Lecture Notes in Civil Engineering

Priyanka Kulshreshtha
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Indoor Environmental Quality

Select Proceedings of ACIEQ 2023

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Priyanka Kulshreshtha · Sumanth Chinthala ·
Prashant Kumar · Barun Aggarwal
Editors

Indoor Environmental Quality

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Editors
Priyanka Kulshreshtha
Society for Indoor Environment (SIE)
New Delhi, India

Prashant Kumar
University of Surrey
Guildford, Surrey, UK

Sumanth Chinthala
Department of Civil Engineering
National Institute of Technology, Warangal
Hanumakonda, Telangana, India

Barun Aggarwal
Indian Society for Heating, Refrigerating
and Airconditioning Engineers (ISHRAE)
New Delhi, India

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Foreword I

Increasing air pollution has become a major public health concern across the world in recent years. The population of India is pertinently aware of air pollution outdoors and they presume that they are safe in indoor environments. This perception has created a lot of health hazards, to the occupants who are spending most of the time indoors. Many researchers have worked in indoor air pollution for the past few decades, have shared interesting observations with reference to its effect on human health and productivity but dissemination of this knowledge is still lacking for the common people, who are the worst affected.

For many years, industry and academia have faced many challenges to converge their thoughts and work together to achieve their common goals of protecting human health. During Covid-19 pandemic, millions of citizens were forced to stay indoors for a longer time, and it gave all the stakeholders an opportunity to understand more about the importance of maintaining good indoor air quality (IAQ). The researchers in various institutions in India and the world over have been involved in carrying out their research pertaining to IAQ. These researchers needed a platform where they can present and enhance their research/technical outcomes on IAQ while keeping abreast with innovative research and technologies evolving around the world. Asian Conference on Indoor Environmental Quality (ACIEQ) has brought together the academics, industry experts and budding researchers who have worked in indoor air pollution by giving them an international platform to showcase their scientific and technical contributions in IAQ, thermal comfort, lighting, acoustics, health, and productivity. This book has selected papers published by various scientists, academicians, researchers and industry experts from India and the globe, who have contributed to the event by publishing their work.

I look forward to this 2nd Edition of Proceedings of ACIEQ 2023 to make an impact in the niche area of indoor environmental research to the people who are affected the most, fulfilling the SDG Goal 3 for good health and well-being.

May 2023

Mukesh Khare, Ph. D. Engg. (U.K.)
Professor Emeritus
Environmental Engineering Group,
Department of Civil Engineering
Indian Institute of Technology Delhi
New Delhi, India

Foreword II

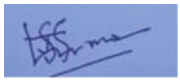
Air, Air everywhere but no air to breathe!

Better air, better life and better health are the three most important aspects of the urban population. The resources, which were once considered to be pure and free, are slowly becoming impure and precious. The air we breathe is slowly and steadily thrusting us into the realms of poor health and wellbeing. The smog episode (New Delhi) in 2016, created a paradigm shift into the unsustainable world we are planning to leave for our future generations.

With the extreme weather conditions and increasing pollution in the outdoor environment, the amount of time that is spent in the indoor environment will always be very high for most of the individuals and for ensuring a better liveable environment, various research insights are needed before scaling up or making modifications to any existing indoor environment on a large scale. The air we breathe knows no boundaries in terms of outdoor or indoors but we continue to pollute it inevitably. Shifting the focus from outdoor air to indoor air, Asian Conference on Indoor Environmental Quality (ACIEQ-2023) has taken a leap to try and understand the components of indoor environment in a more research oriented and innovative manner.

The proceedings of ACIEQ 2023 contains contributions from various experts in the area of Indoor Air Quality (AIQ), lighting, ventilation, thermal comfort and acoustics who have given various insights for a better indoor environment. This book has compiled various articles which help the readers in understanding the important factors that contribute to a better indoor environment. Further, the risks associated with modifying the indoor environment by the introduction of new materials, performing various anthropogenic activities and other related aspects were stressed by the learned contributors in the book. A dive into this book will enable the readers to identify the factors that are to be addressed on a large scale so that they can provide infrastructure- based solutions to the citizens of India, by considering all the factors that contribute to a better indoor environment. This is a first of its kind initiative in India in the field of Indoor Environmental Quality which will prove to be of paramount relevance to researchers, academicians and policymakers to create a roadmap for future research on Indoor Environmental Quality (IEQ) in India.

I compliment you for your endeavour in pursuing the great task of AIR QUALITY for humanity and wish you all success in times to come.



Dr. J. S. Sharma
President
Indian Association for Air Pollution Control
New Delhi, India

Preface

In recent years, there has been a growing recognition of the importance of Indoor Environmental Quality (IEQ) and its impact on our well-being, productivity, and overall quality of life. As buildings become more energy-efficient and tightly sealed, the need to understand and optimize the indoor environment becomes paramount. The second edition of the Asian Conference on Indoor Environmental Quality (ACIEQ) has played a crucial role in bringing together researchers, practitioners, and policymakers from across the world to exchange knowledge, ideas, and solutions in this rapidly evolving field. Held at the Indian Aviation Academy, Vasant Kunj, New Delhi, India on 24–25 February 2023, this collaboration between the Indian Society for Heating Refrigeration and Air Conditioning Engineers (ISHRAE), Society for Indoor Environment (SIE) and Indoor Air Quality Association India Chapter (IAQA) has become the leading platform for cutting edge resource and information exchange on the important topic of IEQ.

This book is a collection of selected papers presented at the Asian Conference on Indoor Environmental Quality, showcasing the latest advancements, research findings, and practical applications in the realm of IEQ. The papers cover a wide range of topics, including indoor air quality, thermal comfort, lighting design, acoustics, ventilation, building performance simulation, occupant behaviour, and sustainable building practices. ACIEQ serves as a platform for interdisciplinary collaboration, fostering dialogue among experts from diverse fields such as architecture, engineering, environmental science, and public health. This book reflects the spirit of knowledge exchange and collaboration that defines the conference, bringing together contributions from renowned researchers and emerging scholars alike.

The papers included in this compilation demonstrate the diversity and depth of the research efforts aimed at enhancing indoor environmental quality. They present innovative methodologies, experimental studies, and case studies shed light on the challenges faced in different contexts, ranging from densely populated urban areas to rural regions. The research findings not only contribute to advancing our understanding of IEQ but also provide valuable insights for policymakers, building professionals, and occupants to make informed decisions that promote healthier and more sustainable indoor environments.

It is our hope that this book will serve as a valuable resource for researchers, practitioners, educators, and students interested in the field of indoor environmental quality. By disseminating knowledge and sharing best practices, we can collectively strive towards creating indoor spaces that prioritize human health, comfort, and well-being. We would like to express our gratitude to all the authors who have contributed their research papers to this compilation. Their dedication, expertise, and commitment to improving IEQ have made this book possible. We would also like to extend our appreciation to the reviewers who have generously shared their time and expertise to ensure the quality and rigor of the included papers.

Finally, we would like to thank the Asian Conference on Indoor Environmental Quality organizing committee for their efforts in organizing an exceptional conference that continues to foster collaboration and knowledge exchange. We hope that this book will further amplify the impact of the conference and contribute to advancing the field of IEQ.

New Delhi, India — Priyanka Kulshreshtha
Warangal, India — Sumanth Chinthala
Surrey, UK — Prashant Kumar
New Delhi, India — Barun Aggarwal

Contents

About the Editors

Priyanka Kulshreshtha is Co-founder of Society for Indoor Environment (SIE). She has 20 years of research experience in the field of indoor air quality monitoring, exposure assessment, and health in both industry and academia. She has to her credit many-post graduate dissertations/projects in the field of environment management and sustainable development. She has worked as Postdoctorate Research Fellow at Ospedale Luigi Sacco, University of Milan, Italy, in the European Commission project "HEALTHVENT". She has to her credit more than 35 publications in refereed international journals, articles, conference papers, and chapters. She is the Reviewer to many international journals and publications. She is a visiting faculty at International Centre for Environmental Audit and Sustainable Development for capacity building of auditors on issues related to environment and sustainable development. She is closely associated with government and industry stakeholders in formulation of Indoor Air Quality Guidelines for India.

Sumanth Chinthala is currently working as Assistant Professor in Water and Environment Division, Department of Civil Engineering at National Institute of Technology, Warangal. His main areas of interests are air pollution modelling, indoor air quality, and sustainable development. He is associated with Central and State Pollution control Board for implementing the actions of National Clean Air Programme (NCAP) launched by MOEFCC, government of India and also currently working as a task force member for legal hearing at state level. He is also serving as Reviewer for top international journals in the field of air pollution. He has presented many papers in international conferences and meetings in countries like Brazil, China, UK, and in many more countries.

Prashant Kumar is Professor & Chair in Air Quality and Health; founding Director of the Global Centre for Clean Air Research (GCARE) and the founding Co-Director of the Institute for Sustainability at the University of Surrey, UK. His current research projects are focused on broad multidisciplinary areas of air pollution monitoring/modelling, low-cost sensing, nature-based solutions, climate change mitigation and developing innovative technological and passive (e.g. green infrastructure) solutions

for air pollution exposure control for both the developing and developed world. He has published ~350 journal articles, attracting ~18,500 citations; h-index, 67; i10index, 255. Prashant is one of the world's top-cited researchers. In 2022, he received the global accolade of being recognised in the top 1% of 'Highly Cited Researchers' by Clarivate. His research has secured over £11M of individual research funding from projects total worth over £30M, funded by the RCUK, EC, industry, charities and international funding bodies. He has developed a network of collaborators across four continents and his research has featured regularly in well-read media outlets such as the BBC and The Times.

Barun Aggarwal is a serial Entrepreneur with a versatile background and international experience spanning 25 years in several continents. Currently, he heads BreatheEasy Consultants Pvt Ltd—a full service indoor air quality (IAQ) solution provider whose focus is not only indoor air quality (IAQ) but also energy conservation. He is Founding Member of Indoor Air Quality Association (IAQA), USA—India Chapter and immediate past chapter Director for IAQA, India Chapter. Currently, he holds the position of Membership Chair, India Chapter. He is Member of ISHRAE and is the Founding Member of the IEQ Committee of ISHRAE that has developed the first international standard for Indoor Environmental Quality (IEQ) published in 2016.

Advanced Ventilation for Better Health

Arsen K. Melikov

Abstract In this paper the need for change of the present practice of building ventilation is discussed. Results on the importance of ventilation for the health of building occupants are presented to justify the need for change of the focus from room ventilation to ventilation for occupants. The present ventilation design based on ventilation rate has to be complimented with ventilation design based on ventilation air distribution. The performance of advanced ventilation methods providing optimal room air distribution is compared with the present mixing ventilation. The importance of proper design of advanced ventilation and its implementation and operation in practice is highlighted. The need for updating the present standards and considering new standards responding to the developed advanced ventilation methods is concluded.

Keywords Ventilation · Health · Mucous layer · Exposure · Design · Occupants

1 Ventilation of Buildings and Health of Occupants

The primary goal of building ventilation is to provide occupants with clean air for breathing. The importance of the ventilation for occupants' health has been documented during the years [1]. Several studies have reported illness and sick leave prevalence reduction with the increase in the amount of clean air, often outdoor air, supplied to occupied spaces (Fig. 1).

Beside the cleanliness of indoor air, its temperature and relative humidity is important for occupants' health and comfort. Therefore often the ventilated air is conditioned in order to maintain room temperature and humidity in comfortable ranges. Figure 2 reveals the importance of air temperature and relative humidity for eye tear film quality. Results reported by Melikov et al. [3] are summarised in the figure. The number of samples of tear film crystallization in the case of healthy eyes (good quality) and unhealthy eyes (bad quality) for 30 subjects exposed to combinations of

A. K. Melikov (✉)
Department of Environmental and Resource Engineering (DTU Sustain), International Centre for Indoor Environment and Energy, Technical University of Denmark, Lyngby, Denmark
e-mail: akme@dtu.dk

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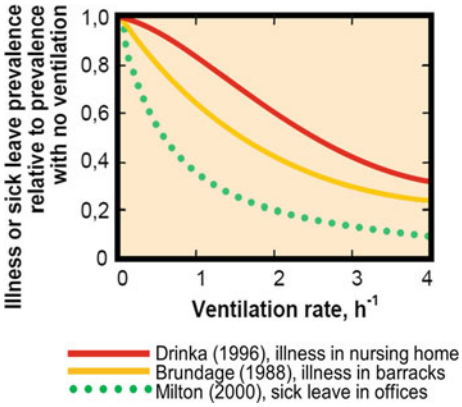

Fig. 1 Positive effect of increased ventilation rate on health [2]

three air temperatures and two relative humidity levels are shown. The results in the figure reveal a decreasing trend in the tear film quality with increase in air temperature and humidity. The percent of tear film mucous layer samples rated as good quality is significantly higher ($P < 0.05$) for the neutral condition (72% at 23 °C) as compared with both higher temperature and humidity conditions (41% at 26 °C and 70%; 34% at 28 °C and 70%).

