institute, and an environmental research center were <1. Indoor air at schools in urban areas can be contaminated by ambient urban air pollution and traffic pollutants and the vicinity of busy roads. Although, during the COVID-19 pandemic, schools and universities were closed in Turkey, the different industrial and transport sectors were running regularly. Outside the periphery of the university campus, there are passing two main highways that connect the Eskişehir with other cities of Turkey like Istanbul, Ankara, Bolu, Sakarya, etc. Apart from this, there are few link roads in this vicinity. Moreover, there is a regular municipality bus service to the other parts of Eskişehir from the university campus. Students, faculty members, and the other administrative support staff were allowed to enter the university premises during the COVID-19 period. However, the students working on the projects or thesis were also allowed to enter on the special permissions. All the activities mentioned above can’t be excluded.

Microbiological indoor air quality assessment is one of the most vital investigations to determine microbial indoor air pollution. The indoor microbial concentrations of airborne bacteria and fungi are necessary to estimate the health hazard and create indoor air quality control standards. I/O ratios for total bacteria and fungi were less than 1 in all university departments except for I/O ratios of fungi in the earth and space sciences institute, which was greater than 1 (Table S2). So, it is clear that for these biological pollutants, there were indoor sources. The atmosphere is considered a means of transportation for airborne fungi and not a habitat where they grow and reproduce. However, it may reflect the diversity and abundance of fungi in the surrounding substrates, continuously supplying the atmosphere with their spores. The aerobiological pathway includes complex, dynamic aerobiological processes that influence fungi occurrence in the ambient air. The presence of spores in the atmosphere results from fungal growth on substrates, production, successful spore liberation, dissemination through the air currents, and subsequent deposition and colonization of new substrates. In recent years, the use of synthetic materials in building and furnishing, adopting modern lifestyles, and extensive use of products for environmental cleaning and personal hygiene have contributed to the deterioration of indoor air quality and introduced new sources of risk to humans [100,101]. The sources vary depending on the type of building studied. Apart from these, two significant factors of indoor pollutants (gases, particles, and airborne microbial community) levels are highly interrelated: human occupancy and ventilation strategy [41,102-105]. Human occupancy and pollutants concentrations in the indoors have a directly proportional relationship. On the other hand, indoor air closely resembles outdoor air in a well-ventilated place regardless of human occupancy [106]. However, it cannot be argued that a mechanically or naturally ventilated indoor environment is unaffected by outdoor air pollutants [107,108]. Increased ventilation implies both bacterial and other air pollutants are transported from the outside to the inside [109]. However, if the outdoor air quality is very good, higher ventilation rates are expected to improve indoor air quality [110]. The ventilation efficiency is an air quality indicator that reflects the fresh air distribution within the space; thus, it shows a qualitative measure of the ventilation system’s performance [111]. Kwan et al. [112] explore how measured ventilation rates influence bacterial and fungal community structure and concentrations in the indoor air of homes. For indoor PM₁₀ and settled dust samples, comparative analyses of microbial communities revealed no significant bacterial or fungal community differences between samples taken from homes dichotomized into high (average high air exchange rates = 0.56 hr⁻¹) and low (average low air exchange rates = 0.16 hr⁻¹) average low air exchange rates regimes (p >0.1 for all), suggesting that ventilation was not a significant factor controlling bacterial and fungal concentrations and ecologies in the indoor air of these homes. Instead, indoor air’s bacterial and fungal content was dominated by microbes emitted from indoor sources such as resuspension.

In general, higher ventilation flow rates lead to lower average pollutant concentrations. ASHRAE 2019 [113] has recommended the standard for ventilation rates like classrooms 5 L/s per person, cafeteria, kitchen and restaurant dining rooms 3.8 L/s per person, bedroom, living rooms, laundry rooms, office buildings, and libraries 2.5 L/s per person. Other international ventilation standards included a wide range of ventilation requirements in office spaces, from 3 L/s per person to about 10 L/s per person [114]. The average chemical concentration will be linearly lowered when the ventilation flow rate increases in an adequately mixed environment [115]. Increased ventilation increases indoor air velocity and ozone transport from outdoors. O₃ concentrations in buildings were between 20 and 80% of those found outside [116]. Therefore, in naturally ventilated buildings, residents can be encouraged to open their windows during the cooler hours of the day, typically late evening and early morning, and to close their windows and retain the cool air during the hottest hours. This will result in reduced ventilation rates during periods of high ozone concentrations [116].

