Czech University of Life Sciences Prague

Faculty of Environmental Sciences

Department of Water Management and Environmental Modeling

Bachelor Thesis

Indoor air pollution: analysis of particulate matter levels in selected environments in the Czech Republic in 2023-24

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CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

Faculty of Environmental Sciences

BACHELOR THESIS ASSIGNMENT

MSc. Victoria Zueva

Environmental Engineering

Thesis title

Indoor Air Pollution: Analysis of Particulate Matter Levels in Selected Environments in the Czech Republic in 2023-24

Objectives of thesis

1. To conduct a comprehensive literature review on the significance of maintaining good indoor air quality, the factors contributing to its deterioration, and the resulting consequences.
2. To get familiar with common methods and instruments for measuring and monitoring indoor air pollution and apply these techniques to the study.
3. To collect both quantitative and qualitative data in predetermined locations using two instruments for measuring and monitoring indoor air quality.
4. To perform statistical comparisons of the data to evaluate in situ indoor air quality in the selected environments.

Methodology

Indoor air pollution is measured using OPS (Optical particles sizer) and P-trak instruments, which determine the amount, size, and distribution of particles in the air. Measurements are conducted in four distinct locations: residential buildings in different districts of Prague (Praha 1 and Praha 10), transportation (car), office (Průhonice), and during different seasons – summer and late autumn-winter to assess variations due to heating. Results obtained from the instruments are analyzed using software provided by the instrument manufacturers, as well as Microsoft Office Excel and RStudio if necessary. The data are then compared to national standards on indoor air quality status in the Czech Republic and the EU to draw conclusions about the air quality in the chosen indoor environments.

The proposed extent of the thesis

30

Keywords

Particulate matter, indoor environment, IAQ, IAP, SBS, PM2.5, PM10

Recommended information sources

Cincinelli, A., Martellini, T., 2017. Indoor Air Quality and Health. Int. J. Environ. Res. Public. Health 14, 1286.

Dockery DW, Pope CA, Xu X, Spengler JD, Ware JH, Fay ME, et al. An association between air pollution and mortality in six US cities. N Engl J Med. (1993) 329:1753-9.

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Declaration

I declare that I have worked on my bachelor thesis titled "Indoor air pollution: analysis of particulate matter levels in selected environments in the Czech Republic in 2023-24" by myself and I have used the sources mentioned at the end of the thesis. I declare that I have used AI tools in accordance with the university's internal regulations and principles of academic integrity and ethics. Appropriate references to the use of those tools have been made in the thesis. As the author of the bachelor thesis, I declare that the thesis does not break copyrights.

In Prague on 25.03.2024.

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ABSTRACT

This study assesses indoor air pollution by analyzing particulate matter (PM) number and mass concentrations in various indoor environments in Prague, Czech Republic, during the summer of 2023 and the winter of 2024. The research aims to elucidate the dynamics of PM, given its potential health risks, particularly respiratory and cardiovascular problems, considering the significant time individuals spend indoors. Residential apartments, workplaces, and transport settings were selected as study sites. Two portable instruments, an Optical Particle Sizer spectrometer (OPS, model 3330) and an Ultrafine Particle Counter (P-Trak, model 8525), were employed for PM measurements, focusing on PM sizes ranging from 0.01 to 10 micrometres (µm).

Activities such as cooking and cleaning, known for their potential to generate PM indoors, were selected for analysis. The influence of window ventilation was examined alongside outdoor PM comparison. Findings revealed noticeable variations in PM number and mass concentrations across different settings and activities, with levels often exceeding recommended thresholds, especially during cooking and cleaning. The observed difference between background levels with no activity and cooking/cleaning was up to 96%. PM produced by cooking persisted for up to 4 hours, resulting in prolonged personal exposure to pollution. Observed variations underscore potential health risks, particularly in environments with poor ventilation or during activities generating high PM levels. The study emphasizes the need for enhanced indoor air quality management and reviews strategies to mitigate exposure to particulate matter. These findings contribute to the broader discourse on indoor air quality, highlighting the importance of monitoring and regulating indoor environments to safeguard public health. It calls for targeted policy interventions and further research into effective PM mitigation strategies in indoor environments where personal exposure to air pollution is much worse than outside.

Keywords: particulate matter, indoor environment, IAQ, IAP, $PM_{2.5}$, PM_{10}, health impact.

ABSTRAKT

Tato studie hodnotí znečištění vzduchu v interiérech analýzou koncentrací částicového materiálu (PM) v různých vnitřních prostředích v Praze, Česká republika, během léta 2023 a zimy 2024. Výzkum si klade za cíl objasnit dynamiku PM vzhledem k jeho potenciálním zdravotním rizikům, zejména respiračním a kardiovaskulárním problémům, s ohledem na významný čas, který jednotlivci tráví v interiérech. Jako studijní místa byly vybrány bytové domy, pracoviště a dopravní prostředky. Pro měření PM byly použity dva přenosné přístroje, spektrometr optických částic (OPS, model 3330) a ultra jemný částicový počítač (P-Trak, model 8525), zaměřené na velikosti PM v rozmezí od 0,01 do 10 mikrometrů (µm). Aktivity jako vaření a úklid, známé pro svůj potenciál generovat PM v interiérech, byly vybrány pro analýzu. Vliv větrání okny byl zkoumán spolu s porovnáním PM v exteriéru. Zjištění ukázala významné rozdíly v počtu a koncentracích hmoty PM v různých prostředích a aktivitách, často překračující doporučené hodnoty, zejména během vaření a úklidu, kdy byl pozorován rozdíl mezi pozadím bez aktivity a během těchto aktivit až 96%. Životnost PM vyprodukovaného vařením trvala až 4 hodiny, což vedlo k prodlouženému osobnímu vystavení znečištění. Pozorované rozdíly zdůrazňují potenciální zdravotní rizika, zejména v prostředích s nedostatečným větráním nebo během aktivit generujících vysoké úrovně PM. Studie zdůrazňuje potřebu zlepšení řízení kvality vzduchu v interiérech a přezkoumání strategií k omezení expozice částicovému materiálu. Tyto zjištění přispívají k širšímu diskurzu o kvalitě vzduchu v interiérech, zdůrazňujíc důležitost monitorování a regulace vnitřních prostředí k ochraně veřejného zdraví. To vyžaduje cílené politické zásahy a další výzkum efektivních strategií k omezení PM v interiérech, kde osobní expozice vzdušnému znečištění je mnohem horší než venku.

Klíčová slova: částicové látky, vnitřní prostředí, kvalita vnitřního ovzduší (IAQ), znečištění vnitřního ovzduší (IAP), PM2.5, PM10, dopad na zdraví.

TABLE OF CONTENTS

1. Introduction and objectives

1.1 Introduction

Indoor air quality is a topic of great concern and interest for researchers from all over the world. That is due to the statistical fact that people spend up to 90% of their time indoors (Klepeis et al., 2001; USEPA, 2023) and, subsequently, get exposed to indoor air pollution, which has been linked to many diseases such as respiratory inflammation, ischemic heart disease, chronic obstructive pulmonary disease, lung cancer, and others. According to the WHO, 3.2 million people die yearly due to various health issues caused by household air pollution (WHO, 2022). The pandemic of COVID-19 has brought even more attention to the problem as teleworking became a new norm during 2020-2021, and now, four years later, many people still choose the option to work from home when possible (Ferreira and Barros, 2022).

Particulate matter is one of the most important indoor air pollutants. It is a mixture of airborne solid particles and liquid droplets made up of chemical, biological, and physical compounds. PM is classified according to the size. Generally, there are two categories - $PM_{2.5}$, or less than 2.5 micrometres in diameter, and PM_{10} or less than 10 micrometres in diameter. The finest particles with a diameter of fewer than 2.5 micrometres are the most dangerous for human health as they can get to the respiratory system and the bloodstream and then become deposited in the lungs, heart, and other organs of the human body, creating health risks and causing different systematic diseases (Guo et al., 2020; WHO, 2022; USEPA, 2023).

The formula for indoor air pollution consists of two parts: infiltration of pollutants from the outdoor environment and generation of pollutants from indoor sources (Thornburg et al., 2001). Every building's facade works as a filter that lets some of the outdoor pollutants into the indoor environments through windows, doors, cracks, and leaks in the building structure (Liu and Nazaroff, 2003; Hall and Spanton, 2012). In general, the location and condition of a building play a significant role in the indoor air quality status. When located near busy roads, a considerable number of pollutants (PM, along with NO_x, SO_x, etc.) can get into the indoor environment depending on the ventilation type and building condition (Abt et al., 2000; Quang et al., 2013; Park et al., 2014).

Indoor sources of PM are different in distinct environments. In residential areas, among the most significant ones are human activities such as cooking, smoking, cleaning, burning candles or aroma sticks, vacuuming, walking and resuspending particles, and even just the physical presence of human individuals (Luoma and Batterman, 2001; Hussein et al., 2006; Wallace and Ott, 2011). In offices, cleaning and the work of installed office equipment like printers and computers affect air quality the most, along with human presence, moving and therefore resuspending particles deposited on the floor, walls and other surfaces (Salthammer et al., 2012; Chatoutsidou et al., 2015). In cars, concentrations inside vehicles depend on many factors such as traffic density and the distance between cars, location of the road, speed, type of fuel, and ventilation inside a vehicle, however, it is generally 5-15x higher than outdoor concentrations (Dor et al., 1995; Wargo et al., 2002; WHO, 2005; Briggs et al., 2008; Diapouli et al., 2008; Zuurbier et al., 2010; Jalava et al., 2012; Querol et al., 2012; Dons et al., 2013).

The outdoor air is constantly monitored through measurements of pollutants at stations across the world. 198 stations in total are in the Czech Republic. The European Union has set targets to protect human health and ecosystems. $PM_{2.5}$ measured yearly must be lower than 20 $\mu g/m^3$, PM_{10} measured daily must not exceed 50 $\mu g/m^3$ 35 times per calendar year; when monitoring yearly – PM_{10} must be lower than 40 $\mu g/m^3$ (European Parliament and the Council, 2008). The WHO has its stricter limits. Daily values of $PM_{2.5}$ must be lower than 15 $\mu g/m^3$, annually – less than 5 $\mu g/m^3$. PM_{10} measured daily has to be lower than 45 $\mu g/m^3$, annually – less than 15 $\mu g/m^3$ (WHO, 2022). Ambient air quality is “good” when obtained values remain under specified threshold numbers set for monitoring daily and yearly. If the aim is not reached, member states should take measures to meet the targets for ambient air quality. In 2010 the WHO recommended applying the same thresholds for PM pollution indoors (WHO, 2010).

The focus of this study is particulate matter levels in selected environments in Prague, Czech Republic. The chosen locations are residential apartments, workplaces, and car cabin. This study aims to measure PM ranging from 0.01 to 10 micrometres (µm). Locations were chosen based on the time people spend in those environments and their frequency of use.

1.2 Objectives

The main objective of this research is to encompass the comprehensive examination and further evaluation of particulate matter levels in distinct locations according to safety and health standards set by Czech legislation and on the international level.

The study primarily focuses on conducting measurements of the PM levels in 16 bins (from 0.1 to 10 micrometers) in indoor environments using two portable instruments: Optical Particle Sizer spectrometer (OPS TSI^{TM}, model 3330) and Ultrafine Particle Counter (P-Trak TSIR, TrakPro^{TM}, model 8525).

Measurements are done in various scenarios, for instance, in different rooms of the same apartment, during distinct activities (cooking, walking, cleaning, vacuuming), with closed/opened windows/doors, during day and night; in an office, in a laboratory; in a car. These diverse scenarios aim to study the variation in PM amounts and sizes indoors under different conditions.

The study's goal is to identify the primary sources of particulate matter and their impact on indoor air quality as well as to assess associated possible health hazards. Additionally, the present research aims to provide recommendations from published studies for improving indoor air status and minimizing individual exposure to particulate matter pollution.

2. Literature review

2.1 Indoor air quality and pollution; the most common pollutants and their sources

According to the United States Environmental Protection Agency (USEPA), the World Health Organization (WHO), and the Occupational Safety and Health (OSH), indoor air quality (IAQ) refers to IAQ within and around indoor environments, such as buildings and structures, and it has a significant impact on human health and comfort (American Lung Association, 2004; WHO, 2022; USEPA, 2023). Indoor air quality may deteriorate due to outdoor air exchange (traffic, industry) and indoor air pollution (IAP). Sources of IAP are various, for instance, fuel-burning combustion appliances (including aroma sticks and candles), tobacco products, household cleaning products, personal care products (dry shampoo, sprays, and perfumes), excess moisture, and high temperature, which can result in particulate matter of different sizes (PM), volatile organic compounds (VOCs), NOx, etc. (USEPA, 2023). According to Thornburg et al. (2001) equation, indoor air pollution is comprised of two components: infiltration of pollutants from the outdoor environment and pollution generation from indoor sources. The pollutants from the outside and indoor environments mix in a relatively sealed space, often without adequate ventilation (Franchi et al., 2006). The USEPA and WHO emphasize that indoor air quality depends on the control of contaminants which can be of three types: chemical (NO_x, VOCs, etc.), physical (dust, pollen, etc.), and biological (molds, etc.). For keeping IAQ at a good level, ideally, it is necessary to provide sufficient ventilation, avoid usage of products that may produce harmful contaminants, use kitchen hoods when cooking, and maintain temperature and humidity at normal levels (optimal temperature is between 18^o and 22^o, humidity – 40-60%) (American Lung Association, 2004; WHO, 2022; USEPA, 2023).

The most common indoor air pollutants are PM, formaldehyde, VOCs, asbestos, carbon monoxide, mold, nitrogen dioxide, smoke, radon, etc. (NIEHS, 2022). For instance, since 1988, formaldehyde has been considered one of the most dangerous pollutants in indoor environments (USEPA, 2023). In research about the relationship between building materials and pollutants by Bartzis et al. (2009), it was found that formaldehyde is emitted by materials used in modern buildings. Moreover, formaldehyde is classified as a carcinogen by the International Agency of Research on Cancer (IARC, 2006).

Volatile organic compounds (VOCs) are gases also emitted by building materials used not only for the outside part of a building but also from the interiors for instance, flooring materials, paints used for wall renovation, etc. Furniture, office equipment such as printers and computers, and household cleaning products are the sources of VOCs. Exposure to VOCs may cause short- and long-term effects, from nose irritation and headache to nausea and memory impairment. On average, VOCs levels are higher indoors, especially after certain activities like cleaning - they may be 1000x higher than background outdoor levels (USEPA, 2022).