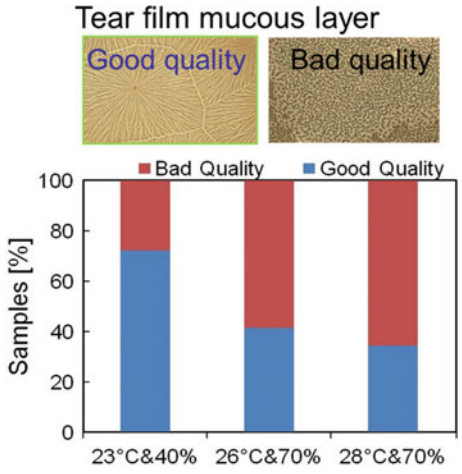

Fig. 2 Percent of samples with good and bad tear film mucous layer quality collected from 30 persons exposed to different combinations of room air temperature and relative humidity [3]

2 Room Air Distribution and Exposure

In buildings, pollution is generated by numerous sources (building materials, office equipment, occupants, infiltrated outdoor pollution, etc.). Source control is often applied for reduction of pollution generation, e.g. development and use of low pouting building materials. In buildings occupants are a major source of pollution. Human body is source of bio-effluents (odours), particles emitted as a result of hair breakage and shedding of epidermal cells, aerosols of different size in the exhaled air, skin oil and its oxidation products, etc. Most of the generated pollution is airborne and is transported by the airflows around the human body and in the rooms. Therefore, air distribution around human body and in rooms is of major importance for exposure of occupants to the generated pollution. The air distribution in rooms is the result of a complex interaction of flows including the free convection flow that exists around the human body and the thermal plume above the body, the transient flow of breathing, the supplied ventilation airflow, buoyancy flows generated by warm/cold objects and surfaces such as window surfaces, office equipment, etc. Figure 3 illustrates an example of possible in practice interaction of a supplied ventilation flow with an upward buoyancy flow generated by the occupant and warm window. The complex airflow interaction in spaces changes in time due to changes in strength and location of heat sources, occupants' movement, etc. Therefore, often the airflow distribution and transport of pollution in occupied spaces is not in steady state. Thus, the exposure of occupants to indoor generated pollution is not constant and often its determination is not accurate.

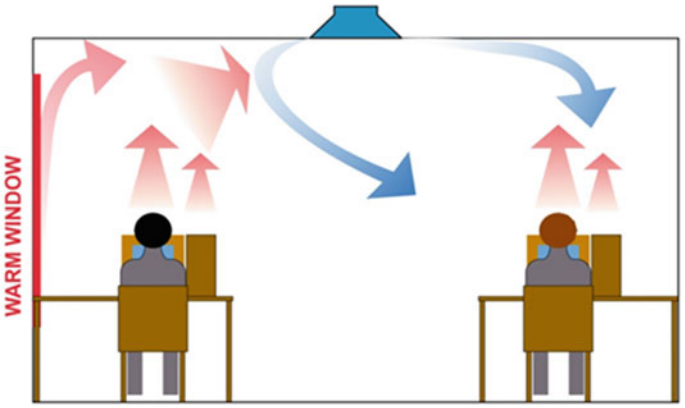

Fig. 3 The interaction of room airflows changes in time and affects occupants' exposure to the indoor environment

3 Present Ventilation Practice

At present mixing air distribution (known also as ventilation by dilution), is most commonly applied in practice [4]. This air distribution strategy is inefficient (Fig. 4). Some of the reasons are: the clean and conditioned air is supplied far from occupants and is mixed with the warm and polluted room air (can carry germs exhaled by sick people) when it reaches the occupants; it is difficult to remove pollution at the source location (occupants, building materials, office equipment, etc.) before it is mixed with room air; often the air distribution pattern enhances the transport of pollution generated outside of the occupied zone (e.g. from wall surfaces, etc.) into the occupied zone; temperature, velocity and contaminant distribution in spaces are determined by the complex flow interactions that are difficult to control; cleaning, conditioning and transportation of huge amount of supply air is needed to ventilate the entire volume of spaces (including unoccupied areas!) and this increases the energy use; large air handling units and bulky duct systems that take space and increased initial costs are used; flexibility in space use is curtailed; the aim is to achieve uniform temperature and velocity in the occupied zone and the environment is designed for an "average occupant" while in reality large differences exist between people with regard to the preferred environment; uniform environments may not be preferred by many people, etc. [5]. In many buildings, the quality of the indoor environment is mediocre even though the ventilation is performing as intended. This is frustrating for engineers and a challenge for the HVAC industry.

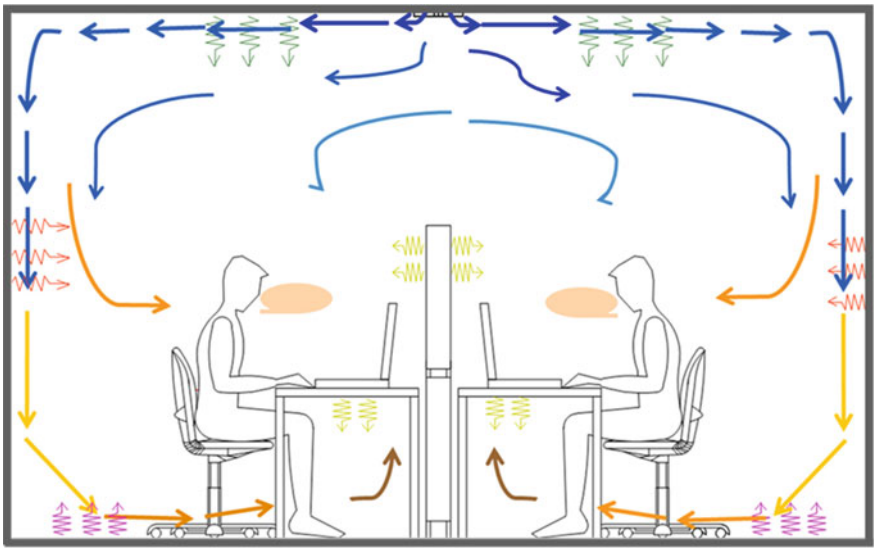

Fig. 4 In rooms with mixing ventilation the distribution of supplied clean ventilation air is not efficient

4 Present Ventilation Design Practice

The first step in the ventilation design is to determine the amount of clean air supply needed to ensure certain air quality level in spaces. For this purpose the ventilation rate is calculated. Comfortable thermal environment is maintained by conditioning and/or increase of the supplied air, use of radiant systems, elevated air movement at high room temperatures (e.g. use of cooling fans), etc. Energy use is also of concern, though often the required indoor environment is achieved by increase of the supplied ventilation air instead of pollution (contaminants and heat) control.

One of the methods for calculation of the ventilation rate is based on the perceived air quality (PAQ) by the occupants [6]. Typically occupants are the major (only) source of CO_2 in spaces. CO_2 is easy to measure. It is used as a proxy of room generated pollution assuming complete room air mixing (often not present in rooms in practice!). The ventilation rate that will ensure CO_2 concentration in occupied space at a certain level above the outdoor CO_2 concentration is calculated. The CO_2 concentration levels correspond to categories of indoor environment (three or four categories) defined by different percent of occupants dissatisfied with the perceived air quality. However, this procedure is based on the impact of indoor pollution on perceived air quality without taking into account the impact of the temperature and humidity of the inhaled air. Research has documented that increase of the inhaled air temperature and relative humidity has negative impact on the PAQ [7]. Warm and humid clean air is perceived as unpleasant while cool and dry polluted air may not be perceived as unpleasant. The importance of air movement for the PAQ is not considered in the standards either. It is documented that acceptability of PAQ and freshness of the air improved when air movement from front, i.e. against the face, is applied [8]. The elevated air movement diminishes the negative impact of increased air temperature, relative humidity and pollution level on PAQ. The degree of improvement depends on the pollution level, the temperature and the humidity of the room air. At a low humidity level of 30% an increased velocity could compensate for the decrease in perceived air quality due to an elevated temperature ranging from 20 to 26 °C (Fig. 5). The study also reports that at air temperature of 26 °C, increased air movement is able to compensate for an increase in humidity from 30 to 60%, but not to 70%. The elevated velocity of recirculated polluted room air (by a cooling fan) does not decrease the intensity of SBS symptoms, but the movement of clean, cool and dry air does. Energy-saving strategy of improving occupants' comfort in rooms by moving room air at high velocity and maintaining room temperature high at reduced supply of outdoor air or by a decrease of indoor air enthalpy should be cautiously implemented in buildings because the pollution level may still cause negative health effects.

The above discussion makes clear that the indoor air quality requirements in the present standards based on perceived air quality are incomplete and need to be updated.

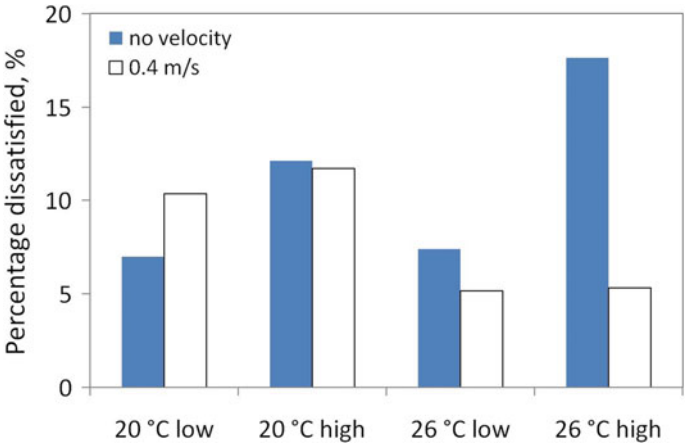

Fig. 5 Percentages dissatisfied people with PAQ exposed to still air (velocity <0.05 m/s) and air movement from front (velocity 0.4 m/s) at combinations of air temperature (20 and 26 °C) and pollution level (low and high); 30% relative humidity

5 Next Development: Advanced Ventilation

Achieving high indoor air quality at reduced energy consumption is an important goal of the ventilation design. Increase of the ventilation rate is suggested in the standards and the guidelines in order to improve indoor air quality. In the case of the present mixing ventilation (ventilation by dilution), the increase of the ventilation rate will dilute the indoor pollution, will reduce its concentration and will improve inhaled air quality but the energy used for conditioning and transportation of the ventilation air will increase. The energy use will decrease if the ventilation rate is reduced but this will lead to decrease of the indoor air quality. Thus, in the case of mixing ventilation the energy saving strategy based on reduction of clean ventilation air is dangerous because it will affect occupant's health negatively and will decrease their work performance.

Are indoor environment designers really at crossroads? Is it possible to design an indoor environment that improves health, comfort, performance and saves energy compared to our present practice? This would create shared values for employees, in terms of their well-being and comfort, for employers, in terms of increased performance and reduced energy use, and for society, in terms of fewer sick leave days, decreased healthcare costs, and energy conservation. However, for the reasons discussed in the previous section, it is not possible to achieve such a win–win solution with the present mixing ventilation strategy. A new approach in the indoor environment design is needed. Clean air distribution instead of ventilation rate and micro-environment around each occupant instead of the entire room should be in the focus. More advanced heating, cooling, and ventilating methods and technological

solutions must be developed. Ventilation design should focus on advanced air distribution based on the following main principles [5]: remove/reduce the air pollution and the generated heat (when not needed) locally; provide clean air, also heating and cooling (where, when, and as much as needed), make possible active control of the air distribution; involve each occupant in creating his/her own preferred microenvironment, reduce energy use. The development of advanced air distribution methods has already started. Several solutions have been reported in the literature and some of them have been implemented in practice. In the following sections of the chapter, the performance of two advanced air distribution methods, namely displacement ventilation and personalised ventilation will be compared with the performance of mixing ventilation.

6 Displacement Ventilation: Impact of Occupant Activities

Displacement ventilation aims at replacing polluted room air without mixing with the supplied clean ventilation air. Typically the clean and cool ventilation air is supplied with low velocity from relatively large diffusers located on the wall near to the floor. Compared to mixing ventilation the use of displacement air distribution for comfort ventilation is relatively new. It has been studied intensively during the last 35–40 years. Detail description on its performance under different conditions, most of them steady-state conditions, is provided in the literature [9]. The performance of displacement ventilation under non-steady state conditions, e.g. moving room occupants, has been studied little. It follows the performance of displacement ventilation and mixing ventilation is compared with regard to airborne cross-infection (e.g. COVID 19) based on results from physical measurements under realistic conditions in a room with walking persons [10]. An office room with two workstations was arranged in a full-scale test room. Two breathing thermal manikins (body size of average Scandinavian woman) were used as sedentary occupants at the workstations. Tracer gas was added to the air exhaled by one of the manikins simulating infected occupant. The tracer gas concentration in the inhaled air was measured without the walking person in the room and with one and two walking persons. In the case of walking persons in the rooms, three possible practice situations were studied: person walking along the desks on the side of the air supply diffuser, person walking along the desks on the side opposite to the diffuser and two walking persons along the desks—one on the desk side near the diffuser and one on the side opposite to the diffuser (Fig. 6). During the experiments 80 L/s of the treated outdoor air at 20 C was supplied to the room by the DV, aiming at an exhaust air temperature of 26 °C. Details of the experiments are reported by Halvoňová and Melikov [10]. In the following the focus is on assessment of airborne transmission.