3.5. Contribution ratios of each measured pollutant to indoor air quality in the buildings

Air pollution, both indoor and outdoor, is one of the most severe problems of our daily time. Indoor air quality is a significant issue in healthcare, and various airborne diseases are related to indoor air quality. The concentrations and I/O ratios for each pollutant measured in the study (SO₂, NO₂, O₃, PM₂.₅, bacteria, and fungi) in the indoor environments of various departments in the campus are shown in Fig. 2 and Table S2. The earth and space science institute had the highest SO₂ concentration, while the faculty of sports science had the lowest SO₂ levels among all the sampling locations. SO₂ is the least investigated pollutant for evaluating indoor air quality in university buildings. Again, the seismic research center had the highest concentration of NO₂, while the earth and space science institute had the lowest NO₂ concentration. Motorized traffic is a significant source of air pollutants such as NOₓ and suspended PM [117]. Several studies suggest an association between living near busy roads and respiratory health [118,119]. Most of these studies have used traffic density on the street of residence and/or distance of the home address to busy roads as exposure measures. The highest mean O₃ concentration is obtained for the seismic research center, while the faculty of aeronautics and astronautics/civil aviation department contributed the least. It has been seen that the seismic research center contributed most toward NO₂ and O₃. As O₃ concentrations increase above the guideline values, health effects become increasingly numerous and severe. Such effects can occur in places where concentrations are currently high due to human activities or elevated during very hot weather episodes.

The concentration of PM₂.₅ was measured at the cafeteria, while the earth and space institute has the least among all sampling locations. The evidence on airborne PM and its public health impact consistently show adverse health effects at exposures currently experienced by urban populations in developed and developing countries. The range of health effects is broad but is predominantly to the respiratory and cardiovascular systems. All populations are affected, but pollution susceptibility may vary with health or age. In biological pollutants, the total fungi count was higher than the total bacteria count in all the university departments. The highest total bacteria count was measured in cafeterias, while the lowest was measured in the faculty of engineering. The highest fungi count was measured in the school of foreign languages, while the lower was measured in the rector building. Attention must be given to controlling environmental factors favoring microbes’ growth and multiplication in an indoor environment. Bioaerosols tend to attach in coarser PM fractions; however, fungal spores, fragmented pollen, and
non-agglomerated bacteria are found in the fine fraction [120] due to the mechanism of the reaction between biological agents and PM [121]. Bioaerosols undergo daily and seasonal changes depending on environmental factors and human activities [122]. The survival of airborne microorganisms may be affected by hydrocarbons, NO2 and SO2 [38], and trace elements [123]. PM bound with airborne pollen and fungal spores [124] could alter their biological and morphological characteristics. Indoor air quality parameters such as the level of pollutants, humidity, temperature, etc., can directly affect the health of the students and staff and the working capacity in the university. People spend most of their time indoors than outdoors; hence, indoor air pollution concentrations might significantly affect the personal exposure concentrations more than the outdoor concentrations. This indoor concentration depends upon human activities and their occupancy. Demirel et al. [55] found personal exposure concentrations were correlated with indoor home concentrations.

3.6. Comparison of the study results with the literature studies

The levels of the pollutants (SO2, NO2, O3, PM2.5, bacteria, and fungi) measured in various indoor environments within the university campus were compared with some literature (Table 4). The reviewed literature shows that many studies conducted in indoor environments like schools and universities are very limited. The studies have either focused on inorganic pollutants or PM or biological pollutants. None of the studies has examined these biological and non-biological pollutants together in schools or university campuses (Table 4). As per the author’s knowledge, this is the first study where biological and non-biological pollutants were evaluated in a university campus until today. This study’s average indoor pollutant concentrations ranged between 2.10 and 54.58 μg/m3 (SO2), 1.36–30.89 μg/m3 (NO2), 12.01–39.05 μg/m3 (O3), and 21–94 μg/m3 (PM2.5). Although air quality data at the exact locations before the lockdown was not collected, however, our research group has previously collected data from the same university, different departments [51], the same city, other schools [55], and different cities [53,54]. Overall, the concentration of SO2, NO2, and O3 in these studies was higher than the average concentration found in this study; however, in a few departments, the average concentration was slightly higher; like Can et al. [51] NO2 13.47–89.77 and O3 3.89–51.82 μg/m3, Demirel et al. [55] NO2 6.61–111.36 and O3 6.23–55.13 μg/m3, Bozkurt et al. [66] NO2 31.4, SO2 19.1 and O3 40.1 μg/m3 [54] Yurdakul et al. SO2 5.2–74, NO2 6.7–75 and O3 5.2–74 μg/m3. This might be due to the different sources present in these indoor environments, as the number of sample locations in these studies was limited.