Other contaminants found in indoor spaces are carbon mono- and dioxide. Increased levels of carbon monoxide may cause headaches, dizziness, and nausea, whereas high levels of the gas may be lethal. Moreover, carbon monoxide is colourless and odourless, meaning that occupants of an indoor environment may not notice it until symptoms develop. Sources of carbon monoxide are tobacco smoke, gas stoves, malfunctioning heating systems, and vehicle exhausts that can get into the ventilation system of a building or through windows/leaks (Jones, 1999; Liu and Nazaroff, 2003; American Lung Association, 2004; Hall and Spanton, 2012; Liu C. et al., 2019). Carbon dioxide is a naturally produced gas via respiration and metabolism. Its levels are much higher in indoor environments, especially in crowded spaces. Elevated levels of CO_2 can lead to dizziness, shortness of breath, tiredness, and headaches. However, these symptoms are easy to avoid or reduce with sufficient and regular ventilation in a room. There are regulations and recommendations on the level of CO_2 in indoor environments. European Standard EN 13779 suggests keeping levels of CO_2 lower than 1000 ppm, while according to American ANSI/ASHRAE Standard 62-2001, a comfortable and safe level of carbon dioxide is less than 700 ppm (Jones, 1999; ANSI/ASHRAE, 2007; CDC, 2009).

Nitrogen dioxide presents a health hazard indoors, with primary sources including gas and wood-burning cooking stoves, kerosene heaters, smoking, and outdoor pollution, notably from vehicular traffic. Prolonged exposure to NO_2 increases susceptibility to various respiratory infections and can significantly impair lung function over time (Frampron et al., 1991).

Another concerning indoor pollutant is particulate matter. It is a mixture of airborne chemical compounds able to attach other chemical and physical pollutants such as dust and pollen. Sources of PM are various: combustion of fossil fuels, soil and dust particles, wildfires, chemical reactions in the atmosphere, extraterrestrial dust, bioaerosol, industrial processes, power plants, agricultural activities, waste burning, construction and demolition activities, vehicular emissions, including brake particles, residential cooking and heating, humans skin, particles from clothes, animals' dander, etc. (Abt et al., 2000; Luoma and Batterman, 2001; Tan and Zhang, 2004; Hussein et al., 2006; Wallace and Ott, 2011; Quang et al., 2013; Amato et al., 2014; Park et al., 2014; Vardoulakis et al., 2020). In many low- to middle-income countries, PM pollution often is caused by the usage of biomass fuels, for instance, wood, dung, and crop residues, primarily for cooking and heating purposes (Li et al., 2022; WHO, 2023). The incomplete combustion of these fuels disproportionately affects young, premature children and women, who spend significant time indoors. Consequently, residents are exposed to other harmful pollutants such as carbon monoxide, nitrous and sulfur oxides (mainly from coal combustion), formaldehyde, and polycyclic organic compounds, including carcinogens like benzo[a]pyrene (de Koning et al., 1985; Bruce et al., 2000). In developed countries, energy comes from petroleum products and electricity that are considered to be safer in terms of producing pollutants into indoor environments. When there is no indoor source of air pollution, the concentration and mass estimates of particulate matter are numerically lower and, thus, behave similarly to outdoor aerosols (Hussein et al., 2006).

Tobacco smoke is another serious indoor air pollutant, which contains thousands of particles and gases, including carbon mono- and dioxides, oxides of nitrogen, ammonia, formaldehyde, phenol, nicotine, and aniline, to name a few (Hines et al., 1993; Rando et al., 1997). Guerin et al. (1992) found out that "passive" smoking is more dangerous as such a person inhales even more different substances than an active smoker when standing at a distance of 50 cm. Consequences of inhaling cigarette smoke include manifestations of such symptoms as irritated nose-throat-eyes, coughing, allergies, and the development of diseases like asthma, bronchitis, lung malfunctioning, and cancer (Maroni et al., 1995).

Changes in physical indicators such as temperature and humidity may cause the appearance of moulds, which are another source of contamination in indoor environments. Hundreds of bacterial and fungi species grow in indoor spaces when there is a high level of moisture in the air (WHO, 2009). Communities of fungi and bacteria differ significantly depending on the indoor environment: mould in a school and an apartment are two different colonies. They consist of distinct species of microbial and/or fungal organisms (Rintala et al., 2008). Moreover, those molds are distinct in different rooms of the same apartment (Adams et al., 2014). Sources of molds are various. Prussin and Marr (2015) created a list of the eight most common and important ones – humans, pets, plants, ventilation/air conditioning systems, plumbing systems, resuspension of dust, and outdoor air.

2.2 Particulate matter as a source of human health risk

According to statistical data provided by USEPA, people spend up to 90% of their time in different indoor environments. On average, adults spend 8 hours per day at a workplace, 30 minutes to 1.5 hours per day in transportation depending on the level of urbanization of a particular location, 10-15 hours per day at home, and 1-2 hours per day in restaurants/shopping malls/fitness centres (Brasche and Bischof, 2005; WHO, 2005). It may vary due to many factors like age, gender, location, health state of an individual, monthly income, etc. Nevertheless, indoor air quality plays a substantial role in the health and comfort of people in all age groups (CDC, 2009; USEPA, 2023). In 2000, following scientific works in the indoor air quality field, the WHO recognized the right to breathe clean indoor air as a fundamental right of humanity as deteriorated indoor air status in dwellings is related to health risks (WHO, 2000).

Particulate matter has been of great concern since the first half of the twentieth century as it brings a long list of issues to human health. It was first associated with negative outcomes after certain events happened in many European cities at the beginning of the previous century. The most famous example of such an event is the London smog that allegedly killed 4,000 people in 1952, leaving approximately 100,000 people to experience health issues for the rest of their lives (Logan, 1953; Stanek et al., 2011). It is observed that there are more reported diseases among the population when levels of concentrations of particles in the ambient air are elevated (Hoek et al., 2002).

PM is classified by origin and size. PM_{10} – up to 10 µm in diameter, $PM_{2.5}$ – up to 2.5 µm in diameter, PM_1 – up to 1 µm in diameter, and ultrafine PM – less than 0.1 µm in diameter (Plutino et al., 2022). Coarse particulate matter in indoor environments mostly originates from pets, housework, and the resuspension of particles due to cleaning/moving. Fine and ultrafine particle sources are cooking, smoking, heating, etc. (Vardoulakis et al., 2020). $PM_{2.5}$, when inhaled, gets to gas exchange regions in the lungs, whereas ultrafine PM can cross the barrier of alveolar epithelium in the lungs, depositing in the lower respiratory tract and getting to the bloodstream, causing cardiovascular diseases and lung issues. From the nasal, ultrafine PM can also easily access the brain. PM_{10} can reach the respiratory system and even the gastrointestinal tract when some numbers of PM are swallowed, causing different respiratory issues like asthma, allergic reactions, lung cancer as well as gastrointestinal disorders, and inflammations (Lomer et al., 2002; Brown et al., 2013; Kish et al., 2013; Salim et al., 2014; Schraufnagel, 2020; WHO, 2022). Figure 1 gives an overview of the PM sizes compared to human hair (Yang et al., 2020).

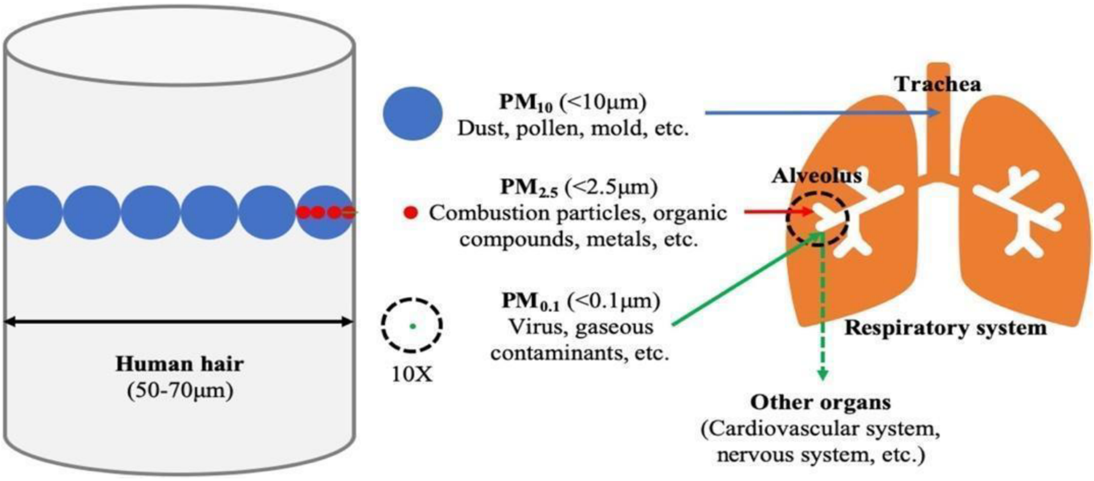


Fig. 1. The size, main composition, deposition spots of the PM in the lungs, and the further transportation of the fine particles in the body compared to hair size (Yang et al., 2020).

Numerous studies consistently linked long-term exposure to PM with a higher incidence of heart attacks, strokes, and lung cancer, emphasizing the critical importance of reducing air pollution for public health (Dockery et al., 1993; Thurston et al., 1994; Atkinson et al., 2014; Cohen et al., 2017; Burnett et al., 2018). The list of diseases provoked by insufficient indoor air quality is practically interminable. Some health conditions and their relation to indoor air pollutants are still being investigated. Cardiovascular diseases are the most important group of health conditions caused by PM. Risks of ischemic heart disease, heart failure, and cerebrovascular disease are much higher when a person is exposed to elevated $PM_{2.5}$ levels (Cosselman et al., 2015; Newby et al., 2015). Medgyesi et al. (2017) studied the effects of exposure to particulate matter and confirmed the link between elevated levels of $PM_{2.5}$ and pulmonary and cardiovascular diseases. Exposure to elevated levels of fine-sized particulate matter not only worsens the existing heart issues but also plays a significant role in the development of cardiovascular diseases, starting with inflammation, atherosclerosis, thrombosis, etc., in the end, possibly leading to a change in heart rate and other heart conditions (Ghio et al., 2000; Sun et al., 2005; Signorelli et al., 2017). Chronic pulmonary disease is registered in many countries. The severity of the disease depends on the lungs' function, which may be reduced due to impaired lung growth in infancy or lung infections during the lifetime (Anderson et al., 1988; Moran et al., 1992; Ellegard et al., 1996; Albalak et al., 1999; Bruce at al., 2000). Moreover, long-term exposure to PM may be a reason for low birth weight, tuberculosis, and other respiratory complications (Wallace and Ott, 2011). However, due to the heterogeneous nature of PM, it is hard to establish a relationship between the exposure to particles of specific compounds, which can also be attached to other agents, and manifestations of health effects (Jones, 1999).

The other common health issue is asthma. Biological pollutants such as dust mites aggravate the symptoms (Platts-Mills and Carter, 1997). Tariq et al. (1998) found that dust mites can be a cause of the development of asthma in a previously healthy individual. Some studies also suggest that exposure to indoor air pollutants from childhood is responsible for the development of such diseases as asthma, allergic reactions, and cardiovascular issues (Kumar et al., 2013; Rosário Filho et al., 2021). Becher et al. (2018) found that using carpeted floors in the newborn's/child's room may play a crucial role in the development of issues with respiratory and other systems, acting as a repository for pollutants, which are resuspended with vacuuming or walking.

The biggest challenge for modern medicine, cancer, is also on the list of diseases induced by PM pollution. Chronic pulmonary disease increases the risk of lung cancer (Samet et al., 1986). Long-term exposure to $PM_{2.5}$ and sulphates is associated with cancer development (Dockery et al., 1993).

A cataract is confirmed to have an association with tobacco and biomass fuels smoke, at first causing eye irritation, then it may lead to the absorption of toxins into the lens (Mishra et al., 1999).

Sick Building Syndrome (SBS) – a group of symptoms like tiredness, headache, nausea, dizziness, nose-throat irritations, shortness of breath, allergy, etc., caused by a low air quality status inside a building by $PM_{2.5}$ and PM_{10} generated by heating, cooking or smoking, VOCs, nitrogen dioxide, and polycyclic aromatic hydrocarbons (PAHs) (Jones, 1999). Symptoms may reduce productivity and the ability to focus. Normally they disappear when leaving the indoor environment. Sufficient ventilation can improve the air quality status at the place (Fisk, 2018). As Gens et al. (2014) and Liu C. et al. (2019) mention, starting from the energy crisis in the 1970s, buildings have become more air-tight to minimize energy consumption. However, that change in the construction had its tradeoffs: as a result, ventilation and air exchange rates were affected, meaning worse indoor air status (Li et al., 2022).

Overall, there is a trend of increasing health risks with decreasing PM size (Shi et al., 1996; Oberdoster, 2000). It is known that the shape of PM is crucial, and the health responses may differ due to that (Plutino et al., 2022). There is a concept of the "fiber paradigm" which states that the biological mechanisms of PM differ by the length, diameter, and biopersistence of fibers PM consist of (Donaldson et al., 2010; Riediker et al., 2019), and therefore inhaled or swallowed particles can interact differently inside an organism.

It is important to note that health issues are not only connected to pollution levels but also depend on exposure time. Some of the health issues may be acute, while others are chronic. The health status is affected by exposure to different pollutants at the same time over many years (Li et al., 2022). Franchi et al. (2006) described three levels at which air contaminants in indoor environments affect human health:

1. The immune system gets activated to react unfavourably to a pollutant.
2. In people who already experience some of the diseases or allergies, indoor pollutants trigger the manifestation of symptoms.
3. Inflammation in the mucous of the respiratory passages is sustained by existing contaminants/allergens leading to the development of further health conditions.

Deteriorated air quality provokes health issues and, thus, is responsible for reduced life expectancy. Dockery et al. (1993) were among the first researchers who found out that there is a negative correlation between chronic mortality and exposure to fine particles. The more health issues a person experiences, the worse the influence of air pollutants on the health overall, with a tendency to cause the development of additional conditions. Individuals with asthma, allergies, chronic respiratory illnesses, and a suppressed immune system are more susceptible to indoor air pollutants overall or to some particular (Franchi et al., 2006). Supposedly, previously experienced health issues like asthma, cardiovascular diseases, etc., are responsible for getting people sick due to high PM levels. Samoli et al. (2008) confirmed the relationship between higher susceptibility to diseases from elevated levels of PM and preexisting health conditions like heart or lung issues. In patients with chronic obstructive pulmonary disease (COPD), exposure to fine PM provokes coughing and general worsening of the condition (Cortez-Lugo et al., 2015). Apte et al. (2018) found that the most susceptible people to PM exposure are elderly adults and pregnant women.