Figure 7 shows the concentration of the tracer gas exhaled by the front (infected) manikin in the air inhaled by the manikin seated behind (simulating occupant exposed to the infected air exhaled by the front manikin). The inhaled tracer gas concentration normalized to the case of complete mixing room air distribution is shown. The

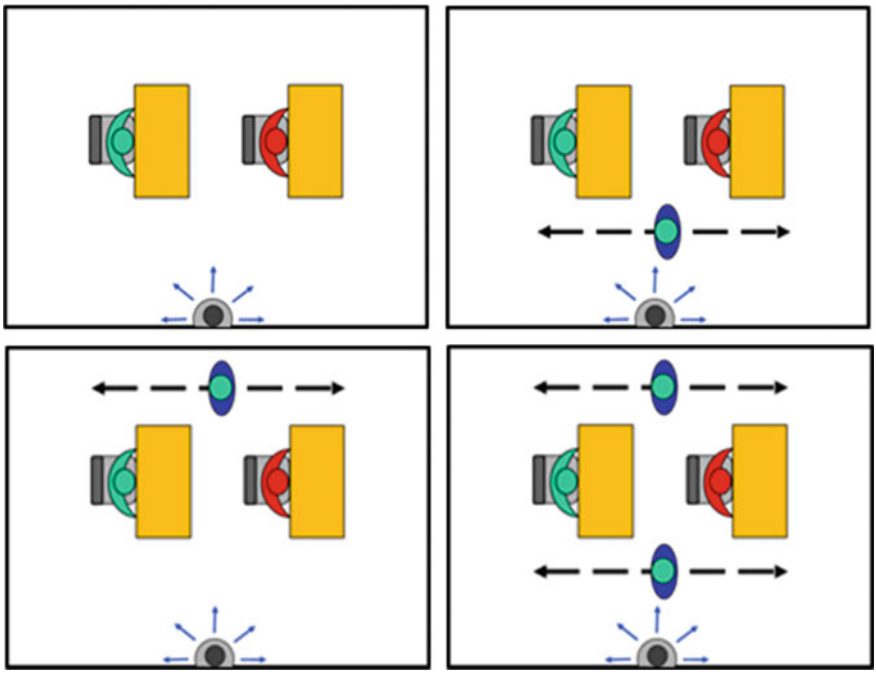

Fig. 6 Studied cases: without walking person; one walking person along the desks on the side of the air supply diffuser; one person walking along the desks on the side opposite to the diffuser; two walking persons along the desks—one on the desk side near the diffuser and one on the side opposite to the diffuser. The manikin simulating infected occupant exhaling tracer gas is seated in front (indicated with red colour)

results are expected and reveal that first, under steady-state conditions (i.e. without moving person), the normalized concentration with displacement ventilation is much lower compared to complete mixing ventilation, i.e. the air inhaled by the exposed manikin is much cleaner with displacement ventilation than with mixing ventilation and second, the walking person causes air mixing and disturbs the superior performance of the displacement ventilation.

In practice the activity of the room occupants is different. In some rooms walking occupants are present often while in other rooms they do not. It is documented that in rooms with displacement ventilation the flow disturbed by the walking person is re-established in a short time after the walking event. The intake fraction (iF) index defined as the ratio of the mass intake of the infected air to the mass exhaled infected air (%) introduced by Bennett et al. [11] is used to assess the impact of the walking person on airborne cross-infection. The iF is calculated for the results presented in Fig. 7 assuming four hours of work for two seated occupants and 10 min walking event (one or two other occupants) during each hour. The results are shown in Fig. 8. The results reveal that the intake fraction for the all studied conditions with displacement ventilation is much lower than in the case of complete mixing.

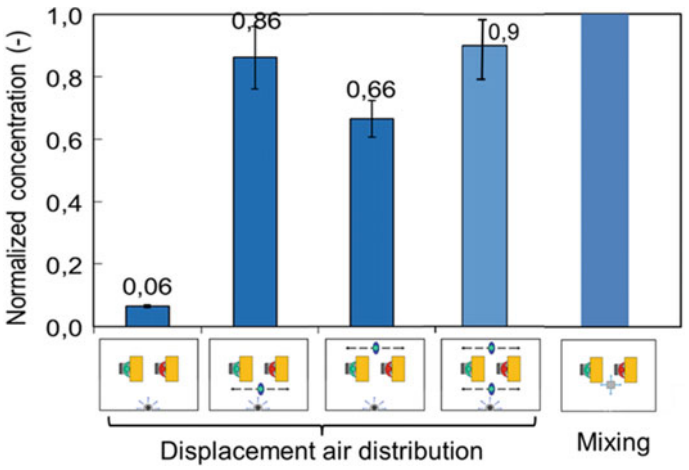

Fig. 7 Impact of disturbance due to walking person on the performance of displacement ventilation

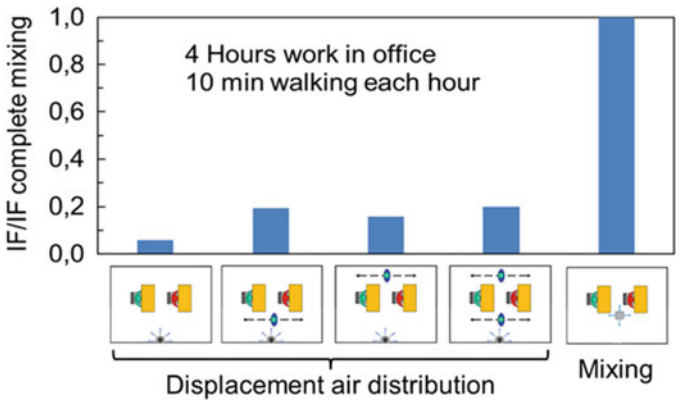

Fig. 8 Impact of walking on the intake fraction

Thus, with regard to airborne transmission displacement air distribution is superior to mixing air distribution.

7 Personalized Ventilation

Personalized ventilation (PV) is an advanced air distribution method aiming at clean air supply close to the breathing zone of the user [12]. Figure 9 shows the principle of the desk installed in personalized ventilation. The user can control the direction and the flow rate of the supplied personalized air and in some cases its temperature and

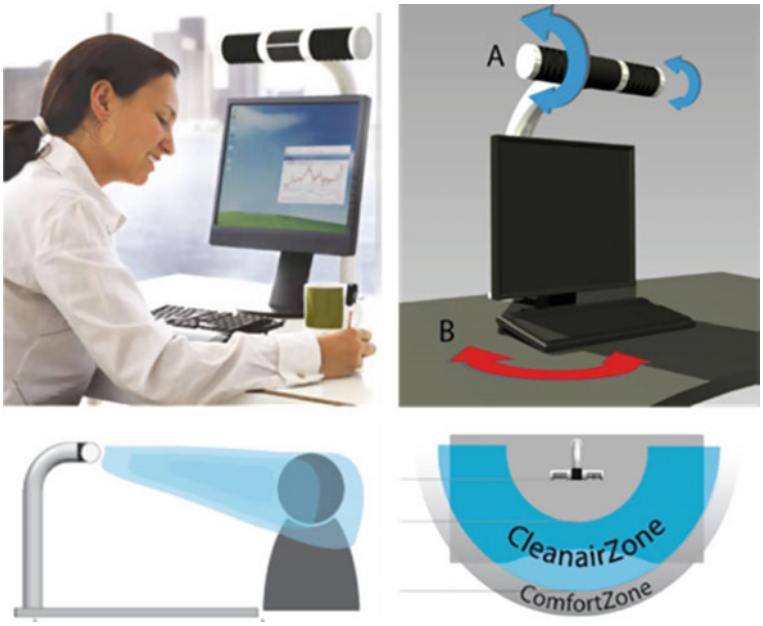

Fig. 9 Desk installed personalized ventilation (curtesy to Exhausto AS, Denmark)

humidity. The characteristics of the supplied flow (e.g. entrainment of the surrounding polluted room air, spread of the jet, etc.) can be controlled by use of air supply diffusers of different designs or by changing the initial characteristics of the supplied flow (velocity distribution, turbulence intensity, etc.). In offices, PV is typically used in conjunction with total volume ventilation [13–15] as well as radiant cooling/heating systems such as chilled ceiling, etc. [16].

Numerous human subject studies have documented that the use of PV reduces SBS (Sick Building Syndrome) and eye symptoms and improves users' perceived air quality, thermal comfort, and performance [3, 17]. Recommendations for design and implementation of PV in practice have been suggested as well [12].

The use of PV is recommended in the recently developed guidelines for reduction of airborne transmission of COVID 19 [18, 19]. Its efficiency is due to breathing clean personalized air before it is mixed with the polluted (infected) surrounding room air. With regard to reduction of airborne transmission the performance of PV is compared with the performance of mixing ventilation in Fig. 10. The reproductive number, defined as a number of secondary infections that arise when a single infectious case is introduced into the population where everyone is susceptible is used [20]. The details of the calculations are presented by Cermak and Melikov [21]. The reproductive number in the case of influenza virus is calculated in the case of an office with ten occupants who work together for eight hours. The calculations include data from physical measurements and available data on characteristics of the influenza virus. Results of clean air supply at a ventilation rate of 10 L/s per

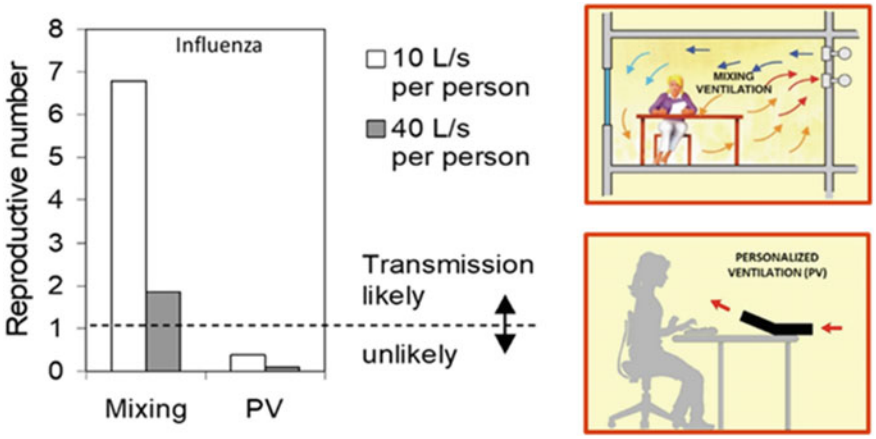

Fig. 10 Reproductive number in the case of office with one infected and nine susceptible occupants working together for 8 h. The reproductive number in case of mixing ventilation and personalized ventilation at two ventilation rates 10 L/s per person and 40 L/s per person is compared [21]

person (as recommended in the present standards [6] as well as four times higher ventilation rate (40 L/s per person) are compared in the figure. It can be seen that in the case of mixing ventilation four times increase of the ventilation rate decreases the number of secondary infections, yet it is likely that at the end of the day, i.e. after eight hours, two occupants will be infected. On contrary, the use of personalized ventilation makes the airborne transmission unlikely already at 10 L/s per person.

The optimal performance of PV depends on its design and proper implementation in practice. The design recommendations are suggested by Melikov [12]. The performance of PV when implemented in practice under different conditions has been studied as well [10, 13]. Figure 10 summarises some of the results on exposure of the occupants to indoor pollution in the case of PV combined with displacement ventilation as reported by Cermak et al. [13]. The experimental conditions described in [13] can be summarised as following: a full scale test room with two breathing thermal manikins is used to simulate the office with two occupants; different tracer gases are used to simulate pollution generated at floor level (e.g. carpet), body bio-effluents (odour) and infected exhaled air. The arrangement in the office is shown in Fig. 11. The body bio-effluents and infected exhaled air are generated by the manikin seated in front, i.e. polluting manikin (indicated with red colour). Results from three studied scenarios are compared: (1) displacement ventilation operates alone; (2) displacement ventilation is combined with PV used only by the manikin in the back (exposed manikin); (3) displacement ventilation is combined with PV used by the manikin in front (polluting manikin). In total, 80 L/s of clean air (= 4.3 air changes per hour) is supplied either by the displacement ventilation when operating alone or the air is distributed between the personalized ventilation (15 L/s) and the displacement ventilation (65 L/s). The temperature of the air supplied from both personalized and displacement ventilation is fixed at 20 °C. The normalized concentration shown in

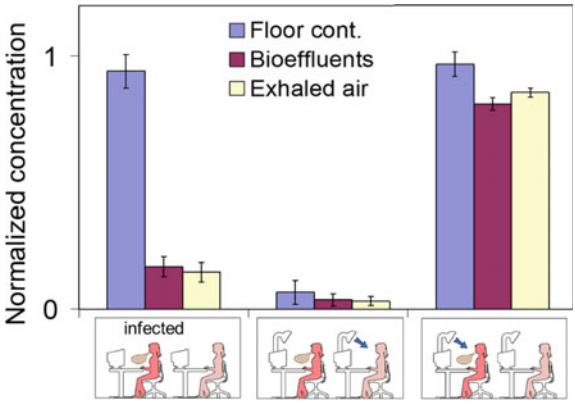

Fig. 11 Exposure to floor pollution, body bio-effluents and exhaled air in the case of displacement ventilation alone and in combination with personalized ventilation

the figure is the ratio of the tracer gas concentration in the air inhaled by the exposed manikin minus the tracer gas concentration in the supplied air divided by the tracer gas concentration at the exhaust room air minus the trace gas concentration in the supplied air. For the first scenario when displacement ventilation is used alone the exposure to floor generated pollution is high since the clean air supplied near the floor is mixed with the floor generated pollution and is transported to the breathing zone by the free convection flow around the manikin's body. However, the exposure to the bio-effluents and the exhaled air is low. The use of PV by the exposed manikin in addition to the displacement ventilation (scenario 2) leads to very low exposure to the three pollutions. However, the exposure to the three pollutions increases dramatically when the polluting manikin uses its PV but the PV of the exposed manikin is not used. In this case the personalised flow mixes the pollution generated by the polluting manikin with the room air and thus the exposed manikin inhales polluted room air. The results reveal that when PV is implemented in practice its operation has to be considered carefully in order to obtain optimal performance.