| Location               | Study                      | Indoor Environment                  | Concentration (μg/m3) | Count (CFU/m3) |
|------------------------|----------------------------|-------------------------------------|-----------------------|----------------|
| Eskişehir, Turkey      | This study                 | University campus                   | 2.84–54.58            | 21.83–514.15    |
| South Holland          | 12 schools                 | 12 schools                           | *                     | *              |
| Illinois, Chicago      | 1 school                   | 1 school                             | *                     | *              |
| Netherlands            | 5 schools                  | 5 schools                            | 5–16                  | 13–38          |
| Detroit, Michigan      | 24 schools                 | 24 schools                           | *                     | 15.5–17        |
| Hong Kong              | 10 schools & offices       | 10 schools                           | *                     | *              |
| Antwerp, Belgium       | 27 schools                 | 27 schools                           | *                     | *              |
| Munich, Germany        | 64 schools                 | 64 schools                           | *                     | *              |
| Taiyuan, China         | 10 schools                 | 10 schools                           | 60–641.1              | *              |
| Antwerp, Belgium       | 27 schools                 | 27 schools                           | 0.1–2.4               | 54–72          |
| Xanthi, Greece         | University classrooms      | *                                   | 25–115                | *              |
| Lisbon, Portugal       | 3 schools                  | 3 schools                           | *                     | 934–1634       |
| Stockholm, Sweden      | 6 schools, 10 pre-schools & 18 homes | *                               | 2.3–29.9              | *              |
| Eskişehir, Turkey      | 2 schools                  | 2 schools                           | *                     | 2.8–19         |
| Zajecar, East Serbia   | 1 school                   | 1 school                            | *                     | *              |
| Kocaeli, Turkey        | 3 schools                  | 3 schools                           | 2.7–4                 | *              |
| Eskişehir, Turkey      | University                 | *                                   | 13.47–89.77           | *              |

Fig. 2. Concentrations of each pollutant measured in the indoor environments of the various departments of the campus.
4. Conclusion

This paper presents the results of an air quality assessment study carried out in different indoor environments in a university campus during the COVID-19 lockdown period.

- I/O ratios for \( \text{SO}_2 \), \( \text{NO}_2 \), \( \text{O}_3 \), bacteria, and fungi were less than 1 in most indoor environments, indicating that outdoor sources were more effective for these pollutants.
- The major problem related to air quality in different indoor environments of the university was associated with \( \text{PM}_{2.5} \). This \( \text{PM}_{2.5} \) investigation should be done more complexly and for an extended period, as the instant screening concentration results can differ.
- The total fungi count (1900.82 CFU/m\(^3\)) was higher than the total bacteria count in all departments.
- The indoor concentration of pollutants was less than the previous studies conducted by our research group before the COVID-19 lockdown at the same university in different departments and the same city.
- Indoor air quality assessment is one of the most vital investigations to determine microbial and non-microbial indoor air pollution. The information on the indoor concentrations of airborne \( \text{SO}_2 \), \( \text{NO}_2 \), \( \text{O}_3 \), \( \text{PM}_{2.5} \), bacteria, and fungi are necessary to estimate the health hazard and create indoor air quality control standards.
- During the last few decades, a highly debatable issue has been the health impact of indoor air quality. Each indoor micro-environment is uniquely characterized, which is determined by the local outdoor air, specific building characteristics, and indoor activities. Consequently, each individual’s exposure is determined by a combination of the local outdoor pollutant levels and the different indoor micro-environments to which he/she is exposed to and his/her residence time in each.
- Failure to prevent indoor air pollution can increase the chance of long-term and short-term health problems for students and staff, reduce teachers’ productivity and degrade the student learning environment and comfort.
- Investigating air quality in university buildings helps us to characterize pollutant levels and implement corrective measures to improve air quality.
- To improve indoor air quality, indoor environments should be kept clean. There should be adequate and regular ventilation, minimizing the number of equipments and removing unnecessary items that increase indoor air pollution.
- Lastly, regular monitoring of comfort parameters such as humidity and temperature, which are especially important for microbial pollutants, and source management of indoor air pollutants should be done.

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CRedit author contribution statement

Mansoor Ahmad Bhat: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Conceptualization. Fatma Nur Eraslan: Writing – review & editing, Visualization, Validation, Software, Formal analysis, Data curation. Alaa Awad: Writing – review & editing. Eftade O. Gaga: Writing – review & editing, Conceptualization. Ozlem Odzen Uzmez: Writing – review & editing, Visualization, Methodology. Tuncay Dogeroglu: Resources, Methodology, Conceptualization. Ozlem Odzen: Writing – review & editing, Editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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