PM has chemical and physical properties such as the number of particles, mass, and surface area (Harrison et al., 2000). Pope (2000) classified chemical constituents of PM that might be responsible for health effects into four categories: particles emitted from fossils and biomass fuels combustion, which are the finest ones; particulate matter borne in industrial processes using high temperatures (smelting); chemical reactions in the atmosphere, producing fine particles; and coarse PM from soil, dust, and other sources. Moreover, PM can carry other agents on them, including metals, for instance, Cr, As, Cd, Ni, and Be, which may potentially cause neurotoxic effects and cancer. The risk of PM carrying other elements is higher when indoor microenvironments are close to roads (Martins et al., 2020). According to an analysis of the data by Cohen et al. (2015), $PM_{2.5}$ is the fifth-ranking reason for mortality, accounting for 4.2 million deaths in 2015.

2.3 Indoor patterns of particulate matter

2.3.1 Residential areas

In residential areas, particle matter number and mass concentrations depend mostly on indoor pollution sources such as cooking, cleaning, smoking, burning of candles, particle resuspension and particles emission from personal care products, dust, human skin, clothes fibres, animals dander, fur, hair, etc. (He et al., 2004; Hussein et al., 2006; Glytsos et al., 2010; Wallace and Ott, 2011; Amato et al., 2014; Park et al., 2014; Vardoulakis et al., 2020). However, as indoor pollution consists of two parts, one of which is outdoor pollution, the location of the building and the condition of its structure are also of significant importance (Abt et al., 2000; Liu and Nazaroff, 2003; Hall and Spanton, 2012; Quang et al., 2013; Park et al., 2014). When there is no active indoor source of pollution, the concentration and mass estimates of particulate matter are numerically lower, and their patterns are similar to outdoor aerosols (Hussein et al., 2006). During summer months, ventilation rates in dwellings are usually higher, leading to a better dilution of PM and the number and mass concentrations are lower than in winter (Chithra and Nagendra, 2014; Park et al., 2014). Additionally, winter months are characterized by higher values for PM due to anthropogenic emissions from fossil fuel combustion for domestic heating, rarely opened windows for keeping warm inside a house, and therefore less ventilated air indoors, and unfavorable meteorological conditions for the dispersion of air pollutants (i.e. more frequent occurrences of stagnant weather and temperature inversion during the cold periods) (Chan and Yao, 2008; Huang et al., 2014; Chithra and Nagendra, 2014; Zhang and Cao, 2015; Tabinda et al., 2019).

2.3.2 Workplaces

Indoor air pollution in offices is site-specific. It depends on the company's activities, the work of the installed office equipment like printers and computers, the cleaning schedule, particle resuspension, human skin, hair, clothes fibres, etc. (Ferro et al., 2004; Hussein et al., 2006; He et al., 2007; Kagi et al., 2007; Wallace and Ott, 2011; Salthammer et al., 2012; Quang et al., 2013; Amato et al., 2014; Park et al., 2014; Chatoutsidou et al., 2015; Vardoulakis et al., 2020). As one of the most significant sources of indoor pollution in offices, printers and hardcopy devices produce ultrafine and fine particles that do not impact mass concentrations but rather particle number concentrations (He et al., 2007; Koivisto et al., 2010). Outdoor pollution is also another factor important for total indoor pollution following that the location, ventilation, building's structure, and cracks/leaks should be considered when determining the indoor air quality status (Liu and Nazaroff, 2003; Hall and Spanton, 2012; Quang et al., 2013; Chatoutsidou et al., 2015). Seasonal variations are also observed in offices as in residential apartments.

2.3.3 Car cabin

Number and mass concentrations of fine and ultrafine PM were reported to be 5-15x higher in vehicles than outdoors in many studies (Wargo et al., 2002; WHO 2005; Diapouli et al., 2008; Bigazzi et al., 2012). Due to the fine size of produced in-vehicle particles, number concentrations are more sensitive for in-car measurements (Wahlin et al., 2001; Weijers et al., 2004). Active transport like cycling and walking, even along the road poses less risk for human health (Rank et al., 2001; Molden et al., 2023). According to some authors, commuting by car accounts for 12-20% of daily exposure to $PM_{2.5}$ (Schäfer and Victor, 2000; Fondelli et al., 2008). Concentrations inside vehicles depend on many factors such as traffic density and the distance between cars, location of the road, speed, type of fuel, and ventilation inside a vehicle (Dor et al., 1995; Briggs et al., 2008; Zuurbier et al., 2010; Jalava et al., 2012; Querol et al., 2012; Dons et al., 2013).

2.4 Existing norms and guidelines on particulate matter pollution

Although human health issues related to PM are acknowledged worldwide, there is only one standard of measuring and controlling ambient PM – by average mass concentrations measured daily or annually at ground stations, without any further specifications regarding its shape or chemical constituents (WHO, 2005).

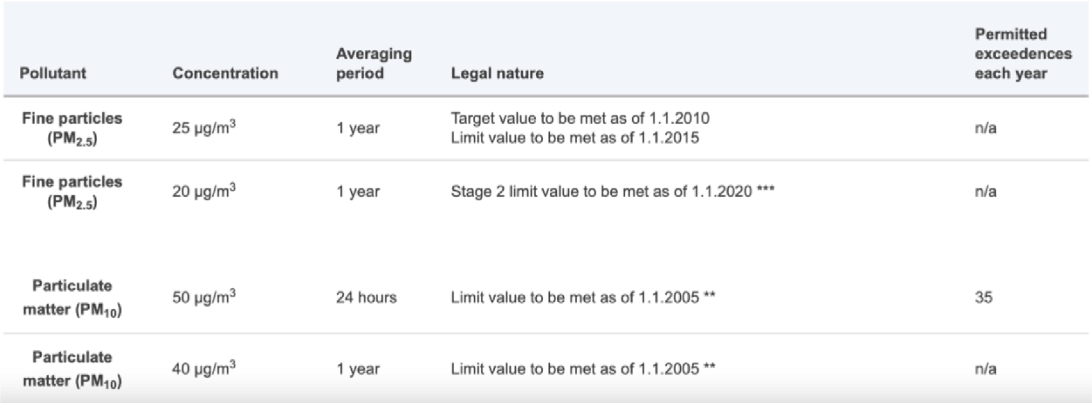
Internationally, the World Health Organization sets limit values for particulate matter and other pollutants, controlling every country's progress in reducing air pollution and making values stricter over time. Recommendations are made based on systematic literature reviews of scientific articles with recent findings and communication with experts from all over the globe. Several working groups work on establishing guidelines. Each has its specific tasks, for instance, the selection of pollutants, literature review, and assessment. The first set of values was published in 1987, then it was updated in 2005. The newest version is from the year 2021. According to the WHO, both outdoor and indoor air pollution is responsible for around 7 million premature deaths yearly, with millions more getting sick (WHO, 2022). Recently set guidelines on particulate matter by the WHO are shown in Table 1 (WHO, 2022).

Table 1. The WHO Air Quality Guidelines 2021 compared to AQG 2005 (WHO, 2022).

Pollutant	Averaging Time	2005 AQGs	2021 AQGs
$PM_{2.5}$, µg/m^3	Annual	10	5
	24-hour^a	25	15
PM_{10}, µg/m^3	Annual	20	15
	24-hour^a	50	45

Less strict guidelines are set by Directive 2008/50/EC of the European Parliament and the Council of 21st May 2008 on Ambient air quality and cleaner air for Europe. Average ambient air mass concentrations of specific pollutants are being measured in every country at the stations, daily and annually. According to the Directive 2008/50/EC, when monitoring daily – measured PM_{10} must not exceed 50 µg/m^3 35 times per calendar year; when monitoring yearly – PM_{10} must be lower than 40 µg/m^3; $PM_{2.5}$ measured yearly must be lower than 20 µg/m^3. Monitoring is done at stations located evenly across the entire EU (198 stations in total in the Czech Republic), although there are more stations in higher populated areas. Stations are of two types: automated and manual. If the aimed limit value is not reached, member states should take measures to meet the targets for ambient air quality. Table 2 is an excerpt from the Directive 2008/50/EC with a set threshold on PM pollution.

Table 2. Annex XI of the Directive 2008/50/EC of the European Parliament and the Council of 21st May 2008 on ambient air quality and cleaner air for Europe. Limit values for the $PM_{2.5}$ and PM_{10}.



Pollutant	Concentration	Averaging period	Legal nature	Permitted exceedences each year
Fine particles ($PM_{2.5}$)	25 µg/m^3	1 year	Target value to be met as of 1.1.2010 Limit value to be met as of 1.1.2015	n/a
Fine particles ($PM_{2.5}$)	20 µg/m^3	1 year	Stage 2 limit value to be met as of 1.1.2020 ***	n/a
Particulate matter (PM_{10})	50 µg/m^3	24 hours	Limit value to be met as of 1.1.2005 **	35
Particulate matter (PM_{10})	40 µg/m^3	1 year	Limit value to be met as of 1.1.2005 **	n/a

Each country has its targets, which are following the European aims. For instance, in the Czech Republic, the Ministry of the Environment published a 2050 strategy called “State Environmental Policy of the Czech Republic 2030 with Outlook to 2050”. The published document describes each goal and its priority, including the clean air in the country with priority 1 (utmost priority). The target value for the

Czech Republic is to reduce $PM_{2.5}$ emissions by 60% by the year 2030 (the Ministry of the Environment of the Czech Republic, 2021).

All the mentioned guidelines and policies set standards and targets for ambient air quality. Nonetheless, the most concerning threat to public health is exposure to indoor air pollutants as people spend up to 90% of their time indoors. Unfortunately, this aspect is not considered and monitored on a large enough scale to ensure optimal public health. Furthermore, the current way of monitoring air quality solely focuses on mass concentrations, neglecting number concentrations entirely. Assessing exposure to indoor pollutants would offer a more precise indicator for evaluating public health impacts rather than monitoring ambient average mass concentrations of pollutants at stations (Li et al., 2022). However, in some Scandinavian European countries, specific guidelines for air quality in dwellings and sets of actions were created. As an example, the Finnish national guideline "The Classification of Indoor Climate, Construction, and Finishing Materials", first published in 1995, has been recently revised. In 2018 targets and limit values for indoor air pollutants were added to the document. These targets are a must to follow when realizing a construction project, starting with using low-emission materials and following installation instructions for each of the materials used so that a building would keep a set ventilation and filtration rates by leakage detection and sealing when constructing. The airflow must be adjustable if there is a need. There are also targets regarding noise and light pollution, temperature and moisture levels, etc. The guideline also mentions the limit values for fine particulate matter in indoor environments. According to the document, the values should be less than 10 $\mu g/m^3$ per 24 hours (Ahola et al., 2019). In 2012, the Health Department of the Canadian government stated there is no safe level for $PM_{2.5}$ indoors, however, they generally recommend avoiding smoking indoors and using a kitchen hood when cooking (Government of Canada, 2012).

2.5 Possible approaches to reduce people's exposure to particulate matter

Better building code for new construction sites regarding materials used in construction - they should be of the low-emission type, as well as the rate of ventilation should be sufficient for removal of indoor originating contaminants (Franchi et al., 2006).

THADE project was carried out in 2003 (Towards Healthy Air in Dwellings in Europe) to learn more about indoor air pollutants and their effects on human health and to search for possible solutions to that problem. A set of actions and recommendations was identified to improve air quality status at homes across Europe and minimize health effects related to indoor air pollution. For instance, proper and regular ventilation and cleaning is the first step to better air in homes. Regular removal of dust from the surfaces and vacuuming of carpets and floors is needed when reducing exposure to indoor air pollution. Cleaning should be done when a dwelling is unoccupied, and adequate ventilation should be provided during the process (Seppanen and Fisk, 2004). When reconstruction takes place, it is better to avoid wall-to-wall carpeting and minimize carpets on the floor as such refurbishing acts as a repository for dust, dirt, PM, etc.; control of the pollution sources is needed, as some materials used in the construction of a building may emit toxic substances over time; avoidance of smoking inside homes (Franchi et al., 2006).

As cooking is one of the main sources of indoor air pollution improved stoves and usage of cleaner fuels should be considered. Open chimneys should be replaced. Efficient cooker bonnets help to reduce the amount of PM during cooking. Mechanical ventilation may improve indoor air quality in air-tightened buildings. Such systems are equipped with special air movement devices that accelerate air exchange rates between indoor and outdoor environments. Plus, such systems usually include air purifiers which can be advantageous for cleaning the air from PM (Li et al., 2022). Deployment of de-humidifiers in a damp environment, avoiding smoking indoors, and restriction of candles and aroma sticks burning are suggested to reduce the PM number and mass concentrations indoors (Jones, 1999).

Risk assessment may improve the situation in different occupational industries and propose mitigation strategies that may include the installation of appropriate ventilation, changing of furbishing and furnishing of the interior to improve the health status of people inhabiting/working in a building as well as limiting the exposure to the pollutants (Ferreira and Barros, 2022). More research on the interaction of different pollutants and substances is needed as it is unlikely to explain health manifestations by studying only specific and particular pollutants and health effects (Seltzer, 1995).

3. Materials and methods

3.1 Study sites

Five indoor environments were chosen in Prague. Among those, two are residential areas in Praha 1 and Praha 10; two offices in Výzkumný ústav Silva Taroucy pro krajinu a okrasné zahradnictví, v.v.i. (VUKOZ), Průhonice; transport – car 9 diesel Volkswagen Tiguan (2019)). Portable instruments of two types were used in this study: Optical Particle Sizer spectrometer - OPS spectrometer model 3330; and Ultrafine Particle Counter - P-Trak model 8525 (TSI®, 2005; TSI®, 2010).

In residential areas, measurements were done in bedrooms and kitchens during distinct activities (cooking, wet/dry cleaning, vacuuming, walking) and without any activity. According to many studies, cooking and cleaning are crucial contributors to indoor air pollution, and people get exposed to a wide range of particle sizes with high number and mass concentrations. Cooking included frying, baking and boiling. Cleaning included the usage of a vacuum cleaner, wet cleaning, and changing of bedsheets. Measurements also were taken with opened and closed windows to see if outdoor air sources affect the situation indoors. Outside air quality was also checked with the same instrument OPS and a conductive tubing, provided by a manufacturer located approx. 10 cm out of a window in the room, where indoor air was measured. When measuring indoor air, instruments were located 30-40 cm from the source (cooking); at ca. 1 m height (vacuuming, wet cleaning, changing bed sheets, walking) for better representation of human exposure to PM emitted during the mentioned processes. Measurements were done in summer and winter. Inhabitants of the apartments kept a diary and wrote down what they were doing and when for later analysis of the data. Information about apartments (year of the building construction, type of ventilation system, size of the rooms, description of the furbishing and furnishing, etc.) was collected for analysis and comparison.