8 Concluding Remarks

The issues discussed in this paper reveal that with the used at present mixing ventilation it is not possible to provide room occupants with high inhaled air quality at reduced energy use. There is need to move the focus from design of room ventilation to ventilation design for occupants. For this purpose the design based on ventilation rate has to be complemented/replaced with design based on ventilation air distribution. Advanced ventilation methods for clean (disinfected) air distribution need to be developed. The methods, when implemented in practice, have to improve inhaled air quality at reduced energy consumption compared to the used at present mixing ventilation. The advantage of this approach is the possibility for implementation of

smart control based on the individual needs and activities of each occupant. Development of design guidelines and recommendations for the practical implementation of advanced air distribution methods is important in order to ensure their optimal performance. Advanced ventilation methods based on the existing ventilation systems (air handling unit, ducting system, etc.) but improved room air distribution are easy to be implemented.

The future development of advanced ventilation providing non-uniform clean air distribution in rooms requires substantial revision of the present indoor air quality/ventilation standards based on the assumption of complete room air mixing. Specific requirements for design, implementation and operation of the advanced ventilation methods has to be included in the standards.

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Evaluation of Health Risks Associated with Household Air Pollution in Rural Areas of Telangana State in India

Yaparla Deepthi and S. M. Shiva Nagendra

Abstract Household Air Pollution (HAP) contributing from open fires or inefficient stoves fed by biomass, coal and kerosene are being used by 2.4 billion people across the world that has resulted in 3.2 million deaths per year. In the present study, Particulate Matter (PM_{10} and $PM_{2.5}$) were investigated in biomass and LPG based households during summer and monsoon seasons, followed by evaluation of health risks for women in rural areas of Telangana state in India. Health impact and risk assessment of air pollution were estimated by WHO developed software tool called AIRQ+ . PM_{10} and $PM_{2.5}$ concentrations in biomass households were ~1.8 and 2.7 times greater than those of LPG due to high emission factor of the biomass. Health risk assessment of women in biomass households exhibited high non-carcinogenic risk against LPG. The health impact assessment revealed high incidence per 100,000 population for an acute exposure of asthma, unhealthy days and lost workdays of 1009, 318 and 312, respectively. However, chronic exposure has resulted in stroke (77.23), ischemic heart disease (71.15), acute lower respiratory infections (51.93) and chronic obstructive pulmonary diseases (33.26). This study establishes the HAP contributing from fuel-type and evaluates health risks associated with the PM exposure.

Keywords Household air pollution · Fuel type · Biomass · Health risk · Health impact · Women

Y. Deepthi (✉) · S. M. S. Nagendra
Department of Civil Engineering, Indian Institute of Technology Madras, Chennai, India
e-mail: yaparladeepthi@gmail.com

S. M. S. Nagendra
e-mail: snagendra@iitm.ac.in

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1 Introduction

Household Air Pollution (HAP) contributing from open fires or inefficient stoves fed by biomass, coal and kerosene are the leading source of health burden across the world. Though there is decline in percentage of people using solid fuels still 2.4 billion people across the world are dependent that has resulted in 3.2 million deaths per year of which 2,37,000 deaths are of children under five years of age [24]. Amongst 3.2 million deaths, Ischaemic heart disease, stroke, lower respiratory infection, chronic obstructive pulmonary disease and lung cancer contribute for 1.024, 0.736, 0.672, 0.608 and 0.192 million deaths, respectively [24]. In India, there is huge decline in solid fuel users (fuel wood, cow dung cakes and agricultural residue) by various policy interventions like Pradhan Mantri Ujjwal Yojana in rural and urban areas by distribution of LPG connections but at the same time 8.33 million people rely on solid fuels resulting in 0.6 million premature deaths [7]. Further, in rural areas biomass fuels contribute for 72% of energy usage followed by 28% of clean fuels comprising of LPG, electricity, solar cookstoves, gobar etc. [4].

Incomplete combustion of solid fuels and unvented fuel stoves release harmful pollutants comprising particulate matter (PM), carbon monoxide (CO), nitrogen oxides (NOx), volatile organic compounds (VOCs) [23]. Women and children accompanying them are highly exposed to these dirty smoke as they spend hours involving in household activities like cooking. These exposure results in increased respiratory diseases, cardio-respiratory illnesses and also non-respiratory problems including adverse pregnancy effects, prematurity and low birth weight [8]. Apart from these disease burden, household air pollution exposures are attributable to disability-adjusted life-years (DALYs), lost work days, hospital admissions etc. [5].

A lot of studies have been carried out to understand the HAP in rural areas of India but mostly dominated in north India [14, 15, 20] and a few in south India [4, 22]. Health impacts associated with ambient air pollution are assessed in urban areas across the world [1, 2, 21] and few in India [13, 18]. Not many studies are available on health impacts associated with HAP in developing countries and specifically in India [11]. The objective of the present study is to evaluate the exposure to HAP in rural settings when compared for solid fuels and LPG. Followed by investigation of health impact and risk assessment for child, women and elderly by the World Health Organisation (WHO) a software tool called AIRQ+ was developed.

2 Materials and Methods

2.1 Study Area

The study area selected for the present study is Kishannagar village of Mahbubnagar district in southern part of Telangana state, India (17.3850° N, 78.4867° E). Figure 1 depicts the Topo map of Kishannagar village. Fuel used for cooking and heating

activities, socioeconomic status, energy usage pattern and climatic conditions were the attributes used for finalising the Kishannagar village as it is a representative of south India with tropical climate. This village has a total area of 1571 hectares with a population of 3,639 dominated by males with 51% and females by 49% residing in 737 households. The primary occupation of the villagers being agriculture with around ~60% of the population followed by cattle farming by remaining 30%. The primary fuel used for cooking by 80.5% of villagers was biomass while 17.7 relied on LPG according to the census, 2011. A questionnaire survey was carried out to collect the primary data in order to check the applicability of data and though there is decrease in the percentage of the people using solid fuels the trend remained the same.

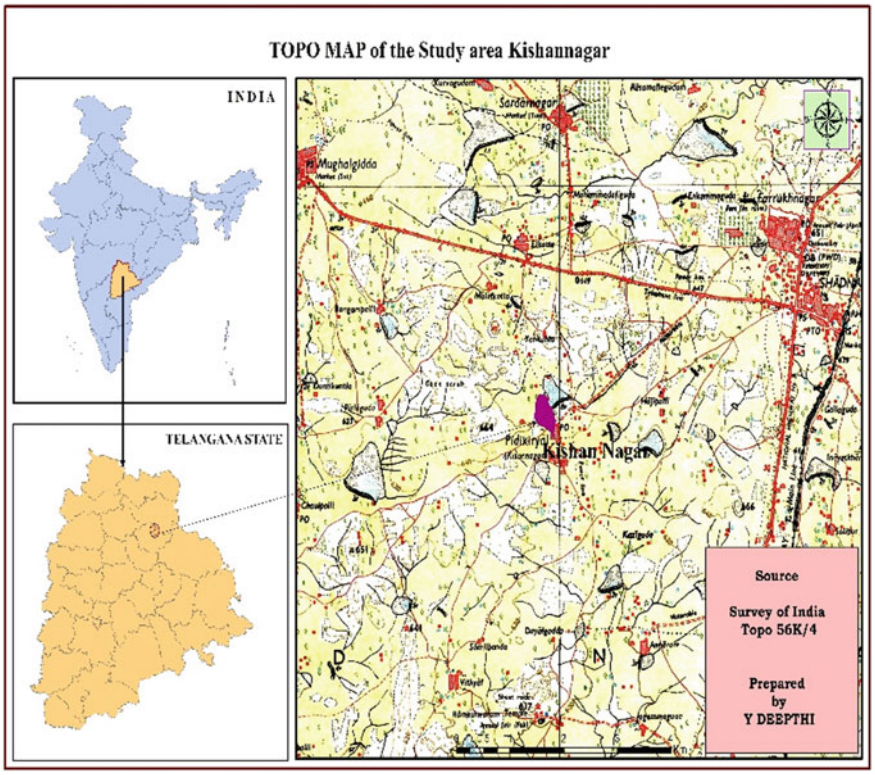

Fig. 1 Topo map of study area

2.2 Monitoring and Instrumentation

PM mass concentrations (PM_{10} and $PM_{2.5}$) were monitored in the living area locations (people spend most of their time) of biomass and LPG based households. The monitoring was carried out in 36 households in the summer season (April 14, 2017–May 30, 2017) and 18 households in the monsoon seasons (June 15 2017–July 14, 2017). In 36 households, 30 operated on biomass and 6 in LPG while in 18 households, 15 in biomass and 3 in LPG. The monitoring duration was 24 h in each household with 1-min resolution in batches of 3–5 days and break of 1 or 2 days for equipment maintenance placed at 1.5 m above the ground level (breathing height). Optical particle Sizer (OPS) Model 3330 spectrometer was used to measure particles ranging between 0.3 and 10 μm in 16 size channels using single particle counting technology.

2.3 Health Risk Assessment

The risk assessment guidance approved by US EPA has been used to study the health risks associated with continuous exposure to $PM_{2.5}$ as it can easily penetrate deep inside the human respiratory systems i.e., to bronchi and alveolar regions having serious health hazards. Non-carcinogenic risks and carcinogenic risks associated with PM exposure were assessed using hazard quotient (HQ) (Eq. 1) and cancer risk (CR) (Eq. 4), respectively for women who are the most affected persons due to HAP.

Non-carcinogenic risk estimates the negative impacts associated with systematic exposure to high concentrations of PM and doesn't contribute to cancer.

$$HQ = \frac{CDI}{Rfd'} \tag{1}$$

$$CDI = \frac{PM * IR * ED * Ef * LE}{BW * ATL * NDY} * PPF \tag{2}$$

$$Rfd' = \frac{Rfc * IR}{BW} \tag{3}$$

where, CDI is chronic daily inhalation (mg/kg/day) and Rfd is the reference dose of pollutant exposure (mg/kg/day), PM is particle mass (mg/m^3), IR is particle inhalation rate (m^3/hours), ED is exposure duration (hours/week), Ef is exposure frequency (weeks/year), LE is the length of exposure (years), BW is bodyweight of passengers, ATL is the average time of human life (years), NDY is the number of days per year (days/year), and PPF is particle penetration factor. Rfc is the reference dose of exposed air pollutant (mg/m^3). As per US EPA, (HQ <1) indicates no risk; (HQ >1) indicates non-carcinogenic risk; and (HQ >10) indicates high chronic risk [18].

The carcinogenic risk evaluates the probability of incidence of dangerous health impacts due to high level exposure of PM and is cancer causing.

$$CR = \frac{CDI}{CSF} \tag{4}$$

$$CSF = IUR * \frac{BW}{IR} * 10 \wedge 3 \tag{5}$$

where, CSF is cancer slope factor (kg day/mg), IUR is inhalation unit risk of suspended particles (m^3/mg).

US EPA prescribed limit of CR $<10^{-6}$ is tolerable for individual compounds, and CR $<10^{-4}$ is regarded as tolerable for cumulative risk [18].

2.4 Evaluation of Health Impacts

The short-term and long-term health impacts associated with prolonged exposure to PM released from HAP primarily contributing from solid fuels were established by using AIRQ+ software developed by WHO [25]. The software uses the epidemiological data of hazardous health impacts linked with persistent exposure to air pollution. The incidence rates of acute and chronic health impacts pertaining to the present-day Indian conditions were extracted from the reported epidemiological research studies in India. Overall mortality [24], respiratory diseases [17], cardiovascular diseases [17] and asthma are the most commonly used acute impacts while mortality due to ALRI [10] COPD [9], IHD [19], LC [12] and stroke [16] are the chronic health impacts considered for the present evaluation based on Indian studies [18]. Reference values prescribed by WHO guidelines were considered for the study i.e., $PM_{2.5:}$ 24 h average is 15 μg/m^3 and annual average is 5 μg/m^3 and PM_{10}: 24 h average is 45 μg/m^3 and annual average is 15 μg/m^3 [24].