Praha 1 is characterized by its location in the historic centre right next to the Old Town Square (Staroměstská naměsti) with limited traffic. The apartment is on the first floor, with two windows facing the road and one window facing the yard. The flat is ventilated naturally and has central heating with radiators located below the windows. The apartment is fully furnished, with carpets in the kitchen and bedroom. An electric stove is installed in Prague 1. Measurements were taken between

16.07.2023 and 10.08.2023 on different days and times. The weather conditions at the time of measurements were hot and sunny, with a few rainy days. The minimum temperature was 15 degrees Celsius, the maximum temperature was around 34 degrees Celsius. In the apartment in Prague 1, two cats live as well.

The apartment in Praha 10 is in a residential area of the city, close to the railway station and bus stop. The traffic in the area is heavy. The apartment is on the fifth floor, with all four windows facing the road. The apartment is ventilated naturally and has central heating with radiators located below the windows. The apartment is fully furnished, with carpets in the kitchen and bedroom. A gas stove is installed in the kitchen. Measurements were taken between 14.06.2023 and 27.06.2023 on different days and times. The weather conditions at the time of measurements were hot and sunny, with a few rainy days. The minimum temperature was 19 degrees Celsius, the maximum temperature was around 31 degrees. In the apartment in Prague 10, a dog lives as well.

The office building is located outside Prague, fifteen kilometres from the city center. The area around the building is quite green, with Průhonický Park close to the entrance. Two offices were chosen for measurements. One is the "dirty" laboratory for measurements of barley (cutting each stalk into pieces, separating husks and leaves, and moving it from one bag to another). Usually, two people were working in the laboratory. Here measurements were done during two days in different scenarios. In summer, on the first day, measurements were done with opened windows and on the second day windows were closed to observe how the ventilation rate impacts the amounts of PM indoors. In winter, measurements were again done over the two days, but windows were closed all the time. On the first day, employees of the Research Institute were working with samples in the lab. On the second day, no one entered the room.

The other room is a regular office, with two computers and a printer. Measurements were done for two days as well, in parallel with measurements in the laboratory. In the office, windows could not be opened. In summer, on the first day, measurements were done with one person constantly located in the office. The other day's measurement was done right after dry and wet cleaning in the office. In winter, on the first day, one person was constantly located in the office, and cleaning took place that day at 5 pm. On the second day, one person was working in the office all day.

For in-car measurements, a four-year-old diesel Volkswagen Tiguan (2019) with a sunroof was used. In summer, measurements were taken during the trip to Lichnice Castle. The road took 1.5 hours, almost 100 km. On the way to the place, the AC was on as it was a hot day with a maximum temperature of 38 degrees Celsius. On the road back from the castle, it was cooler, windows and sunroof were opened during the measurements, and the AC was off. In winter, the destination was the same for the clarity of the experiment. Measurements were taken only with closed windows, and the AC was used for heating in both ways. These measurements were taken in a short period during driving/stopping/parking, therefore, this data was then extrapolated for 24 hours for comprehensible comparison.

3.2 Instrumentation

In the study portable instruments of two types were used: OPS spectrometer model 3330 – optical particle sizer spectrometer; and P-Trak model 8525 – ultrafine particle counter (TSI®, 2005; TSI®, 2010).

OPS is a Class I laser-based instrument that measures aerosol optical diameter. It works on the principle of optical scattering from single particles when those are illuminated using a laser beam located below the inlet nozzle (Ardon-Dryer et al., 2022). The air gets sucked into the OPS at a rate of 1.0 L/min ± 5% (configurable).

Particles intercept the beam of visible light, causing it to scatter in pulses, which are then measured and categorized by the instrument in real-time. The airborne particles that are counted and categorized are subsequently expelled through a high-efficiency particulate air filter (HEPA). This exhaust stream maintains a consistent sheath flow rate of 1.0 L/min (non-configurable). The internal circulation of this sheath flow is essential for preventing contamination of the optics and ensuring that particles entering the inlet remain well-focused across the laser light. The instrument comprises 16 bins or channels representing various particle sizes ranging from 0.3 to 10 micrometers. These channels are customizable, allowing the instrument to provide detailed information about specific particle characteristics, including concentration, size distribution, and total particle count. For this study, the instrument was set to its factory default configuration, utilizing all 16 bins for data collection. The pulses generated from the scattering of light by aerosols enable the instrument to count particles and record their sizes, with the optical particle size being directly proportional to the recorded data. The Model 3330 instrument offers size distribution data for particles with optical diameters ranging from 0.3 to 10 micrometers. However, it's important to note that particles larger than 10 micrometers are counted but not sized, as this exceeds the maximum size detectable by the OPS.

The instrument in the study was used in a standalone mode, saving data to internal memory, which then was transferred to Aerosol Instrument Manager^R for data analysis. Logging data was mostly done in the mode of surveying 5 minutes every hour for 24 hours (Operation and Service manual, TSI®, 2010). In the car measurements were done every 5 minutes, and then data was extrapolated in RStudio to predict the values for 24 hours.

P-Trak Ultrafine particle counter is used for tracking ultrafine particles (UFPs) smaller than 0.1 micrometer in diameter. UFPs constitute the highest number of particles and yet make up only a small fraction of the mass. P-Trak determines the concentration of aerosols in the air in particles per cubic centimeter (pt/cm^3).

The instrument has three main modes of operation - Survey, Sample, and Data log. All three were used in this study. Survey mode displays real-time particle concentration readings, updating every second. This mode was used to track the source of UFPs. Sample mode gives a 10-second, averaged concentration reading. Data log mode was used to record particle concentration readings over time: every second of every hour and every 10 seconds every hour. This data was stored in the internal memory of the instrument and then was transferred to a computer for analysis using the software TrakPro Software. The particle size range recognizable by the P-Trak is from 0.02 to 1 micrometer. Concentration range – from 0 to 5 x 10^5 particles/cm^3 (Operation and Service manual, TSI®, 2010).

3.3 Data processing

The data obtained from both instruments was analyzed in software programs from manufacturers of the instruments (Aerosol Instrument Manager^R for data from OPS and TrakPro Software for data obtained with P-Trak). After that, data from the software was extracted into an Excel sheet. Measurements from the car were extrapolated in Rstudio to get daily average values, and the data was compiled together in Microsoft Office Excel. The Microsoft Excel sheet was then used for data visualization. The results were compared to the WHO thresholds for particulate matter pollution.

4. Results

4.1 Residential areas, Praha 1

4.1.1 Kitchen

Summer

In the absence of any activity and with closed windows, background particle number concentrations for $PM_{2.5}$ with closed windows were measured in the range between 0.1 cm^{-3} and 421.1 cm^{-3}, with a median value of 1.9 cm^{-3}. Background particle number concentrations for PM_{10} varied between 0.1 cm^{-3} and 1.1 cm^{-3}, with a median value of 0.2 cm^{-3}. Mass concentrations of $PM_{2.5}$ were measured at the range between 0.1 $\mu g/m^3$ and 9.8 $\mu g/m^3$, with a median value of 1.6 $\mu g/m^{-3}$. PM_{10} mass concentration varied between 0.1 $\mu g/m^3$ and 126.8 $\mu g/m^3$, with a median value of 12.0 $\mu g/m^{-3}$. Particulate matter diameter that occurred the most often was 0.337 micrometers with 74% of occurrence out of all 16 measured sizes. With opened windows, number concentrations for $PM_{2.5}$ were measured in the range between 0.2 cm^{-3} and 215.2 cm^{-3}, with a median value of 1.7 cm^{-3}. Number concentrations of PM_{10} varied between 0.1 cm^{-3} and 1.0 cm^{-3}, with a median value of 0.1 cm^{-3}. Mass concentrations of $PM_{2.5}$ were measured at the range between 0.2 $\mu g/m^3$ and 8.2 $\mu g/m^3$, with a median value of 1.3 $\mu g/m^{-3}$. PM_{10} mass concentration varied between 1.6 $\mu g/m^3$ and 168.4 $\mu g/m^3$, with a median value of 5.9 $\mu g/m^{-3}$. Particulate matter diameter that occurred the most often was 0.337 micrometers with 66% of occurrence out of all 16 measured sizes. During cooking, number concentrations for $PM_{2.5}$ were measured in the range between 0.3 cm^{-3} and 7190 cm^{-3}, with a median value of 12.8 cm^{-3}. Number concentrations of PM_{10} varied between 0.1 cm^{-3} and 22.8 cm^{-3}, with a median value of 0.3 cm^{-3}. Mass concentrations of $PM_{2.5}$ were measured at the range between 0.5 $\mu g/m^3$ and 338.8 $\mu g/m^3$, with a median value of 5.7 $\mu g/m^{-3}$. PM_{10} mass concentration varied between 0.1 $\mu g/m^3$ and 802.2 $\mu g/m^3$, with a median value of 19.3 $\mu g/m^{-3}$. On average, during cooking number concentrations rose by 90% compared to the background levels, and mass concentrations increased by 88% compared to the background levels. Particulate matter diameter that occurred the most often was 0.337 micrometers with 65% of occurrence out of all 16 measured sizes. The lifetime of the produced fine particles varied between 3.5 h when the total particle number concentrations came back to levels that occurred before the activity with number concentrations of ~350 cm^{-3}.

Winter

In the absence of any activity and with closed windows, background particle number concentrations for $PM_{2.5}$ were measured in the range between 0.1 cm^{-3} and 295.6 cm^{-3}, with a median value of 4.5 cm^{-3}. Background particle number concentrations for PM_{10} varied between 0.1 cm^{-3} and 0.6 cm^{-3}, with a median value of 0.1 cm^{-3}. Mass concentrations of $PM_{2.5}$ were measured at the range between 0.6 $\mu g/m^3$ and 9.8 $\mu g/m^3$, with a median value of 2.2 $\mu g/m^{-3}$. PM_{10} mass concentration varied between 0.1 $\mu g/m^3$ and 147.8 $\mu g/m^3$, with a median value of 4.8 $\mu g/m^{-3}$. Particulate matter diameter that occurred the most often was 0.337 micrometers with 61% of occurrence out of all 16 measured sizes. With opened windows, number concentrations for $PM_{2.5}$ were measured in the range between 0.1 cm^{-3} and 886.3 cm^{-3}, with a median value of 10.0 cm^{-3}. Number concentrations of PM_{10} varied between 0.1 cm^{-3} and 6.2 cm^{-3}, with a median value of 0.1 cm^{-3}. Mass concentrations of $PM_{2.5}$ were measured at the range between 0.5 $\mu g/m^3$ and 115 $\mu g/m^3$, with a median value of 4.9 $\mu g/m^{-3}$. PM_{10} mass concentration varied between 0.1 $\mu g/m^3$ and 90.5 $\mu g/m^3$, with a median value of 4.5 $\mu g/m^{-3}$. Particulate matter diameter that occurred the most often was 0.337 micrometers with 62% of occurrence out of all 16 measured sizes. During cooking, number concentrations for $PM_{2.5}$ were measured in the range between 0.5 cm^{-3} and 18200 cm^{-3}, with a median value of 23.3 cm^{-3}. Number concentrations of PM_{10} varied between 0.1 cm^{-3} and 9.2 cm^{-3}, with a median value of 0.1 cm^{-3}. Mass concentrations of $PM_{2.5}$ were measured at the range between 0.7 $\mu g/m^3$ and 722 $\mu g/m^3$, with a median value of 7.2 $\mu g/m^{-3}$. PM_{10} mass concentration varied between 2.6 $\mu g/m^3$ and 133.1 $\mu g/m^3$, with a median value of 12.4 $\mu g/m^{-3}$. On average, during cooking number concentrations rose by 91% compared to the background levels, and mass concentrations increased by 83% compared to the background levels. Particulate matter diameter that occurred the most often was 0.337 micrometers with 79% of occurrence out of all 16 measured sizes. The lifetime of the produced fine particles varied between 3.5 h when the total particle number concentrations came back to levels that occurred before the activity with number concentrations of ~250 cm^{-3}. In winter the second instrument, P-Trak, was also used. The lifetime of particles was determined using P-Trak. Cooking started at 17:00, with the peak occurring at 17:45, with particle number concentrations exceeding 220000 cm^{-3}. In around 4 hours, the levels of fine particulate matter returned to the background that was measured before cooking started ~7000 #/cm^3.

Figures 2-4 show the number and mass distributions in the kitchen in Prague 1 in summer and winter and during different activities.

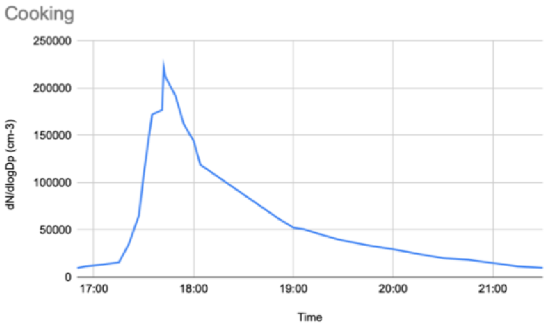


Fig. 2. Levels of particulate matter in the kitchen, in Prague 1. Measurements were taken in the winter of 2024. The graph represents the number distribution (#/cm^3) of particles emitted during cooking.

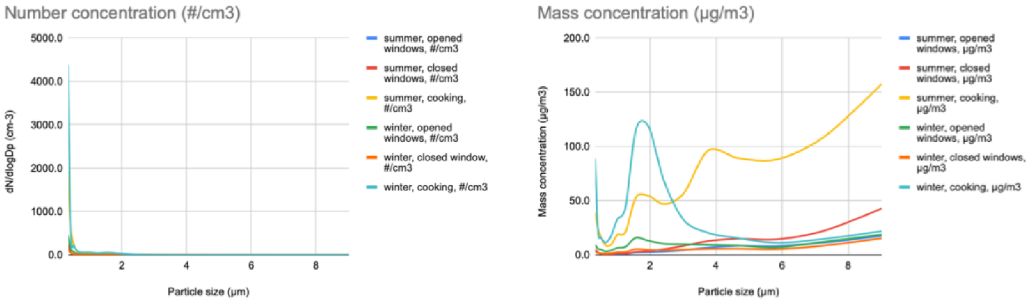


Fig. 3 and 4. Averaged levels of particulate matter in the kitchen, in Prague 1. Measurements were taken in the summer of 2023 and winter 2024. Fig. 3 (left) represents particle raw counts (#/cm^3) during cooking, and without any activity (with closed and opened windows). Fig. 4 (right) shows mass distributions (µg/m^3) over mentioned activities.