3 Results

3.1 PM Characteristics in Biomass and LPG Households

The daily mean mass concentrations of PM_{10} and $PM_{2.5}$ (concentrations ± standard error) released from biomass and LPG households are depicted in Fig. 2. Biomass households had high concentrations followed by LPG:

	Biomass	LPG	
PM_{10}	111.69 ± 10	61.12 ± 10	$\mu g/m^3$
$PM_{2.5}$	41.76 ± 5	15.58 ± 2	$\mu g/m^3$

PM_{10} and $PM_{2.5}$ concentrations in biomass-based households were ~1.8 and 2.7 times higher than those of LPG due to high emission factor of biomass. All the households surpassed the WHO's guidelines ($PM_{2.5}$ −15 $\mu g/m^3$ and PM_{10} −45 $\mu g/m^3$). These results were comparable to earlier studies where PM_{10} and $PM_{2.5}$ concentrations in biomass were in the range of 86–287 $\mu g/m^3$ and 66–197 $\mu g/m^3$, respectively and LPG households were between PM_{10}: 75–178 $\mu g/m^3$ and $PM_{2.5}$: 89–95 $\mu g/m^3$ [4, 14, 22]. However, the values reported in the present study were in the lower range due to various attributes like fuels type, kitchen types, ventilations, and climatic conditions. PM_{10} and $PM_{2.5}$ concentrations for biomass and LPG households during summer and monsoon season are provided in Table 1.

Figures 3 and 4 represent the temporal variations of PM_{10} and $PM_{2.5}$ concentrations in biomass and LPG households, respectively. It was observed that the biomass concentrations were very high compared to those of LPG in both the figures. There were two peaks representing morning and evening cooking hours primarily contributing from cooking activities [4].

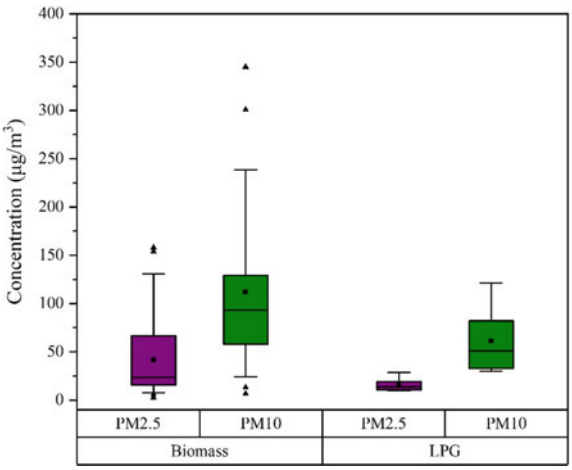

Fig. 2 Box plots showing the distribution of 24 h mean mass concentrations of $PM_{2.5}$ and PM_{10} concentrations for Biomass and LPG households

Table 1 Average concentrations of PM_{10} and $PM_{2.5}$ during summer and monsoon seasons

Type of fuel	Season	PM_{10} ($\mu g/m^3$)	$PM_{2.5}$ ($\mu g/m^3$)
Biomass	Summer (n = 30)	133.17	45.58
	Monsoon (n = 6)	67.32	33.87
LPG	Summer (n = 15)	67.05	15.24
	Monsoon (n = 3)	49.23	16.29

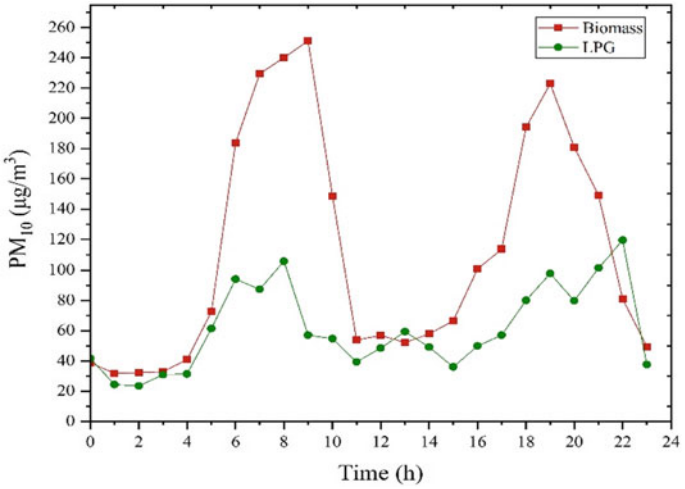

Fig. 3 Temporal pattern of PM_{10} concentrations in biomass and LPG households

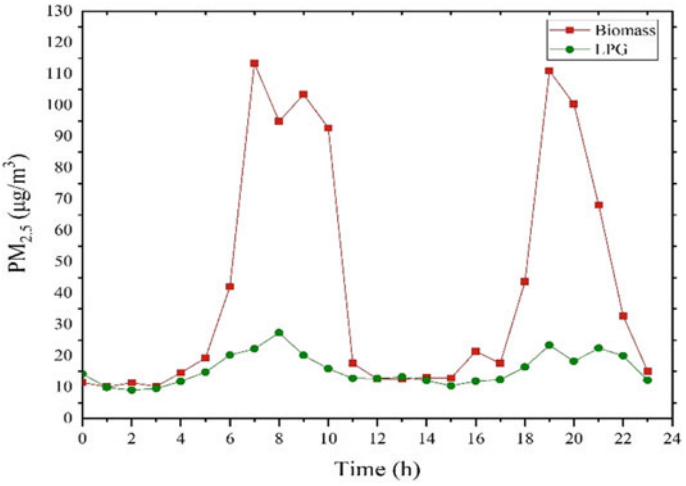

Fig. 4 Temporal pattern of $PM_{2.5}$ concentrations in biomass and LPG households

3.2 Health Risk Assessment

Persistent exposure to HAP has huge impact on human health in rural areas. Health risk assessment to women who are primarily associated to HAP was considered for the assessment. Mean $PM_{2.5}$ concentrations of biomass and LPG households were considered, IR was taken for light intensity work (sitting + operation) = 0.65 (EPA), ED = 22.45 h/week (on an average women spend around 192.5 min per day for

Table 2 Health risk to women exposed from HAP for different fuel types

Type of fuel	CDI	HQ	CR
Biomass	2.2124E-06	2.78	5.659E-05
LPG	8.2572E-07	1.04	2.1121E-05

cooking), Ef = 50 weeks/year, LE = 1 year (calculated for 1-year regular exposure), BW = 44.2 kg (as per average body weight of women in rural India), ATLT = 70 years, NDY = 365 days/year, PPF = 0.082 [3], Rfc = 0.015 (WHO), and IUH = 0.01 [6]. Table.2 reports the average HQ is >1 and <10. It implies the noncarcinogenic health risk of exposure to PM as CR $<10^{-4}$. Further, the exposure is determined for just one year exposure and both HQ and CR will rise when the exposure durations increase resulting in severe health impacts.

Acute and chronic health impacts are presented in Table 3 and Table 4, respectively. Table 3 reports EAP (estimated attributable proportions), ENAC (estimated number of attributable cases), and ENAC-R (estimated number of attributable cases per 100,000 population at risk) where the health impact assessment revealed high incidence per 100,000 population for an acute exposure of asthma, unhealthy days and lost workdays of 1009, 318 and 312, respectively. From Table 4 it was observed that the chronic exposure has resulted in stroke (77.23), ischemic heart disease (71.15), acute lower respiratory infections (51.93) and chronic obstructive pulmonary diseases (33.26).

Table 3 Evaluation of health impact on exposure to PM in HAP

Health impacts	Incidence rate	RR*	EAP (%)	ENAC	ENAC-R (per 100,000)
Total mortality	939.73	1.062 (1.04–1.083)	19.84 (13.43–25.41)	7(5–9)	186.43 (126.17–238.74)
Hospital admissions, respiratory diseases	932	1.019 (1–1.0402)	4.91 (0–10.01)	2 (0–3)	45.78 (0–93.29)
Hospital admissions, Cardiovascular diseases	882	1.0019 (1.0017–1.0166)	2.4 (045–4.31)	1 (0–1)	21.12 (4–38.01)
Restricted activity days	2753.73	1.047 (1.042–1.053)	11.57 (10.43–12.91)	12 (11–13)	318.48 (287.08–355.43)
Work days lost	2753.73	1.046 (1.039–1.053)	11.34 (9.73–12.91)	12 (10–13)	312.24 (267.98–355.43)
Incidence of asthma symptoms (children)	6000	1.028 (1.006–1.051)	16.82 (3.91–28.24)	37 (9–63)	1009.35 (234.69–1694.13)

* RR = relative risk with 95% confidence interval

Table 4 Assessment of the burden of disease due to HAP

Health impacts	Incidence rate	RR*	EAP (%)	ENAC	ENAC-R (per 100,000)
Mortality due to ALRI (0–5 years)	85.5	2.9 (2–3.8)	60.73 (44.87–69.5)	2 (1–2)	51.93 (38.37–59.43)
Mortality due to COPD (adults)	64.7	2.3 (1.7–3.1)	51.41 (36.3–63.09)	1 (1–1)	33.26 (23.48–40.82)
Mortality due to LC (adults)	6.9	2.3 (1.5–2.8)	51.41 (28.93–59.44)	0	3.55 (2–4.1)
Mortality due to IHD (adults)	144	1.4–2.2	24.56–49.41	1–2	35.37–71.15
Mortality due to stroke (adults)	145	1.4–2.4	24.56–53.26	1–2	35.62–77.23

* RR = relative risk with 95% confidence interval

4 Conclusions

Household Air Pollution (HAP) contributing from biomass and LPG based households during summer and monsoon seasons were assessed followed by evaluation of health risks for women in rural areas of Telangana state in India. Health impact and risk assessment of air pollution were estimated by the World Health Organisation (WHO) developed software tool called AIRQ+. PM_{10} and $PM_{2.5}$ concentrations in biomass-based households were ~1.3 and 2.2 times greater than those of LPG due to high emission factor of biomass. Health risk assessment of women (major affected subject) in biomass households exhibited high non-carcinogenic risk (Hazard quotient = 2.79 and Cancer risk $<10^{-4}$) against the LPG Households (Hazard quotient = 1.26 and Cancer risk $<10^{-4}$) for an exposure period of 1 year. The health impact assessment revealed high incidence per 100,000 population for an acute exposure of asthma, unhealthy days and lost workdays of 1392, 205.3 and 201.3, respectively. However, chronic exposure has resulted in stroke (68.32), ischemic heart disease (62.35), acute lower respiratory infections (38.71) and chronic obstructive pulmonary diseases (29.29). This study establishes the HAP contributing from fuel-type and evaluates health risks associated with the PM exposure.

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Chemical Fingerprinting of Volatile Organic Compounds—A Forensic Tool to Apportion Pollution Sources in Industrial Micro-Environments

Abinaya Sekar, George Kuttiparichel Varghese, and Ravi Varma

Abstract Volatile organic compounds (VOCs) are effective finger-print compounds to apportion pollutants to their sources and also to detect certain diseases. Hence there is an increasing number of studies on the sensitive and selective detection of these compounds in the gas phase. In the present study, sampling and analysis for VOCs were carried out as per the USEPA Compendium Method TO-17 for 54 selected VOCs in industrial indoor environments. The samplers were allowed to run for 8 h at the blast hole drilling yard (BHD), conveyor belt yard (CB) and Belt re-conditioning plant (BRP) in an open-cast lignite mine. Results of chemical fingerprinting revealed that chloroform was present in higher concentrations in BHD and CB, whereas toluene was present in higher levels at BRP. Trichloroethylene (TCE) was only identified in BHD but not in the other two locations. Its presence in BHD is due to the chemicals or degreasing solvents utilized. The level of aliphatic VOCs was higher in BHD and CB, whereas, in the case of BRP aromatic VOCs level was higher. Naphthalene is one of the most volatile polyaromatic hydrocarbons, and it was only found in BRP. Rubber solution is commonly used in belt reconditioning, and this could be the source of naphthalene. The identified fingerprint compounds can be used for the forensic investigation of pollution from mining-related activities.

Keywords Indoor air quality · Chemical finger-printing · Forensic analysis · Volatile organic compounds

A. Sekar · G. K. Varghese (✉)
Department of Civil Engineering, National Institute of Technology Calicut, Kozhikode, Kerala, India
e-mail: gkv@nitc.ac.in

R. Varma
Department of Physics, National Institute of Technology Calicut, Kozhikode, Kerala, India

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1 Introduction

Volatile organic compounds (VOCs) are defined and classified by vapor pressure and boiling point. Different nations and organizations have coined various definitions for VOCs. Sources of VOCs can be natural or anthropogenic [1]. Anthropogenic sources include emissions from vehicles, industrial emissions, oil evaporation, waste disposal & burning, and others. The studies summarized in Table 1 show that vehicular and industrial sources contribute a significant fraction of the VOCs found in the ambient environment in Asian countries. This calls for a detailed characterization of such species in the industrial micro-environments. Understanding the chemical components in the air matrix becomes crucial to understanding the health effects associated with the exposure [2] and dispersion of these pollutants to the ambient air, a public health concern. To date, the studies conducted in occupational settings focusing on exposure and health are a handful in India.

Studies have shown that the operation of printers and photocopiers releases pollutants like VOCs, O_3, Semi-volatile Organic Compounds (SVOCs), benzene, toluene and PM. It was also observed that there was up to an eight-fold increase in the level of toluene when the duration, temperature and rate of printing increased, but the levels were within the occupational exposure limits. Persons who are occupationally exposed to contaminants during photocopying have increased levels of oxidative stress [3]. In a comet assay study conducted among photocopier operators and maintenance workers, increased DNA damage was observed compared with control samples. The genotoxic effects among maintenance workers may be due to the exposure to carbon black, iron, silicon, magnetite and other elements present in the photocopier toners. In the case of operators, DNA damage may be due to exposure to higher levels of PM and VOCs emitted during the operation of photocopiers [4]. In a similar study conducted in photocopier centers, PM_{10} and $PM_{2.5}$ concentrations were found to exceed the level prescribed by Indian NAAQS. However, they found the levels of CO, NO_2, O_3, SO_2, Pb, Ni, NH_3, benzene and benzo(a) pyrene within the permissible limits. There was no significant difference in lung function among the photocopier operators and the controls. However, higher oxidative stress and systemic inflammation were noticed among the workers, leading to a higher chance of getting cardiovascular diseases [5]. Exposure to PM, TVOC, CO_2, CO, lung function, blood pressure and urinary microalbumin was monitored among kitchen workers in North and South India. A higher level of $PM_{2.5}$ was observed in South Indian (78.55 $\mu g/m^3$) kitchens when compared with North Indian kitchens (68.18 $\mu g/m^3$). The level of CO and VOCs was higher in North Indian Kitchens. A decline in systolic blood pressure and lung function was observed among kitchen workers in India. The risk of developing obstructive and restrictive lung function was observed among South Indian kitchen workers [6]. Similarly, in a study conducted among 100 petrol pump workers in India, a higher level of benzene was detected in the blood of the workers and a level of 100–250 ppb was found in the air sample of petrol pumps. A higher

level of DNA damage was also observed among the workers. Among the metabolites of benzene, p- benzoquinone caused the most significant DNA damage to the workers [7].

To the best of our knowledge in India, no studies have focused on the dispersion of VOCs from industrial micro-environments to ambient air. This study will be a base to conduct a chemical fingerprinting of VOCs which can be used to understand the

Table 1 VOCs source apportionment studies conducted in South Asia

Study location	Model	Sources	References
China—Urban Beijing	PMF	TE—21.0%, SFC—24.4%, and OVOC (32.3 and 22.3%)	[8]
China—Suburban Beijing	PMF	LPG/NG—20–30%, Gasoline vapors and industrial production—30–35%, VE—40–45%	[9]
Thailand—Bangkok	PMF	Maptaphut industrial area—MS—43–57%, Industrial-24–45%, household—2.6–9.8%, BC—5.1–10.5% and unidentified—4.1–17.2% Dindaeng—MS—50.5%, household—31.5%, BC—7.6% and unidentified—10.3%	[10]
India—Indo-Gangetic plain	PMF	BF and WD—23.2%, WB—22.4%, Cars—16.2%, MDS—15.7%, IE—11.8%, and two-wheelers—8.6%	[11]
India—Mumbai Location 1 Location 2 Location 3 Location 1 Location 2 Location 3 Location 1 Location 2 Location 3	CMB Residential Commercial Industrial	E—47%, NG—24%, VEC—17%, O—7%, S—4% and D—1% E—87%, VEC—8% and NG—5% E—65%, VEC—10%, S—10%, O—8%, DE—3%, NG—3% and AR—1% E—81%, VEC—10%, DE—4%, D—2%, S—1% and Others—2% E—75%, VEC—14%, DE—2%, D—2%, S—5% and Others—2% E—79%, VEC—10%, DE—2%, D—2%, S—1% and Others—6% E—87%, VEC—7%, D—3%, DE—2% and S—1% E—80%, VEC—10%, D—7%, DE—2% and S—1% E—82%, VEC—10%, D—3%, DE—3% and S—5%	[12]

(continued)

Table 1 (continued)

Study location	Model	Sources	References
Delhi Location 1 Location 2 Location 3 Location 1 Location 2 Location 3 Location 1 Location 2 Location 3	CMB Residential Commercial Industrial	AR—6%, D—18%, VEC—14%, NG—19%, OD—12%, DE—27% and others—4% AR—13%, D—6%, VEC—14%, NG—27%, OD—2%, DE—26% and others—12% AR—14%, D—3%, VEC—14%, NG—24%, OD—2%, DE—42% and others—1% E—20%, AR—1%, D—1%, VEC—5%, NG—21%, OD—1% and DE—51% E—9%, AR—1%, D—2%, VEC—12%, NG—21%, OD—1% and DE—54% E—13%, AR—1%, D—1%, VEC—11%, NG—24%, OD—1% and DE—49% E—13%, AR—16%, D—4%, VEC—7%, NG—15%, OD—4% and DE—41% E—11%, AR—11%, D—2%, VEC—10%, NG—10%, OD—13% and DE—40% E—12%, AR—16%, D—2%, VEC—8%, NG—15%, OD—6% and DE—40%	[13]
Kolkata		Exhaust dispersed + refueling >75%	
Malaysia—Kuala Lumpur		E—31%, VE—43%, petrol pump/ solvent usage—15% and IE—10%	

VE—Vehicle exhaust emission; SFC—Solid Fuel Combustion; TE—traffic emissions; OVOC—Oxygenated Volatile Organic Compounds; Mobile source—MS; BC—Background Concentration; E—Evaporative; Auto repair—AR; D—Degreasing; VEC—Vehicle exhaust composite; NG—Natural Gas; OD—Open defecation; DE—Diesel eng. Exhaust; Sludge—S; Oceanic—O; Biofuel—BF; WD—Waste Disposal; WB—Wheat-residue burning; MDS—Mixed daytime sources; IE—Industrial emissions

transport of industrial emissions to the ambient air and to conduct forensic investigations. With the advancement in analytical and detection technologies, it is possible to do detailed chemical characterization of the air matrix. However, the process becomes challenging while analyzing the concentration of the pollutant because of the unknown and complex composition of the sample matrix.

Hence the objective of the present study was to look for the presence of 54 selected components (Appendix A) in the micro-environment of the mining industry and to identify the finger print compounds emitted from mining allied activities. The

activities considered were the preparatory work for blast hole drilling, storage of vulcanization chemicals and carrying out the process of vulcanization. The detected VOCs were quantified to evaluate the influence of the activities. In addition to the forensic applications, this study will be useful to undertake pollutant specific air quality management in the industrial settings.

2 Methodology

2.1 Site Description

The investigation site is a pit-head open-cast lignite mine (Fig. 1). This lignite mine's overburden is mostly argillaceous and ferruginous sandstone, which is hard and abrasive. This necessitates the usage of massive volumes of explosives. Mining occurs in an open environment, hence monitoring for VOCs in enclosed places was done to determine the fingerprint chemicals from mining allied activities. Table 2 lists the specifics and types of operations carried out at each monitoring station, and Fig. 2 shows images of the sampling sites.

Fig. 1 Google map of the sampling area

Table 2 Details of the sampling site

Sampling location ID	Sampling site	Activities
BHD	Blast hole drilling yard	1. Blasting and drilling preparation work 2. Welding 3. Assembling drill rods and other machinery 4. Explosives storage 5. Degreasing and greasing
CB	Conveyor belt yard	1. Storage of vulcanization chemicals 2. Plate oil preparation and other vulcanization preparation work
BRP	Belt reconditioning plant	1. Fixing and reconditioning worn-out belts

BHD CB BRP

Fig. 2 Photographs of the sampling sites

2.2 Sampling and Analysis

Sampling

The sampling and analysis were carried out in accordance with the Compendium method TO-17. A battery-powered low-volume air sampler (Model SKC AirLite sample pump) sampled air at 0.5 L/min through an adsorption cartridge containing a sorbent. Each sampling lasted eight hours. Using a rotameter, the flow was kept uniform during the sampling duration.

Analysis

A thermal desorption system was used to desorb the sorbent after heating it at 200 degrees Celsius for 20 min (Make: MARKES International, Model: TD100-XR). A high-resolution gas chromatography-mass spectrometer (GC–MS; Agilent 7890 B GC, MSD 5977B Agilent Technologies) was employed to characterize VOCs. For the analysis, a DB-624 capillary gas chromatographic column (60 m 0.32 mm 1.8 m) with helium as the carrier gas was employed.

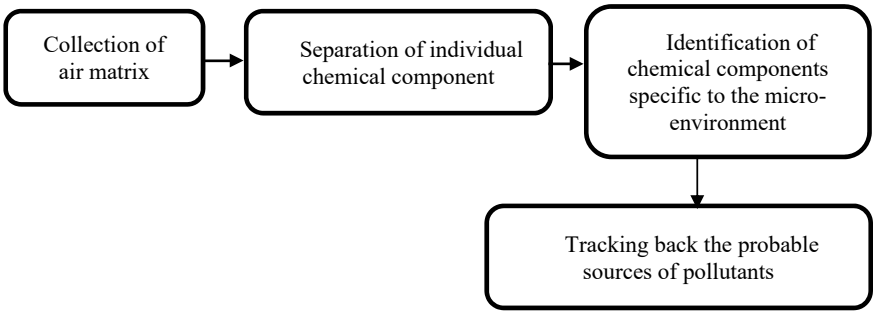

Fig. 3 Schematic sketch of the study methodology

Calibration

The instrument's operating conditions were set using the USEPA TO-17 technique. Before analyzing the samples, the instrument was calibrated according to the USEPA TO-17 procedure to assure the validity and quality of the experimental data. For calibration, a 54 VOC mixed standard solution bought from Sigma Aldrich was utilized. The recovery rates for all 54 VOCs ranged from 80 to 120%. For the selected VOCs, a six-point calibration curve (10–100 ng) with a linear relation coefficient (R^2) greater than 0.99 was created.

2.3 Identification of Chemical Fingerprints

The schematic sketch of the study methodology is provided in Fig. 3. The possible sources of the pollutants are tracked by identifying the unique species in the air matrix. In the present study, the fingerprints are attempted to be identified based on the characterizing and quantification of the pollutants.

3 Results and Discussions

Figures 4, 5 and 6 depicts the VOCs detected at the three sampling sites. Trichloroethylene was only found in BHD. The concentration of VOCs detected in the three sites were within the 'Permissible limits of exposure of chemical and toxic substances' provided under the Factories Act, 1948, Government of India [14] and Occupational Exposure Limits as prescribed by United States Occupational Safety and Health Administration (OSHA). Trichlorethylene is not derived from nature. The occurrence of this substance in industrial micro-environments can be traced back to the chemicals or solvents utilized. Trichloroethylene is a common degreasing agent.

It is used to clean tools, remove paint, spots and others [15]. Trichloroethylene was identified in an earlier investigation conducted at a metal degreasing facility [16].

BHD and CB have greater concentrations of chlorinated VOCs. These chemicals are commonly employed as solvents and degreasing agents, and the work performed in these micro settings includes preparation work and equipment cleaning [17]. The level of benzene was much higher in BHD and it was <1 $\mu g/m^3$ at BRP. It is used as a raw material in industries to produce chemicals such as ethylbenzene, isopropyl benzene and cyclohexane [18]. Yang et al. has proposed benzene, toluene, ethylene benzene and xylene as marker species for solvent use and benzene, toluene, ethylbenzene, xylene and 1,2-dichloroethane as the marker species for industrial emissions [19]. Higher levels of cumene (isopropyl benzene) and cymene (isopropyl toluene) were observed only in CB.

Toluene, M-xylene, O-xylene, propyl benzene, 1,3,5-trimethylbenzene, naphthalene, and N-butylbenzene were all found in BRP. Toluene is utilized as a cleaning