4.1.2 Bedroom

Summer

In the absence of any activity and with closed windows, background particle number concentrations for $PM_{2.5}$ were measured in the range between 0.1 cm^{-3} and 751.1 cm^{-3}, with a median value of 1.6 cm^{-3}. Background particle number concentrations for PM_{10} varied between 0.1 cm^{-3} and 1.7 cm^{-3}, with a median value of 0.1 cm^{-3}. Mass concentrations of $PM_{2.5}$ were measured at the range between 0.1 µg/m^3 and 15.2 µg/m^3, with a median value of 1.4 µg/m^{-3}. PM_{10} mass concentration varied between 0.1 µg/m^3 and 203.7 µg/m^3, with a median value of 6.8 µg/m^{-3}. Particulate matter diameter that occurred the most often was 0.337 micrometers with 61% of occurrence out of all 16 measured sizes. With opened windows, number concentrations for $PM_{2.5}$ were measured in the range between 0.2 cm^{-3} and 286.4 cm^{-3}, with a median value of 2.3 cm^{-3}. Number concentrations of PM_{10} varied between 0.1 cm^{-3} and 1.8 cm^{-3}, with a median value of 0.1 cm^{-3}. Mass concentrations of $PM_{2.5}$ were measured at the range between 0.1 µg/m^3 and 15.6 µg/m^3, with a median value of 1.4 µg/m^{-3}. PM_{10} mass concentration varied between 0.5 µg/m^3 and 125.9 µg/m^3, with a median value of 7.4 µg/m^{-3}. Particulate matter diameter that occurred the most often was 0.337 micrometers with 66% of occurrence out of all 16 measured sizes. During cleaning, number concentrations for $PM_{2.5}$ were measured in the range between 1.0 cm^{-3} and 697 cm^{-3}, with a median value of 5.1 cm^{-3}. Number concentrations of PM_{10} varied between 0.3 cm^{-3} and 3.8 cm^{-3}, with a median value of 1.2 cm^{-3}. Mass concentrations of $PM_{2.5}$ were measured at the range between 0.3 µg/m^3 and 29.2 µg/m^3, with a median value of 4.7 µg/m^{-3}. PM_{10} mass concentration varied between 28.1 µg/m^3 and 405.2 µg/m^3, with a median value of 88.7 µg/m^{-3}. On average, during cleaning number concentrations rose by 56% compared to the background levels, and mass concentrations increased by 86% compared to the background levels. Particulate matter diameter that occurred the most often was 0.337 micrometers with 74% of occurrence out of all 16 measured sizes.

Winter

In the absence of any activity and with closed windows, background particle number concentrations for $PM_{2.5}$ were measured in the range between 0.4 cm^{-3} and 214.8 cm^{-3}, with a median value of 4.7 cm^{-3}. Background particle number concentrations for PM_{10} varied between 0.1 cm^{-3} and 0.6 cm^{-3}, with a median value of 0.1 cm^{-3}. Mass concentrations of $PM_{2.5}$ were measured at the range between 0.7 µg/m^3 and 9 µg/m^3, with a median value of 2.3 µg/m^{-3}. PM_{10} mass concentration varied between 0.1 µg/m^3 and 33.5 µg/m^3, with a median value of 4.6 µg/m^{-3}. Particulate matter diameter that occurred the most often was 0.337 micrometers with 61% of occurrence out of all 16 measured sizes. With opened windows, number concentrations for $PM_{2.5}$ were measured in the range between 2.5 cm^{-3} and 1050 cm^{-3}, with a median value of 5.7 cm^{-3}. Number concentrations of PM_{10} varied between 0.1 cm^{-3} and 0.8 cm^{-3}, with a median value of 0.1 cm^{-3}. Mass concentrations of $PM_{2.5}$ were measured at the range between 0.7 µg/m^3 and 21.4 µg/m^3, with a median value of 3.3 µg/m^{-3}. PM_{10} mass concentration varied between 0.1 µg/m^3 and 68.2 µg/m^3, with a median value of 4.2 µg/m^{-3}. Particulate matter diameter that occurred the most often was 0.337 micrometers with 67% of occurrence out of all 16 measured sizes. During cleaning, number concentrations for $PM_{2.5}$ were measured in the range between 0.1 cm^{-3} and 1950 cm^{-3}, with a median value of 4.3 cm^{-3}. Number concentrations of PM_{10} varied between 0.1 cm^{-3} and 0.6 cm^{-3}, with a median value of 0.1 cm^{-3}. Mass concentrations of $PM_{2.5}$ were measured at the range between 0.5 $\mu g/m^3$ and 39.5 $\mu g/m^3$, with a median value of 2.4 $\mu g/m^{-3}$. PM_{10} mass concentration varied between 0.1 $\mu g/m^3$ and 45.6 $\mu g/m^3$, with a median value of 1.8 $\mu g/m^{-3}$. On average, during cleaning number concentrations rose by 67% compared to the background levels, and mass concentrations increased by 20% compared to the background levels. Particulate matter diameter that occurred the most often was 0.337 micrometers with 60% of occurrence out of all 16 measured sizes. Figures 5-6 show the number and mass distributions in the bedroom in Prague 1 in summer and winter and during different activities.

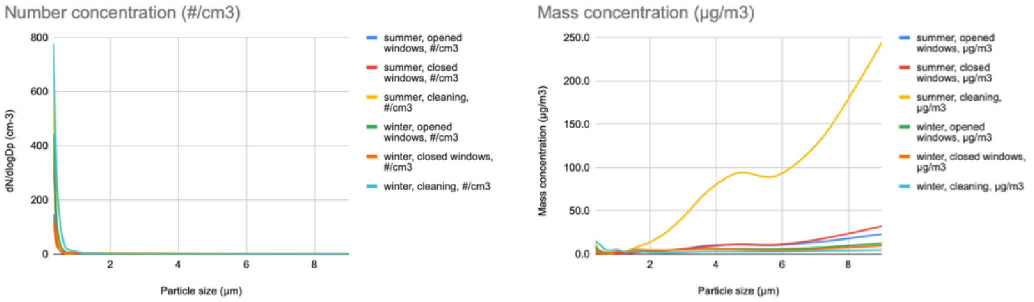


Fig. 5 and 6. Averaged levels of particulate matter in the bedroom, in Prague 1. Measurements were taken in the summer of 2023 and winter 2024. Fig. 5 (left) represents particle raw counts (#/cm^3) during cleaning, and without any activity (with closed and opened windows). Fig. 6 (right) shows mass distributions ($\mu g/m^3$) over mentioned activities.

4.1.3 Outside measurements

In summer, outdoor number concentrations for $PM_{2.5}$ were measured in the range between 0.1 cm^{-3} and 1100 cm^{-3}, with a median value of 2.1 cm^{-3}. Outdoor number concentrations of PM_{10} varied between 0.1 cm^{-3} and 9 cm^{-3}, with a median value of 0.1 cm^{-3}. Mass concentrations of $PM_{2.5}$ were measured at the range between 0.1 $\mu g/m^3$ and 22.3 $\mu g/m^3$, with a median value of 1.6 $\mu g/m^{-3}$. PM_{10} mass concentration varied between 0.1 $\mu g/m^3$ and 93 $\mu g/m^3$, with a median value of 4.9 $\mu g/m^{-3}$. Particulate matter diameter that occurred the most often was 0.337 micrometers with 69% of occurrence out of all 16 measured sizes. In winter, outdoor number concentrations for $PM_{2.5}$ were measured in the range between 0.1 cm^{-3} and 2190 cm^{-3}, with a median value of 9.8 cm^{-3}. Outdoor number concentrations of PM_{10} varied between 0.1 cm^{-3} and 1.2 cm^{-3}, with a median value of 0.1 cm^{-3}. Mass concentrations of $PM_{2.5}$ were measured at the range between 1.0 µg/m^3 and 44.4 µg/m^3, with a median value of 5.3 µg/m^{-3}. PM_{10} mass concentration varied between 0.1 µg/m^3 and 93 µg/m^3, with a median value of 6.0 µg/m^{-3}. On average, outdoor number concentrations were 72% higher in winter than in summer, mass concentrations were 53% higher in winter than in summer. Particulate matter diameter that occurred the most often was 0.337 micrometers with 63% of occurrence out of all 16 measured sizes.

4.2 Residential areas, Praha 10

4.2.1 Kitchen

Summer

In the absence of any activity and with closed windows, background particle number concentrations for $PM_{2.5}$ were measured in the range between 0.1 cm^{-3} and 421.1 cm^{-3}, with a median value of 1.9 cm^{-3}. Background particle number concentrations for PM_{10} varied between 0.1 cm^{-3} and 1.0 cm^{-3}, with a median value of 0.1 cm^{-3}. Mass concentrations of $PM_{2.5}$ were measured at the range between 0.2 µg/m^3 and 8.6 µg/m^3, with a median value of 1.5 µg/m^{-3}. PM_{10} mass concentration varied between 0.1 µg/m^3 and 52.9 µg/m^3, with a median value of 6.0 µg/m^{-3}. Particulate matter diameter that occurred the most often was 0.337 micrometers with 75% of occurrence out of all 16 measured sizes. With opened windows, number concentrations for $PM_{2.5}$ were measured in the range between 0.3 cm^{-3} and 700.5 cm^{-3}, with a median value of 2.4 cm^{-3}. Number concentrations of PM_{10} varied between 0.1 cm^{-3} and 0.9 cm^{-3}, with a median value of 0.1 cm^{-3}. Mass concentrations of $PM_{2.5}$ were measured at the range between 0.4 µg/m^3 and 14.2 µg/m^3, with a median value of 2.1 µg/m^{-3}. PM_{10} mass concentration varied between 1.1 µg/m^3 and 52.6 µg/m^3, with a median value of 4.0 µg/m^{-3}. Particulate matter diameter that occurred the most often was 0.337 micrometers with 75% of occurrence out of all 16 measured sizes. During cooking, number concentrations for $PM_{2.5}$ were measured in the range between 0.5 cm^{-3} and 9103.8 cm^{-3}., with a median value of 107.2 cm^{-3}. Number concentrations of PM_{10} varied between 0.1 cm^{-3} and 25.2 cm^{-3}, with a median value of 1.9 cm^{-3}. Mass concentrations of $PM_{2.5}$ were measured at the range between 0.7 µg/m^3 and 377.5 µg/m^3, with a median value of 52.7 µg/m^{-3}. PM_{10} mass concentration varied between 0.7 μg/m^3 and 872.5 μg/m^3, with a median value of 182.1 μg/m^{-3}. On average, during cooking number concentrations rose by 91% compared to the background levels, and mass concentrations increased by 96% compared to the background levels. Particulate matter diameter that occurred the most often was 0.337 micrometers with 62% of occurrence out of all 16 measured sizes. The lifetime of the produced fine particles varied between 4-5 h when the total particle number concentrations came back to levels that occurred before the activity with number concentrations of ~400 cm^{-3}.

Winter

In the absence of any activity and with closed windows, background particle number concentrations for $PM_{2.5}$ were measured in the range between 0.4 cm^{-3} and 864.3 cm^{-3}, with a median value of 10.5 cm^{-3}. Background particle number concentrations for PM_{10} varied between 0.1 cm^{-3} and 5.0 cm^{-3}, with a median value of 0.1 cm^{-3}. Mass concentrations of $PM_{2.5}$ were measured at the range between 0.9 μg/m^3 and 81.5 μg/m^3, with a median value of 3.8 μg/m^{-3}. PM_{10} mass concentration varied between 2.5 μg/m^3 and 97.8 μg/m^3, with a median value of 10.2 μg/m^{-3}. Particulate matter diameter that occurred the most often was 0.337 micrometers with 53% of occurrence out of all 16 measured sizes. With opened windows, number concentrations for $PM_{2.5}$ were measured in the range between 0.1 cm^{-3} and 2600 cm^{-3}, with a median value of 8.3 cm^{-3}. Number concentrations of PM_{10} varied between 0.1 cm^{-3} and 8.7 cm^{-3}, with a median value of 0.1 cm^{-3}. Mass concentrations of $PM_{2.5}$ were measured at the range between 0.5 μg/m^3 and 135.7 μg/m^3, with a median value of 4.6 μg/m^{-3}. PM_{10} mass concentration varied between 0.1 μg/m^3 and 193.3 μg/m^3, with a median value of 3.6 μg/m^{-3}. Particulate matter diameter that occurred the most often was 0.337 micrometers with 62% of occurrence out of all 16 measured sizes. During cooking, number concentrations for $PM_{2.5}$ were measured in the range between 0.3 cm^{-3} and 12800 cm^{-3}, with a median value of 61.7 cm^{-3}. Number concentrations of PM_{10} varied between 0.1 cm^{-3} and 22.8 cm^{-3}, with a median value of 0.3 cm^{-3}. Mass concentrations of $PM_{2.5}$ were measured at the range between 1.2 μg/m^3 and 466.2 μg/m^3, with a median value of 21.0 μg/m^{-3}. PM_{10} mass concentration varied between 2.1 μg/m^3 and 802.2 μg/m^3, with a median value of 12.9 μg/m^{-3}. On average, during cooking number concentrations rose by 80% compared to the background levels, and mass concentrations increased by 86% compared to the background levels. Particulate matter diameter that occurred the most often was 0.337 micrometers with 61% of occurrence out of all 16 measured sizes. The lifetime of the produced fine particles varied between 4-5 h when the total particle number concentrations came back to levels that occurred before the activity with number concentrations of ~560 cm^{-3}. In winter the second instrument, P-Trak, was also used. The lifetime of particles was determined using P-Trak. Cooking started at 13:45, with the peak occurring at 14:20, with particle number concentrations exceeding 350000 cm^{-3}. In around 4 hours, the levels of fine particulate matter returned to the background that was measured before cooking started ~3000 #/cm^3. Figures 7-9 show the number and mass distributions in the kitchen in Prague 10 in summer and winter and during different activities.

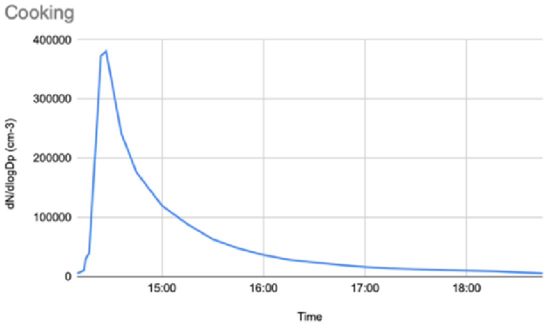


Fig. 7. Levels of particulate matter in the kitchen, in Prague 1. Measurements were taken in the winter of 2024. The graph represents the number distribution (#/cm^3) of particles emitted during cooking.

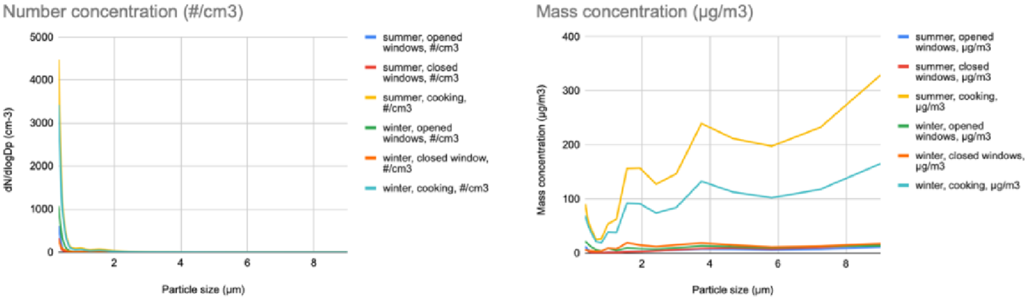


Fig. 8 and 9. Averaged levels of particulate matter in the kitchen, in Prague 10. Measurements were taken in the summer of 2023 and winter 2024. Fig. 8 (left) represents particle raw counts (#/cm^3) during cooking, and without any activity (with closed and opened windows). Fig. 9 (right) shows mass distributions (µg/m^3) over mentioned activities.

4.2.2 Bedroom

Summer

In the absence of any activity and with closed windows, background particle number concentrations for $PM_{2.5}$ were measured in the range between 0.2 cm^{-3} and 499.3 cm^{-3}, with a median value of 1.5 cm^{-3}. Background particle number concentrations for PM_{10} varied between 0.1 cm^{-3} and 0.9 cm^{-3}, with a median value of 0.1 cm^{-3}. Mass concentrations of $PM_{2.5}$ were measured at the range between 0.1 $\mu g/m^3$ and 10.1 $\mu g/m^3$, with a median value of 1.3 $\mu g/m^{-3}$. PM_{10} mass concentration varied between 0.1 $\mu g/m^3$ and 60.3 $\mu g/m^3$, with a median value of 5.5 $\mu g/m^{-3}$. Particulate matter diameter that occurred the most often was 0.337 micrometers with 76% of occurrence out of all 16 measured sizes. With opened windows, number concentrations for $PM_{2.5}$ were measured in the range between 0.3 cm^{-3} and 193.4 cm^{-3}, with a median value of 1.8 cm^{-3}. Number concentrations of PM_{10} varied between 0.1 cm^{-3} and 0.8 cm^{-3}, with a median value of 0.1 cm^{-3}. Mass concentrations of $PM_{2.5}$ were measured at the range between 0.2 $\mu g/m^3$ and 7.8 $\mu g/m^3$, with a median value of 1.2 $\mu g/m^{-3}$. PM_{10} mass concentration varied between 1.2 $\mu g/m^3$ and 91.9 $\mu g/m^3$, with a median value of 7.7 $\mu g/m^{-3}$. Particulate matter diameter that occurred the most often was 0.337 micrometers with 68% of occurrence out of all 16 measured sizes. During cleaning, number concentrations for $PM_{2.5}$ were measured in the range between 0.6 cm^{-3} and 751.1 cm^{-3}, with a median value of 4.3 cm^{-3}. Number concentrations of PM_{10} varied between 0.1 cm^{-3} and 3.8 cm^{-3}, with a median value of 1.0 cm^{-3}. Mass concentrations of $PM_{2.5}$ were measured at the range between 0.3 $\mu g/m^3$ and 29.2 $\mu g/m^3$, with a median value of 3.7 $\mu g/m^{-3}$. PM_{10} mass concentration varied between 7.2 $\mu g/m^3$ and 405.2 $\mu g/m^3$, with a median value of 80.2 $\mu g/m^{-3}$. On average, during cleaning number concentrations rose by 69% compared to the background levels, and mass concentrations increased by 92% compared to the background levels. Particulate matter diameter that occurred the most often was 0.337 micrometers with 74% of occurrence out of all 16 measured **sizes.**

Winter

In the absence of any activity and with closed windows, background particle number concentrations for $PM_{2.5}$ were measured in the range between 0.1 cm^{-3} and 427 cm^{-3}, with a median value of 3.7 cm^{-3}. Background particle number concentrations for PM_{10} varied between 0.1 cm^{-3} and 0.4 cm^{-3}, with a median value of 0.1 cm^{-3}. Mass concentrations of PM$_{2.5}$ were measured at the range between 0.4 μg/m^3 and 8.7 μg/m^3, with a median value of 1.7 μg/m^{-3}. PM$_{10}$ mass concentration varied between 0.1 μg/m^3 and 25.4 μg/m^3, with a median value of 1.7 μg/m^{-3}. Particulate matter diameter that occurred the most often was 0.337 micrometers with 68% of occurrence out of all 16 measured sizes. With opened windows, number concentrations for PM$_{2.5}$ were measured in the range between 0.4 cm^{-3} and 808.2 cm^{-3}, with a median value of 6.8 cm^{-3}. Number concentrations of PM$_{10}$ varied between 0.1 cm^{-3} and 0.4 cm^{-3}, with a median value of 0.1 cm^{-3}. Mass concentrations of PM$_{2.5}$ were measured at the range between 0.9 μg/m^3 and 16.4 μg/m^3, with a median value of 3.6 μg/m^{-3}. PM$_{10}$ mass concentration varied between 1.7 μg/m^3 and 19 μg/m^3, with a median value of 5.8 μg/m^{-3}. Particulate matter diameter that occurred the most often was 0.337 micrometers with 65% of occurrence out of all 16 measured sizes. During cleaning, number concentrations for PM$_{2.5}$ were measured in the range between 0.4 cm^{-3} and 2550 cm^{-3}, with a median value of 13.0 cm^{-3}. Number concentrations of PM$_{10}$ varied between 0.1 cm^{-3} and 2.5 cm^{-3}, with a median value of 0.2 cm^{-3}. Mass concentrations of PM$_{2.5}$ were measured at the range between 1.6 μg/m^3 and 51.6 μg/m^3, with a median value of 9.7 μg/m^{-3}. PM$_{10}$ mass concentration varied between 1.3 μg/m^3 and 268.5 μg/m^3, with a median value of 9.4 μg/m^{-3}. On average, during cleaning number concentrations rose by 59% compared to the background levels, and mass concentrations increased by 69% compared to the background levels. Particulate matter diameter that occurred the most often was 0.337 micrometers with 65% of occurrence out of all 16 measured sizes. Figures 10-11 show the number and mass distributions in the bedroom in Prague 10 in summer and winter and during different activities.

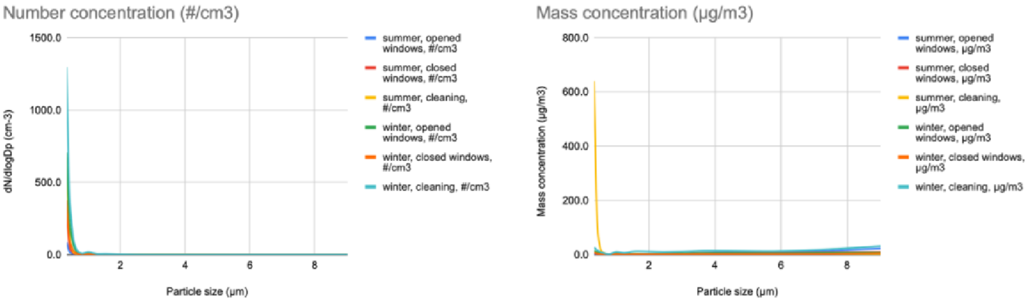


Fig. 10 and 11. Averaged levels of particulate matter in the bedroom, in Prague 10. Measurements were taken in the summer of 2023 and winter 2024. Fig. 10 (left) represents particle raw counts (#/cm^3) during cleaning, and without any activity (with closed and opened windows). Fig. 11 (right) shows mass distributions (μg/m^3) over mentioned activities.

4.2.3 Outside measurements

In summer, outdoor number concentrations for $PM_{2.5}$ were measured in the range between 0.5 cm^{-3} and 748.7 cm^{-3}, with a median value of 2.7 cm^{-3}. Outdoor number concentrations of PM_{10} varied between 0.1 cm^{-3} and 1.2 cm^{-3}, with a median value of 0.3 cm^{-3}. Mass concentrations of $PM_{2.5}$ were measured at the range between 0.4 $\mu g/m^3$ and 15.2 $\mu g/m^3$, with a median value of 2.1 $\mu g/m^{-3}$. PM_{10} mass concentration varied between 2.1 $\mu g/m^3$ and 167.7 $\mu g/m^3$, with a median value of 15.7 $\mu g/m^{-3}$. Particulate matter diameter that occurred the most often was 0.337 micrometers with 70% of occurrence out of all 16 measured sizes. In winter, outdoor number concentrations for $PM_{2.5}$ were measured in the range between 0.2 cm^{-3} and 1450 cm^{-3}, with a median value of 5.9 cm^{-3}. Outdoor number concentrations of PM_{10} varied between 0.1 cm^{-3} and 0.4 cm^{-3}, with a median value of 0.1 cm^{-3}. Mass concentrations of $PM_{2.5}$ were measured at the range between 1.1 $\mu g/m^3$ and 29.3 $\mu g/m^3$, with a median value of 2.8 $\mu g/m^{-3}$. PM_{10} mass concentration varied between 1.7 $\mu g/m^3$ and 18.2 $\mu g/m^3$, with a median value of 3.9 $\mu g/m^{-3}$. On average, number concentrations were 74% higher in winter than in summer, however, mass concentrations were 51% higher in summer than in winter. Particulate matter diameter that occurred the most often was 0.337 micrometers with 70% of occurrence out of all 16 measured sizes. Figures 12-13 show the number and mass distributions observed outside in Prague 1 and Prague 10 in summer and winter.

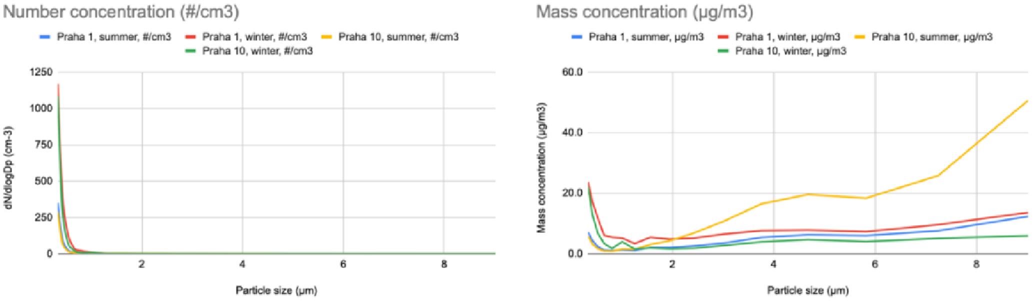


Fig. 12 and 13. Averaged levels of particulate matter outside in both residential areas. Measurements were taken in the summer of 2023 and in the winter of 2024. Fig. 12 (left) represents particle raw counts (#/cm^3). Fig. 13 (right) shows mass distributions ($\mu g/m^3$).

4.3 Workplaces

4.3.1 Laboratory

Summer

On the first day, number concentrations for $PM_{2.5}$ were measured in the range between 0.1 cm^{-3} and 505.4 cm^{-3}, with a median value of 1.4 cm^{-3}. Number concentrations of PM_{10} varied between 0.1 cm^{-3} and 0.8 cm^{-3}, with a median value of 0.1 cm^{-3}. Mass concentrations of $PM_{2.5}$ were measured at the range between 0.2 $\mu g/m^3$ and 10.2 $\mu g/m^3$, with a median value of 1.1 $\mu g/m^{-3}$. PM_{10} mass concentration varied between 0.1 $\mu g/m^3$ and 57.9 $\mu g/m^3$, with a median value of 9.5 $\mu g/m^{-3}$. Particulate matter diameter that occurred the most often was 0.337 micrometers with 80% of occurrence out of all 16 measured sizes. On the second day, number concentrations for $PM_{2.5}$ were measured in the range between 0.5 cm^{-3} and 882.9 cm^{-3}, with a median value of 2.6 cm^{-3}. Number concentrations of PM_{10} varied between 0.1 cm^{-3} and 1.1 cm^{-3}, with a median value of 0.2 cm^{-3}. Mass concentrations of $PM_{2.5}$ were measured at the range between 0.6 $\mu g/m^3$ and 17.9 $\mu g/m^3$, with a median value of 3.1 $\mu g/m^{-3}$. PM_{10} mass concentration varied between 5.2 $\mu g/m^3$ and 62.2 $\mu g/m^3$, with a median value of 15.4 $\mu g/m^{-3}$. On average, number concentrations were 47% higher on the second day (with closed windows) than on the first day (with opened windows), as well as mass concentrations: their increase accounted for 39% on the second day than on the first day. PM with a diameter of 0.337 micrometers prevailed on that day too, it accounted for 80%.

Winter

Measurements were done during two days in different scenarios. On the first day, number concentrations for $PM_{2.5}$ were measured in the range between 0.004 cm^{-3} and 233.3 cm^{-3}, with a median value of 0.8 cm^{-3}. Number concentrations of PM_{10} varied between 0.1 cm^{-3} and 0.4 cm^{-3}, with a median value of 0.1 cm^{-3}. Mass concentrations of $PM_{2.5}$ were measured at the range between 0.032 $\mu g/m^3$ and 4.7 $\mu g/m^3$, with a median value of 0.5 $\mu g/m^{-3}$. PM_{10} mass concentration varied between 0.1 $\mu g/m^3$ and 18 $\mu g/m^3$, with a median value of 0.8 $\mu g/m^{-3}$. Particulate matter diameter that occurred the most often was 0.337 micrometers with 65% of occurrence out of all 16 measured sizes. On the second day, number concentrations for $PM_{2.5}$ were measured in the range between 0.002 cm^{-3} and 43.4 cm^{-3}, with a median value of 1.2 cm^{-3}. Number concentrations of PM_{10} varied between 0.1 cm^{-3} and 0.5 cm^{-3}, with a median value of 0.1 cm^{-3}. Mass concentrations of PM$_{2.5}$ were measured at the range between 0.016 µg/m^3 and 6.6 µg/m^3, with a median value of 0.5 µg/m^{-3}. PM$_{10}$ mass concentration varied between 0.1 µg/m^3 and 11.2 µg/m^3, with a median value of 0.4 µg/m^{-3}. On average, number concentrations were 47% higher on the first day (activity was recorded in the laboratory) than on the second day (the room was empty), as well as mass concentrations: the increase accounted for 76% on the second day than on the first day. PM with a diameter of 0.337 micrometers prevailed on that day too, it accounted for 58%. Figures 14-15 show the number and mass distributions observed in the laboratory in summer and winter.