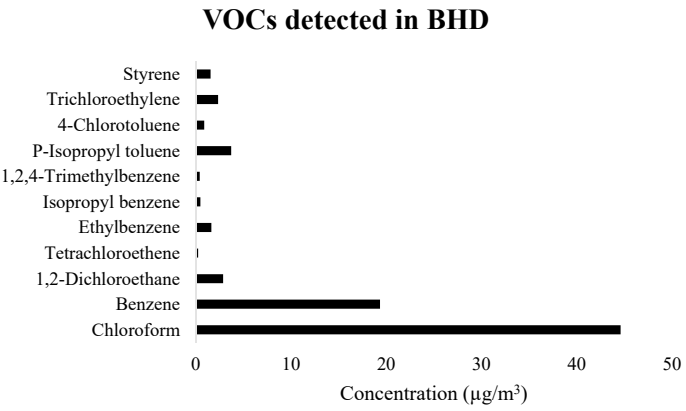

Fig. 4 Concentration of VOCs detected in BHD

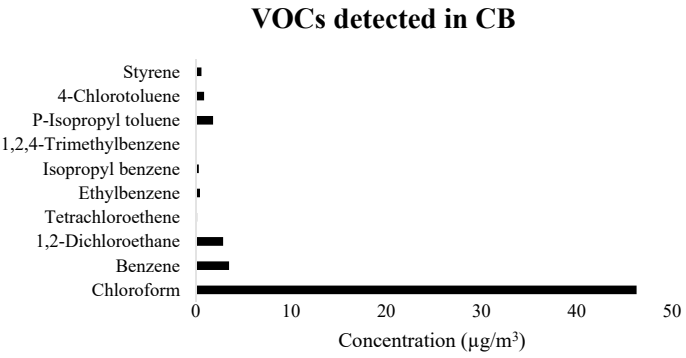

Fig. 5 Concentration of VOCs detected in CB

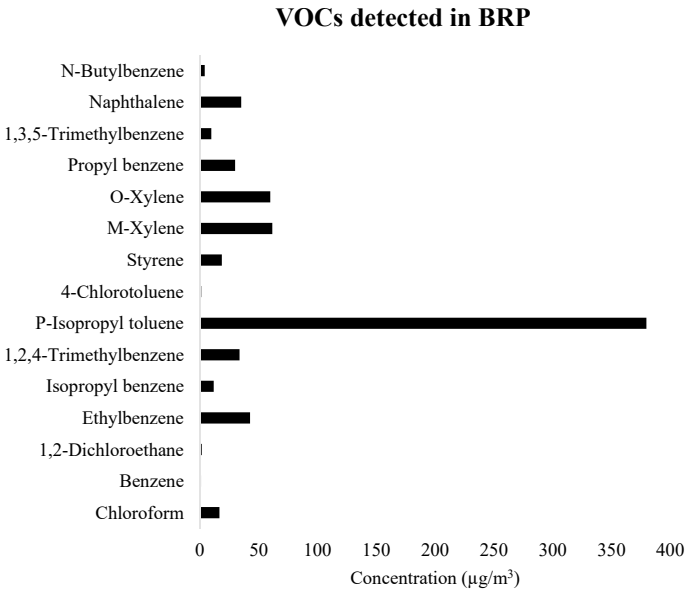

Fig. 6 Concentration of VOCs detected in BRP

and thinning solvent. Toluene is also an accelerator in the vulcanization and rubber reconditioning processes [20]. Toluene is utilized as a primer in the rubber synthesis process, which begins with the manufacture of rubber. It breaks down the rubber sheets' components and makes them sticky [21]. This could explain why toluene and toluene-based chemicals were found in higher concentrations in BRP. In Fig. 6 toluene is not included as the concentration was much higher (2058 $\mu g/m^3$) to fit in the scale of the plot. Similar to toluene, xylene is also used as a solvent in rubber and it is widely used as a thinner [22]. Naphthalene is used as a dispersant in synthetic and natural rubbers [23]. Rubber solution is used in belt reconditioning, which might be the source of naphthalene. A recent study has also estimated that the vulcanization process emits carbon disulfide, naphthalene, acetone, dichloromethane and xylene. It was also found that the VOCs emitted during the process had highest ozone forming potential [24]. Similarly, another study has reported the presence of toluene, xylene, trimethylbenzene and naphthalene in eleven rubber manufacturing industries across in The Netherlands [25]. Hence, these VOCs can be considered as the finger-print species emitted during vulcanization activity. Figure 7 shows that the percentage of aliphatic VOCs were higher in the BHD and CB, indicating the utilzsation of aliphatic solvents in the activities carried out in the micro-environment.

VOC analysis is widely used in medical diagnostics, safety, forensics, nutrition and healthcare, molecular communication, and other fields. Accurate measurements with on-site real-life applications are now possible, thanks to the advancements in detection technology [26]. This simplifies the tracking of contaminants. For example, if the air matrix was found to be contaminated with trichloroethylene near a lignite

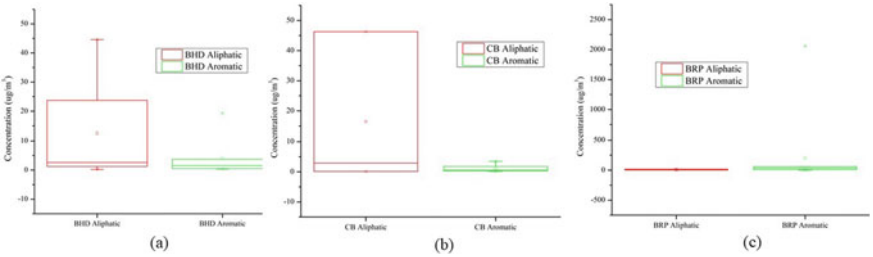

Fig. 7 Summation of aliphatic and aromatic compounds detected in the sampling sites

mine, the concentration of trichloroethylene trends along the down-wind direction must be chased or measured. However, natural attenuation and other potential sources of trichloroethylene are a concern. VOC chemical fingerprinting is a popular forensic method [27–29]. However, environmental forensic investigations are still in their nascent stage in India, and the process becomes more challenging when it comes to industrial clusters with several polluting enterprises [30]. When structured technical liability allocation is performed in the future, the identification of process specific marker species will be useful in liability allocation.

4 Conclusion

To the best of authors' knowledge, this is the first study that characterize VOCs in the mining allied micro environments. The detected compounds are related to the type of activities carried out in each micro-environment. Results from this study will add knowledge base to the existing list of marker species emitted from different activities. Toluene was observed to be in higher concentration in the belt reconditioning plant, however it was within the permissible limits prescribed under the Factories Act. The identified finger-print compounds can be included in the source apportionment models to detect the possible source of these pollutants dispersed into the ambient air. The study can also suggest the need for pollutant specific regulations in the industrial micro-environments.

Appendix A

List of 54 compounds

1. Dichloromethane
2. 1,1-Dichloroethylene
3. Trans-1,2-Dichloroethane
4. 1,1-Dichloroethane

5. Cis-1,2-Dichloroethane
6. 2,2-Dichloropropane
7. 1,1-Trichloroethane
8. Cis-1,3-Dichloropropane
9. 1,1-Dichloropropane
10. Chloroform
11. Carbon tetra chloride
12. Bromochloromethane
13. Toluene
14. Benzene
15. 1,2-Dichloropropane
16. Trans-1,3-Dichloropropane
17. 1,1,2-Trichloroethane
18. Bromodichloromethane
19. 1,2-Dichloroethane
20. Trichloroethylene
21. Di bromo methane
22. 1,3-Dichloropropane
23. 1,2-Dibromoethane
24. Dibromochloromethane
25. 1,1,1,2-Tetrachloroethane
26. Tetrachloroethene
27. M-Xylene
28. P-Xylene
29. O-Xylene
30. Ethylbenzene
31. Chlorobenzene
32. Bromobenzene
33. Styrene
34. 1,2,3-Trichloropropane
35. Iso propyl benzene
36. 1,1,2,2-Tetrachloroethane
37. Propyl benzene
38. Bromoform
39. 1,2,4-Trimethylbenzene
40. P-Iso propyl toluene
41. 1,4-Dichlorobenzene
42. 1,3-Dichlorobenzene
43. 1,3,5-Trimethylbenzene
44. 2-Chlorotoluene
45. 4-Chlorotoluene
46. Naphthalene
47. 1,2-Dibromo-3-Chloropropane
48. 1,2,3-Trichlorobenzene
49. Sec-Butylbenzene

50. T-Butylbenzene
51. N-Butylbenzene
52. 1,2-Dichlorobenzene
53. 1,2,4-Trichlorobenzene
54. Hexachloro-1,3-Butadiene

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Age-Specific Deposition of Indoor Particulate Matter in the Human Respiratory Tract

Akshay Kale, Ritwika Roy, and P. Gursumeeran Satsangi

Abstract Exposure to indoor particulate matter (PM) plays a significant role in human respiratory problems resulting in multiple adverse health outcomes. PM having an aerodynamic diameter $\leq 10\,\mu m$, enters the human airways due to its smaller size and gets deposited in different parts of the human lungs. In the present communication, we measured real-time size segregated particulate matter mass concentrations in residential houses' indoor environments in Pune's urban locations by Grimm aerosols spectrometer during the day hours (i.e.10 a.m–5 p.m.) in the month of July 2021. Average concentrations of indoor PM_{10}, $PM_{2.5}$, and PM_1 were found to be 60.7 ± 30.6, 37.3 ± 24.6, and $23.2 \pm 19.7\,\mu g\,m^{-3}$, respectively. Particle deposition in human airways diversely depends on the airway's geometric structure. Thus, the evaluation of respiratory deposition doses (RDDs) in the head airway (HD), tracheobronchial (TB), and alveolar (AL) regions of PM (i.e., PM_{10}, $PM_{2.5}$, and PM_1) were estimated by using the human respiratory tract model (ICRP 1994) for different age groups like infants, children, adults, and elderly in residential premises. For the calculation of RDDs, tidal volume and breathing frequency of lungs for different age groups were considered. Total respiratory deposition of PM_{10} was frequently higher than $PM_{2.5}$ and PM_1 over all age groups. However, among all, the elderly people experienced the highest total PM_{10}, $PM_{2.5}$, and PM_1 deposition (46×10^{-2}, 29×10^{-2}, and $9 \times 10^{-2}\,\mu g\,min^{-1}$), followed by adults, children, and infants. Results derived from tracheal regional deposition exhibited the dominance of PM_{10}, $PM_{2.5}$, and PM_1 in HD, TB, and AL regions, respectively.

Keywords Indoor air pollution · Size-segregated particulate matter · Respiratory deposition doses

A. Kale · R. Roy · P. G. Satsangi (✉)
Department of Chemistry, Savitribai Phule Pune University, Pune 411007, India
e-mail: pgsatsangi@unipune.ac.in

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1 Introduction

Air pollution, indoors and outdoors, attributed to natural and anthropogenic emissions, is nowadays a severe problem worldwide. The World Health Organization evaluates around seven million deaths globally are due to air pollution and that nine out of ten people breathe contaminated air [1]. Particulate matter (PM) pollution is one of the six criterion pollutants (carbon monoxide, lead, ground-level ozone, particulate matter, nitrogen dioxide, and sulfur dioxide), and it is made up of a diverse range of harmful chemicals and compounds [2]. On an average, a human spends 90% of their time indoors, so inhalation of coarse and fine particles aggravates numerous pulmonary diseases [3]. Various epidemiological studies have also shown that long-term exposure to elevated particulate matter (PM) is interrelated with multiple chronic and acute health problems. Therefore, researchers have received increasing attention for indoor air pollution in the last decades. Plentiful studies have explored different indoor PM directions, PM mass distribution, spatio-temporal variation, indoor-outdoor ratios, chemical constituents, biological composition, health risk analysis, and respiratory deposition doses [3, 4].

The aerodynamic diameter of PM is an essential element for governing where each particle is expected to be deposited in the respiratory tract upon inhalation [5]. Fine particles ($PM_{2.5}$), mainly sub-micron (PM_1) particles, can enter deeper into the human lungs and rest there for a very long time and thus, entering the alveolar regions of the lung and entering into the bloodstream more quickly, causing cardiovascular, cerebrovascular, and respiratory problems [5]. Evidence is depicting that particulate matter also impacts other organs, the liver, heart, and brain [5] and causes other diseases [1]. PM deposition into the human respiratory tract (HRT) can be influenced by parameters such as PM size, shape, density, gender, age, tidal volume, and breathing rate [6, 7]. The mortality and morbidity of humans differ with the exposure to particulates having different size bins. PM deposition is generally examined by deposition dose and fraction. PM dose can be considered diversly, such as mass concentration per unit area, particle number count, time, and volume. Therefore, deposition dose in the HRT is essential for assessing adverse health effects [4]. Models such as the Multiple Path Particle Dosimetry Model (MPPD) and International Commission on Radiological Protection (ICRP) model estimate the retention and clearance of PM in HRT [6, 8].

Exposure assessment studies are essential to understand the impact of particulate matter concentration, frequency, and time span for PM exposure in the human body [9]. Earlier researchers investigated PM exposure in indoor micro-environments to understand particulates variation [6], health risk analysis [3], and respiratory deposition doses (RDD) [4, 10]. In the different age groups, the coarse particles (PM_{10}) were deposited more in children and adults [11]. In view of these points, the present study is also designed to determine the deposition of inhaled particulate matter (PM_{10} and $PM_{2.5}$) in the respiratory tract of different age group people such as infants, children, adults, and elderly, by using the ICRP model in the Pune region.

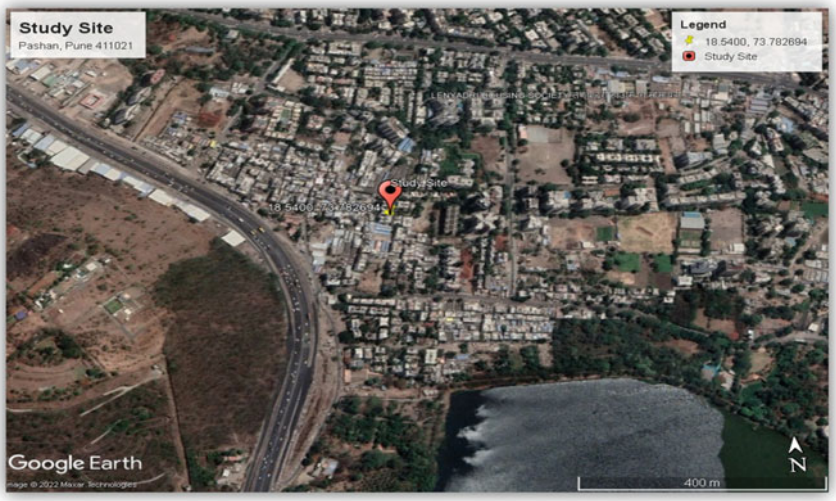

Fig. 1 Study site

2 Methodology

2.1 Description of the Study Site and Sampling

Size-specific PM concentrations were monitored on the 3rd floor of a residential building located in the Pashan area, Pune (Fig. 1). The site is approximately 100 m from a busy express highway. The PM sampling was conducted during the day hours (10 am–5 pm) during July 2021 for fifteen days. The sampler was positioned at 1.2 m above the floor to measure the particulate matter exposure to humans in the breathing zone. Details of the air quality monitor are listed in Table 1 [12].