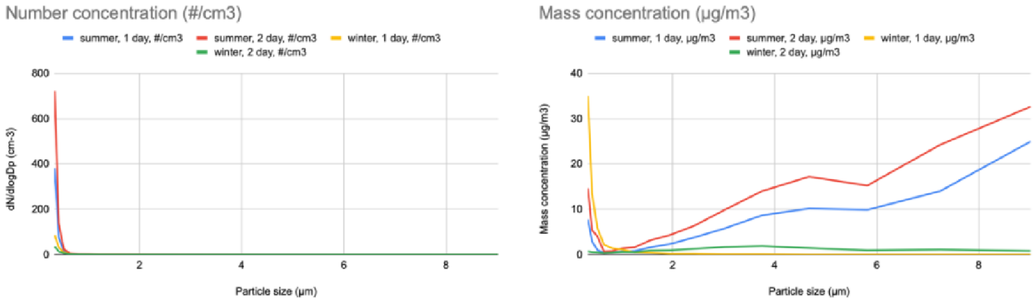


Fig. 14 and 15. Averaged levels of particulate matter in the laboratory, in Pruhonice. Measurements were taken in the summer of 2023 and winter 2024. Fig.14 (left) shows particle raw counts (#/cm^3). Fig.15 (right) represents mass distributions (µg/m^3).

4.3.2 Office

Summer

On the first day, number concentrations for PM$_{2.5}$ were measured in the range between 0.126 cm^{-3} and 572 cm^{-3}, with a median value of 1.7 cm^{-3}. Number concentrations of PM$_{10}$ varied between 0.1 cm^{-3} and 2.9 cm^{-3}, with a median value of 0.1 cm^{-3}. Mass concentrations of PM$_{2.5}$ were measured at the range between 0.296 µg/m^3 and 26.8 µg/m^3, with a median value of 1.1 µg/m^{-3}. PM$_{10}$ mass concentration varied between 0.1 µg/m^3 and 58.5 µg/m^3, with a median value of 2.5 µg/m^{-3}. Particulate matter diameter that occurred the most often was 0.337 micrometers with 80.6% of occurrence out of all 16 measured sizes. On the second day, number concentrations for PM$_{2.5}$ were measured in the range between 0.043 cm^{-3} and 742.7 cm^{-3}, with a median value of 3.6 cm^{-3}. Number concentrations of PM$_{10}$ varied between 0.1 cm^{-3} and 5.1 cm^{-3}, with a median value of 0.3 cm^{-3}. Mass concentrations of PM$_{2.5}$ were measured at the range between 0.139 µg/m^3 and 44.3 µg/m^3, with a median value of 2.3 µg/m^{-3}. PM$_{10}$ mass concentration varied between 0.1 µg/m^3 and

140 µg/m^3, with a median value of 22.1 µg/m^{-3}. On average, number concentrations were 28% higher on the second day (right after cleaning took place) than on the first day (one person was working in the office), as well as mass concentrations: their increase accounted for 78% on the second day than on the first day. PM with diameter of 0.337 micrometers prevailed on that day too, it accounted for 79%.

Winter

On the first day, number concentrations for $PM_{2.5}$ were measured in the range between 0.004 cm^{-3} and 214.2 cm^{-3}, with a median value of 1.4 cm^{-3}. Number concentrations of PM_{10} varied between 0.1 cm^{-3} and 3.6 cm^{-3}, with a median value of 0.1 cm^{-3}. Mass concentrations of $PM_{2.5}$ were measured at the range between 0.032 µg/m^3 and 27.3 µg/m^3, with a median value of 0.7 µg/m^{-3}. PM_{10} mass concentration varied between 0.1 µg/m^3 and 251.1 µg/m^3, with a median value of 1.4 µg/m^{-3}. Particulate matter diameter that occurred the most often was 0.337 micrometers with 64% of occurrence out of all 16 measured sizes. The other day, the number concentration for $PM_{2.5}$ was measured in the range between 0.004 cm^{-3} and 37.9 cm^{-3}, with a median value of 0.9 cm^{-3}. Number concentrations of PM_{10} varied between 0.1 cm^{-3} and 0.3 cm^{-3}, with a median value of 0.1 cm^{-3}. Mass concentrations of $PM_{2.5}$ were measured at the range between 0.016 µg/m^3 and 3 µg/m^3, with a median value of 0.4 µg/m^{-3}. PM_{10} mass concentration varied between 0.1 µg/m^3 and 9.7 µg/m^3, with a median value of 0.4 µg/m^{-3}. On average, number concentrations were 65% higher on the second day (cleaning took place) than on the first day (one person was working in the office), as well as mass concentrations: their increase accounted for 85% on the second day than on the first day. PM with a diameter of 0.337 micrometres prevailed on that day too, accounting for 59%. Figures 16-17 show the number and mass distributions observed in the office in summer and winter.

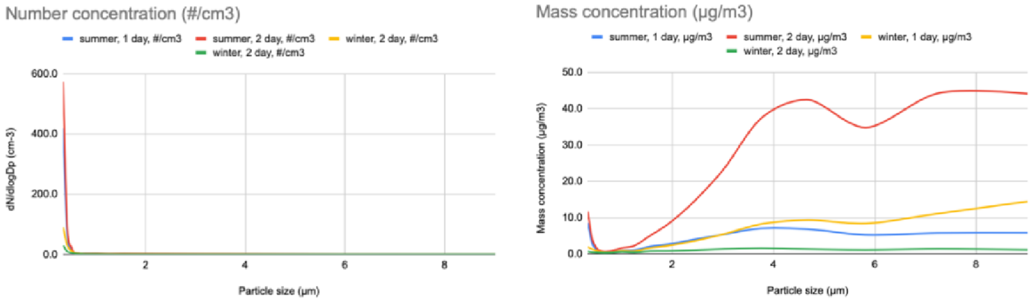


Fig.16 and 17. Averaged levels of particulate matter in the office, in Pruhonice. Measurements were taken in the summer of 2023 and winter 2024. Fig.16 (left) shows particle raw counts (#/cm^3). Fig.17 (right) represents mass distributions (µg/m^3).

4.4 Car cabin

Summer

Measurements were done on the way to Lichnice Castle and back to the initial location. On the way to the castle, AC was on, the trip took 1.5 hours. Number concentrations for $PM_{2.5}$ were measured in the range between 0.001 cm^{-3} and 523 cm^{-3}, with a median value of 1.2 cm^{-3}. In-car number concentrations of PM_{10} varied between 0.1 cm^{-3} and 1.3 cm^{-3}, with a median value of 0.3 cm^{-3}. Mass concentrations of $PM_{2.5}$ were measured at the range between 0.004 $\mu g/m^3$ and 10.6 $\mu g/m^3$, with a median value of 1.0 $\mu g/m^{-3}$. PM_{10} mass concentration varied between 0.4 $\mu g/m^3$ and 135.8 $\mu g/m^3$, with a median value of 19.3 $\mu g/m^{-3}$. The way back was faster, 1 hour 20 minutes, the AC was off, and the roof was opened. Number concentrations for $PM_{2.5}$ were measured in the range between 0.019 cm^{-3} and 587.5 cm^{-3}, with a median value of 1.6 cm^{-3}. In-car number concentrations of PM_{10} varied between 0.1 cm^{-3} and 1.8 cm^{-3}, with a median value of 0.4 cm^{-3}. $PM_{2.5}$ mass concentration was measured between 0.1 $\mu g/m^3$ and 12.1 $\mu g/m^3$ with a median value of 1.2 $\mu g/m^{-3}$. While PM_{10} mass concentration varied between 0.4 $\mu g/m^3$ and 185.6 $\mu g/m^3$ with a median value of 24.4 $\mu g/m^{-3}$. On average, on the way back number concentrations were higher by 14% than on the way to the Castle. Mass concentrations were higher by 26% on the way back than on the way to the Castle. PM with a diameter of 0.337 micrometers prevailed on the way to and back, on average they accounted for 79%.

Winter

Measurements were done in the same way as in summer. The road took 1.5 hours. Number concentrations for $PM_{2.5}$ were measured in the range between 0.011 cm^{-3} and 103.5 cm^{-3}, with a median value of 0.7 cm^{-3}. In-car number concentrations of PM_{10} varied between 0.1 cm^{-3} and 0.4 cm^{-3}, with a median value of 0.1 cm^{-3}. Mass concentrations of $PM_{2.5}$ were measured at the range between 0.041 $\mu g/m^3$ and 2.6 $\mu g/m^3$, with a median value of 0.4 $\mu g/m^{-3}$. PM_{10} mass concentration varied between 0.1 $\mu g/m^3$ and 73.5 $\mu g/m^3$, with a median value of 0.5 $\mu g/m^{-3}$. The way back was longer due to traffic, 1 hour 45 minutes. Number concentrations for $PM_{2.5}$ were measured in the range between 0.01 cm^{-3} and 431.4 cm^{-3}, with a median value of 0.7 cm^{-3}. In-car number concentrations of PM_{10} varied between 0.1 cm^{-3} and 0.3 cm^{-3}, with a median value of 0.1 cm^{-3}. $PM_{2.5}$ mass concentration was measured between

0.1 μg/m^3 and 8.8 μg/m^3, with a median value of 0.3 μg/m^{-3}, while PM$_{10}$ mass concentration varied between 0.1 μg/m^3 and 36.7 μg/m^3 with a median value of 0.1 μg/m^{-3}. On average, on the way back number concentrations were higher by 43% than on the way to the Castle. Mass concentrations were higher by 6% on the way back than on the way to the Castle. PM with a diameter of 0.337 micrometres prevailed on the way to and back, on average they accounted for 66%. Figures 18-19 show the number and mass distributions observed in the car cabin in summer and winter.

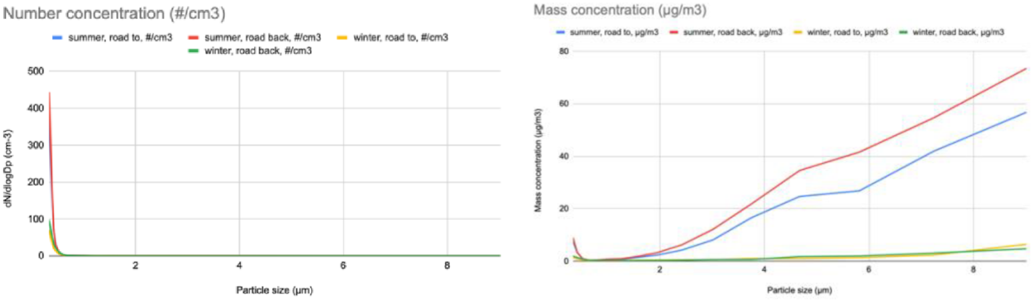


Fig.18 and 19. Averaged levels of particulate matter in the car. Measurements were taken in the summer of 2023 and winter 2024. Fig.18 (left) shows particle raw counts (#/cm^3) during the starting of the engine, driving, and parking with AC on/opened windows. Fig.19 (right) represents mass distributions (μg/m^3) during mentioned activities.

5. Discussion

Recorded data in all selected locations contributed to the understanding of patterns of particulate matter pollution in different environments. Variations due to different activities were observed as well as seasonal changes. The biggest concern is personal exposure to PM during cooking and cleaning in residence apartments; the work of printers and computers are the main concern for offices as well as in-car levels of PM during driving. These activities are the top ones that contribute to elevated number and/or mass concentrations of particulate matter in the moment of the activity and sometime after, prolonging the possible exposure of individuals to indoor air pollution.

Indoor air quality in residential areas

Data from residential locations showed very similar patterns except for the observations in the kitchen in Prague 10. In summer, both in kitchen and bedroom in Prague 1 and bedroom in Prague 10, opening windows would decrease the amount of particulate matter inside suggesting that better ventilation diluted the concentration of pollutants, which, in spite of any activity, could be resuspension of particles by moving of residents and animals, and also PM from animals (fur, hair, dander, dust and pollen carried from outside, litter boxes, bedding, etc.) (Tan and Zhang, 2004; Vardoulakis et al., 2020). However, in the kitchen of Prague 10, opening the window worsened the indoor air quality. Reasons for that could be the location of the apartment – right above the busy road, and construction works nearby – a facade of a neighbouring building was under restoration in that period (June 2023) (Franchi et al., 2006; Holton et al., 2008; Chang et al., 2014; Yang et al., 2020). As expected, cooking and cleaning were the largest sources of pollution in the residential areas, producing much higher number and mass concentrations of PM compared to background levels, with a difference of up to 96%. A similar increase was reported by Wan et al. (2011) and Li et al. (2022). In summer, cooking in Prague 1 on the electric stove produced less PM than cooking in Prague 10 on the gas stove. It is in accordance with a study by Dennekamp (2001), who investigated differences between produced amounts of PM by electric and gas stoves. A similar amount of particulate matter in both locations was observed during cleaning, being the second most significant source of pollution in indoor environments (Luoma and Batterman, 2001; Hussein et al., 2006; Wallace and Ott, 2011). Regarding background levels of PM in winter, in the absence of any activity, the pattern was the opposite. Closed indoor environments indicated lower values for both fine and coarse PM, and opening windows notably increased the values of PM measured indoors. The study by Chithra and Nagendra (2014) suggests that lower outdoor temperatures in winter favor atmospheric stability and lower mixing layer height in winter, leading to higher air pollution as the dispersion of pollutants is lower than in summer. In kitchen in Prague 10, values with opened windows were almost 10x higher than those with closed windows, suggesting that vehicle emissions from the road located just under the kitchen window contributed to observed elevated indoor air pollution (Kumar et al., 2013; Grigoratos et al., 2015). As in summer, cooking and cleaning in winter were the most significant sources of worsened air quality indoors. Concentrations in the kitchens were the biggest compared to bedrooms in both apartments. It is following research by Huboyo et al. (2011) and Poon et al. (2016), who found that concentrations in the kitchens are much higher than in other rooms of the same residence. That is because people tend to close the door to the kitchen while cooking to avoid the smell in other rooms. In the case of so-called "studio" apartments, where a kitchen is not separated, the concentrations spread out evenly over the entire living space.

All values for mass concentrations from background measurements in summer and winter were in line with the WHO 24-hour thresholds set at the level of 15 μg/m^3 for PM$_{2.5}$ and 45 μg/m^3 for PM$_{10}$. During cooking and cleaning in most cases, values exceeded the thresholds. Table 3 provides mean 24-hour values for each of the locations in different seasons and comparison with the WHO guidelines.

Table 3. Summary statistics for indoor concentrations of PM measured in residential areas (Prague 1 and Prague 10) during summer and winter seasons. Mean background levels and mean values during cooking (kitchen) and cleaning (bedroom) are compared with the WHO guidelines.

Summary statistics for indoor concentrations of PM measured in residential areas during summer and winter seasons				
parameters	mean background	mean cooking(kitchen),	WHO guidelines	WHO guidelines (cooking/cleaning)

		cleaning (bedroom)	(mean background)	
PM2.5 kitchen summer Prague 10 (µg/m3)	3	80	Allowed	Exceeding
PM10 kitchen summer Prague 10 (µg/m3)	9	226	Allowed	Exceeding
PM2.5 kitchen winter Prague 10 (µg/m3)	9	53	Allowed	Exceeding
PM10 kitchen winter Prague 10 (µg/m3)	14	119	Allowed	Exceeding
PM2.5 bedroom summer Prague 10 (µg/m3)	2	7	Allowed	Allowed
PM10 bedroom summer Prague 10 (µg/m3)	9	102	Allowed	Exceeding
PM2.5 bedroom winter Prague 10 (µg/m3)	4	11	Allowed	Allowed
PM10 bedroom winter Prague 10 (µg/m3)	4	17	Allowed	Allowed
PM2.5 kitchen summer Prague 1 (µg/m3)	2	29	Allowed	Allowed
PM10 kitchen summer Prague 1 (µg/m3)	14	99	Allowed	Exceeding
PM2.5 kitchen winter Prague 1 (µg/m3)	5	53	Allowed	Exceeding
PM10 kitchen winter Prague 1 (µg/m3)	9	19	Allowed	Allowed
PM2.5 bedroom summer Prague 1 (µg/m3)	2	7	Allowed	Allowed

PM10 bedroom summer Prague 1 (µg/m3)	13	113	Allowed	Exceeding
PM2.5 bedroom winter Prague 1 (µg/m3)	3	6	Allowed	Allowed
PM10 bedroom winter Prague 1 (µg/m3)	7	3	Allowed	Allowed

Outdoor measurements

Summer measurements indicated lower number and mass concentrations of outdoor PM, except for the PM_{10} measured in Prague 10, which can be explained by the mentioned ongoing facade restoration of a neighbouring building in that period and the busy road located just under the kitchen window from where the measurements were done. Measurements in Prague 1 were lower, probably due to less traffic (Abt et al., 2000; Quang et al., 2013; Park et al., 2014). Another reason could be the location of the apartment, in the vicinity of the river Vltava and park Letna. Studies by Janhäll (2015), Diener and Mudu (2021), and Wang et al. (2021) suggest that urban vegetation filtrates fine-sized particles by deposition and dispersion. Xuan et al. (2010) and Liu et al. (2016) investigated the effects of waterbodies on PM pollution and found that lakes and rivers serve as deposition sinks for coarse PM, impacting the local microclimate and changing air circulation. As expected, the number and mass concentrations of outdoor PM were higher in winter in both locations. Surprisingly, observed values in Prague 1 showed higher values in winter than those measured in Prague 10. That could happen because the apartment in Prague 10 is located on the fifth floor and does not face another building as in the case of the apartment in Prague 1, located in the city centre with densely constructed buildings. In both locations, winter measurements indicated relatively higher concentrations of fine-sized particles. These findings are in agreement with the study by Chan and Yao (2008), who found that particulate matter levels depend on the season and the geographical location, with a trend to be higher in winter as anthropogenic emissions from fossil fuel combustion are elevated (domestic heating). Additionally, unfavorable meteorological conditions for the dispersion of air pollutants prevail in winter. Studies by Huang et al. (2014), Chithra and

Nagendra (2014), Zhang and Cao (2015) and Tabinda et al. (2019) propose the same trends and reasons behind higher values of fine PM in winter. In summer, reduced anthropogenic sources lead to generally lower values of PM pollution. All the values measured in Prague 1 and Prague 10 did not exceed the WHO guidelines as shown in table 4.

Table 4. Summary statistics for outdoor concentrations of PM measured in summer and winter seasons. Mean background levels are compared with the WHO guidelines.

Summary statistics for outdoor concentrations of PM measured in summer and winter seasons	SUMMER	WINTER		
parameters	mean	mean	WHO guidelines (summer)	WHO guidelines (winter)
PM2.5 Prague 1 (µg/m3)	3	9	Allowed	Allowed
PM10 Prague 1 (µg/m3)	7	9	Allowed	Allowed
PM2.5 Prague 10 (µg/m3)	3	6	Allowed	Allowed
PM10 Prague 10 (µg/m3)	24	4	Allowed	Allowed

Indoor air quality in workplaces

As in the case of residential buildings, the location of the workplaces plays a considerable role in the indoor air quality status as a building's facade works as a filter for particles from outside through cracks, leaks, and holes (Abt et al., 2000; Quang et al., 2013; Park et al., 2014). Amounts of air pollutants in both workplaces – in the laboratory and office – were at approximately the same level despite being used differently. The results could be affected by the fact that in the laboratory there was a possibility to open the windows, while in the office, it was impossible.

Laboratory

The laboratory is a standard office room where samples of barley are stored on the shelves, and a drying machine is installed, which was not used in summer. On the first day in summer, the window was opened. With closed windows, mass and number concentrations for fine and coarse particles were higher, proposing that indoor activity – working with barley stalks (measuring and weighing, cutting, and sorting stalks, moving bags with samples, etc.) influenced the PM levels. When the windows were opened, the rate of ventilation was higher, reducing pollutant concentrations in the laboratory. In winter, on both days windows were closed. On the first day, employees used the drying machine and worked with samples of wood. Due to that activity, levels of PM_{10} were higher than those from the other day when no one entered the room and the drying machine was off. Table 5 shows that all the mass concentrations were lower than the WHO thresholds for indoor particulate matter pollution.

Table 5. Summary statistics for indoor concentrations of PM measured in the laboratory in summer and winter seasons. Mean background levels for summer and winter are compared with the WHO thresholds.

Summary statistics for indoor concentrations of PM measured in the laboratory in summer and winter seasons				
	SUMMER	WINTER		
parameters	mean	mean	WHO guidelines (summer)	WHO guidelines (winter)
PM2.5 1 day (µg/m3)	2	1	Allowed	Allowed
PM10 1 day (µg/m3)	12	3	Allowed	Allowed
PM2.5 2 day(µg/m3)	4	1	Allowed	Allowed
PM10 2 day (µg/m3)	19	1	Allowed	Allowed

Office

Surprisingly, PM levels in the office were very close to levels observed in the laboratory. That may be explained by the fact that windows could be opened neither in summer nor in winter and by cleaning the office, which produced noticeable spikes in the PM_{10} mass concentrations both in summer and winter. Cleaning in the office produced the same number concentration of particles as handling barley stalks in the laboratory with closed windows and even higher mass concentrations of coarse particulate matter. That is in line with many studies that suggest cleaning is one of the most significant sources of indoor air pollution (Luoma and Batterman, 2001; Hussein et al., 2006; Wallace and Ott, 2011). Another possible reason for the elevated PM levels is the usage of computers and printers (Salthammer et al., 2012). The physical presence of people in an office and the resuspending of particles by moving around the room were found to contribute to an increase in the number and mass concentrations of particles in the absence of any activity in the study by Chatoutsidou et al. (2015). That was the case for present research as well, as both in summer and winter, on one of the days when measurements took place in the office, there was no activity other than a person working on the computer. Physical presence and resuspension of particles produced lesser amounts of PM than those during the cleaning. Recorded mass concentrations were compared to the WHO threshold for PM in Table 6. All of them were less than set levels.

Table 6. Summary statistics for indoor concentrations of PM measured in the office in summer and winter seasons. Mean background levels for summer and winter are compared with the WHO thresholds.

Summary statistics for indoor concentrations of PM measured in the office in summer and winter seasons				
	SUMMER	WINTER		
parameters	mean	mean	WHO guidelines (summer)	WHO guidelines (winter)
PM2.5 1 day (µg/m3)	2	1	Allowed	Allowed
PM10 1 day (µg/m3)	6	9	Allowed	Allowed
PM2.5 2 day(µg/m3)	5	1	Allowed	Allowed
PM10 2 day (µg/m3)	38	1	Allowed	Allowed

Indoor air quality in the car cabin

Measurements in the car were done in summer and winter during trips to Lichnice castle, located 100 km from the starting point in Praha 10. In summer, on the way to the castle, the AC was on, and on the way back windows and roof were opened, and the AC was off. Recorded data indicated worse air quality on the way from the castle, suggesting that opened windows and roof decreased air quality, being close to the WHO threshold for daily allowed PM concentrations. This finding is in agreement with the studies by Jain (2017) and Qiu et al. (2019), who investigated in-car pollution levels, comparing different road and tunnel environments and experimenting with opened and closed windows in the vehicle, noting that opened windows would increase the number and mass concentrations of particles inside a car. The authors suggest reducing exposure to PM by switching to internal recirculation of the air inside the vehicle. That was done in winter when AC was used as heating and internal recirculation mode was on. Data showed lower levels of pollution inside the car compared to the data from summer measurements. However, the way back in winter was characterized by higher values for PM than those recorded on the way to the castle, as the car was stuck in traffic closer to Prague, indicating that the purification system did not work effectively. These findings are consistent with the study by Molden et al. (2023), who compared several means of transport including private cars. They found that the purification system was not very effective at filtering out particles, especially, fine ones. Nevertheless, it was the safest way of transportation along with active transport (walking, cycling) compared to trains, buses and trams. Recorded results of PM in car in summer and winter were averaged and compared with the WHO guidelines, as shown in Table 7.

Table 7. Summary statistics for indoor concentrations of PM measured in the car in summer and winter seasons. Mean background levels for summer and winter are compared with the WHO thresholds.

Summary statistics for indoor concentrations of PM measured in the car in summer and winter seasons				
	SUMMER	WINTER		
parameters	mean	mean	WHO guidelines (summer)	WHO guidelines (winter)
PM2.5 road to the castle (µg/m3)	2	1	Allowed	Allowed
PM10 road to the castle (µg/m3)	29	2	Allowed	Allowed
PM2.5 road from the castle (µg/m3)	3	1	Allowed	Allowed
PM10 road from the castle (µg/m3)	40	2	Allowed	Allowed

6. Conclusion

The present study focused on particle number and mass concentrations in selected indoor environments in Prague: residential apartments, workplaces, and car cabin. Selection was made according to the amount of time people tend to spend in different indoor spaces. Most of the time, statistically, people spend at home and work**,** while transportation can also significantly contribute to particulate matter exposure depending on the means of transport. Personal exposure to particulate matter over time can provoke the development of a broad spectrum of diseases, from allergies to lung cancer. The study's objective was to measure the number and mass concentrations of PM and compare them with the WHO guidelines on the daily allowed concentrations of $PM_{2.5}$ and PM_{10}.

As was expected, in the residential apartments, cooking and cleaning produced the highest levels of both number and mass concentrations of PM, being elevated not only during the activity but also sometime after the activity was finished, up to 4 hours, resulting in prolonged personal exposure to pollution. The observed difference between background levels with no activity and during cooking/cleaning was up to 96%. In the absence of any activity, in summer in closed environments, higher levels of PM pollution were observed, while opening windows decreased the number of pollutants indoors. However, in winter, the trend was the opposite and opening windows worsened air quality indoors.

Outdoor mass and number concentrations measured from residential areas demonstrated lower values in summer due to fewer anthropogenic pollution sources compared to winter results. Prague 1 had lower summer PM pollution values due to less traffic in the area and proximity to the river and park. However, winter measurements indicated higher values of PM pollution. It could be explained by dense urban planning, as the building is facing another one. In Prague 10 summer values could be affected by ongoing facade renovation of a neighboring building and busy road right under the apartment's windows.

In workplaces, levels of PM were dependent on human activity as well. In the laboratory where stalks of barley in summer and wood chips in winter, were handled, observed values for PM were higher, than in the absence of mentioned activities. In the office, where one person was working on the computer, from time-to-time printing documents, levels of PM were approximately the same as in the laboratory due to the impossibility of opening the windows in the office. These results suggest that installed hardcopy devices, the physical presence of a person and the resuspension of particles, that were already on the surfaces in the office contribute to overall pollution. When cleaning occurred in the office, values were even higher than during working in the laboratory, suggesting that cleaning was the largest source of pollution in the office environment as well.

In the car cabin, measurements showed drastic differences between summer and winter and between opened and closed windows. It was observed that opening windows significantly decreased the air quality status, making the values of PM_{10} close to the WHO threshold, while using the AC and internal recirculation reduced the pollution levels.

Producing PM during human activities is inevitable. However, there are various options to reduce exposure and minimize the health risks. For instance, the usage of low-emission type of materials in the construction and renovation of interiors; reducing carpeting on the walls and floors; installation of mechanical ventilation systems; proper ventilation and regular cleaning; avoidance of smoking and candles burning inside; improving stoves; usage of cleaner fuels; usage of cooker bonnets during cooking; etc. The public should know about common methods of exposure reduction to save the health of individuals and the human population of the planet.

Observed variations underscore potential health risks, particularly in environments with poor ventilation or during activities generating high PM levels. The study emphasizes the need for enhanced indoor air quality management and reviews strategies to mitigate exposure to particulate matter. These findings contribute to the broader discourse on indoor air quality, highlighting the importance of monitoring and regulating indoor environments to safeguard public health. It calls for targeted policy interventions and further research into effective PM mitigation strategies in indoor environments where personal exposure to air pollution is much worse than outside.

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8. Figure references

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Table 1. WHO, 2022, "What are the WHO air quality guidelines?".

Table 2. Annex XI of the Directive 2008/50/EC of the European Parliament and the Council of 21st May 2008 on ambient air quality and cleaner air for Europe.

Tables 3-7. Created by the author.