3 Exposure Assessment of the Respiratory Deposition Doses (RDDs)

The RDD was estimated using Eq. (1), which is adapted from International Commission on radiological Protection [8] and has been used by researchers in many previous studies [13–17].

$$RDD = (V_T \times f) \times DF_i \times PM_i \tag{1}$$

Table 1 Specifications of indoor air quality monitor

Instrument used	Principle of instrument	Range	Accuracy	Measurement type
Grimm Aerosol 11D	Dual principle (Light scattering technology) & PTFE backup filter)	0.25–35.15 μm	The precision of data monitored with reproducibility of ±2%	Continuous and real-time measurement

where V_T describes the tidal volume (m^3 per breath), f is for the breathing frequency (breath/minute), DF_i denotes the deposition fraction of a size fraction *i*, and PM_i is the mass concentration of the PM range.

The deposition fraction for the head airways region (DF_{HD}) is

$$DF_{HD} = IF\left(\frac{1}{1+\exp\left(6.84+1.183\ln d_p\right)}+\frac{1}{1+\exp\left(0.924-1.885\ln d_p\right)}\right) \tag{2}$$

Dp is the particle size in μm, and *IF* is the inhalation fraction.
IF is calculated by following Eq. (3) [8]

$$IF = 1-0.5\left(1-\frac{1}{1+0.00076d_p^{2.8}}\right) \tag{3}$$

The deposition fraction for the tracheobronchial region (DF_{TB}) is

$$DF_{TB} = \left(\frac{0.00352}{d_p}\right)\left[\exp\left(-0.234\left(\ln d_p+3.40\right)^2\right)+63.9\exp\left(-0.819\left(\ln d_p-1.61\right)^2\right)\right] \tag{4}$$

The deposition fraction for the alveolar region (DF_{AL}) is calculated by

$$DF_{AL} = \left(\frac{0.0155}{d_p}\right)\left[\exp\left(-0.416\left(\ln d_p+2.84\right)^2\right)+19.11\exp\left(-0.482\left(\ln d_p-1.362\right)^2\right)\right] \tag{5}$$

The total respiratory deposition doses were estimated by adding all regional depositions values obtained from Eqs. (1, 2, 3, 4 and 5). The values of tidal volume of infants, child, adults, and elderly were assumed to be 3.0×10^{-5}, 27.8×10^{-5}, 47.7×10^{-5}, and 75.0×10^{-5} m^3 per breath, respectively. The values of breathing frequency of infants, children, adults, and the elderly were assumed to be 39, 17, 14, and 12 breaths per minute, respectively [6, 7].

4 Results and Discussion

Figure 2 depicts the indoor size-specific average mass concentration of PM. Concentrations of PM_{10}, $PM_{2.5}$, and PM_1 over the study period were found to be 60.66 ± 30.6, 37.29 ± 24.6, and $23.17 \pm 19.7\ \mu g m^{-3}$, respectively. The average mass concentrations of PM_{10} were 1.3 times higher, while concentrations of $PM_{2.5}$ were also 2.5 times higher than the revised WHO 2021 air quality index guidelines (24-h mean limits, i.e., 45 for PM_{10} and 15 for $PM_{2.5}$). Vo et al. [3] in Japan and Sharma and Balasubramanian [10] in Singapore reported that indoor $PM_{2.5}$ concentrations were higher, while Segalin et al. [18] in Sao Paulo, Brazil, reported that the indoor $PM_{2.5}$ concentrations were lower than in the present study, compared with earlier studies carried out in the cities of India. The PM concentration in this study site was relatively lower by values reported by Kumar and Jain [15], Deepthi et al. [19].

PM exposure of the residential indoors was estimated for the RDD values (H.D., T.B., and A.L. regions) for age-specific groups. Size-specific particles are deposited differently in the human respiratory tract (H.D., T.B., and A.L. regions). Particle deposition in human Airways is primarily based on variations in the airway's geometric structure [15]. As per the given expression for RDDs, this study considered that wholly particulates enter the human respiratory system via the mouth or nose. Moreover, as the particle diameter increases with decreasing inhalation frequency, the inhalation frequency of large particles (>PM_{10}) is expected to decrease. Therefore, coarse (PM_{10}) and fine particle (PM_1) deposition is more significant in the H.D. and A.L. regions [15, 17]. Segalin et al. [18] in São Paulo, Brazil reported that the highest RDD was found to be elevated for the coarse (PM_{10}) particles, followed by fine and ultra-fine particles. In our study, among all the size-specific fractions, the highest RDDs of particles were observed for coarse particles (PM_{10}), followed by fine particles $PM_{2.5}$ and PM_1. Percentage distributions of RDDs in the H.D., T.B.,

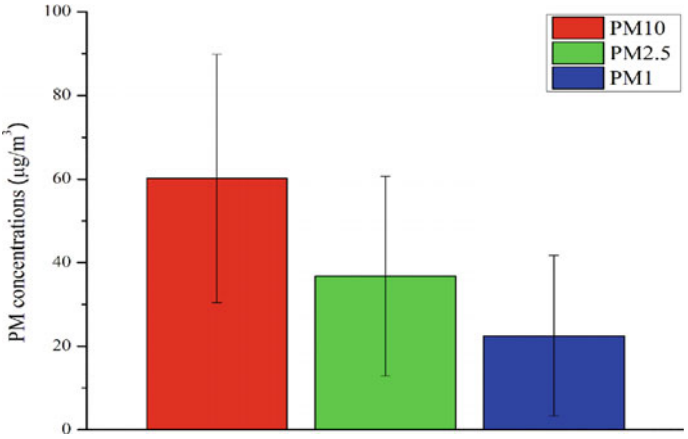

Fig. 2 Mass concentrations of size-specific PM over the study period

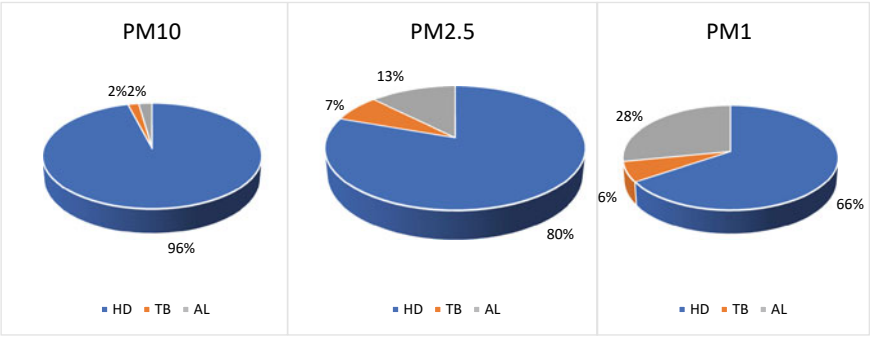

Fig. 3 Percentage distribution of RDD values in HD, TB, and AL regions for PM10, PM2.5, and PM1 for different age groups over the sampling period

and A.L. regions for PM_{10}, $PM_{2.5}$, and PM_1 over the study period are shown in Fig. 3. It was additionally quantified from the results that the highest deposition of PM_{10}, $PM_{2.5,}$ and PM_1 took place in the head airways followed by the bronchial region and alveolar region over the sampling period. In contrast, the alveolar region was the major concerned zone through fine particles, i.e., PM_1. These findings are similar to the earlier study by Kumar and Jain [15], Gupta and Elumalai [17]. The TRDDs of PM_{10}, $PM_{2.5}$, and PM_1 results were depicted in Fig. 4a–c for Elder (46.2×10^{-2}, 28.7×10^{-2}, and 9.1×10^{-2} $\mu g\ min^{-1}$) were found to be higher, followed by an adult (34.3×10^{-2}, 21.3×10^{-2}, and 6.7×10^{-2} $\mu g\ min^{-1}$), children (24.2×10^{-2}, 15.1×10^{-2}, and 4.8×10^{-2} $\mu g\ min^{-1}$) and infants (6.0×10^{-2}, 3.7×10^{-2}, and 1.2×10^{-2} $\mu g\ min^{-1}$). The higher values of RDDs for elders found indoors suggested that the risk of elder residents can increase in indoor environments. Based on the study findings, it is noticeable that the age factor is the key factor for rises in RDDs. Elderly residents breathe a higher amount of PM compared to other age groups.

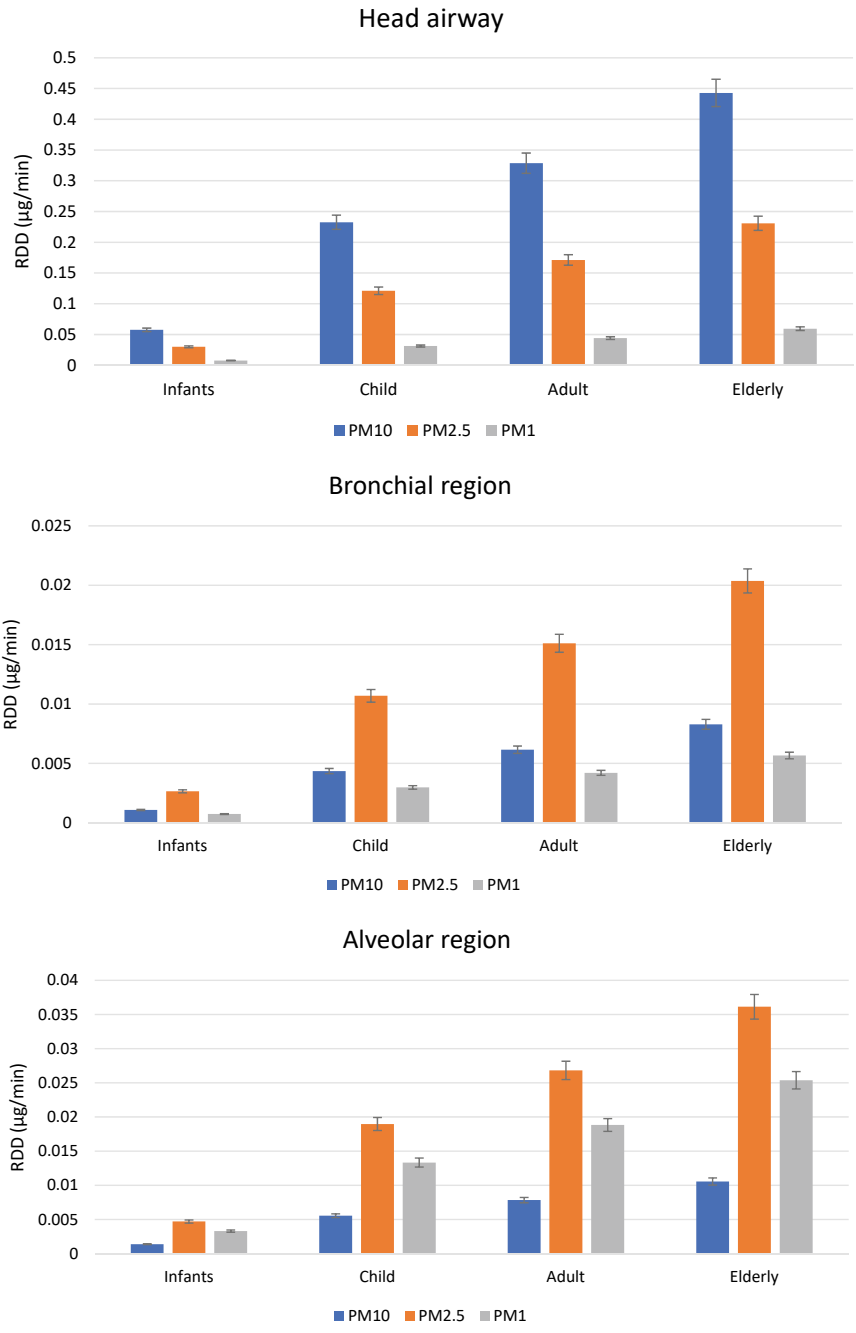

Fig. 4 **a** TRDDs in Head airways for all age groups, **b** TRDDs in Bronchial region for all age groups, **c** TRDDs in the Alveolar region for all age groups

5 Conclusion

The present study's findings reveal that the average values of monitored size-specific PM mass concentrations surpassed the revised WHO air quality guidelines in residential indoors. The finding suggests that residents are exposed to higher levels of PM concentrations. The RDDS in HD, TB, and AL parts of all size-specific PM were maximum for the elderly, followed by adults, children, and infants. This study shows that indoor pollution load can lead to reduced lung function of the residents. Based on study outcomes, it may be encouraged that elderly residents' homes should be adequately ventilated to maintain the air quality in the indoor environment.

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Quantification and Assessment of Indoor $PM_{2.5}$ in North Indian Precinct

Farheen Zehra, Samridhi Dwivedi, and Alfred J. Lawrence

Overview One of the major global causes of indisposition and impermanence, affecting both women and children in developing and under developed nations alike, is indoor air pollution. Exposure of children to $PM_{2.5}$ in metropolitan environments poses very serious health hazards. Compared to other air pollutants, fine particulate matter ($PM_{2.5}$) is known to pose substantial health risks. The goal of the current study is to quantify the levels of $PM_{2.5}$ in both the winter and summer months while also examining seasonal variation. Using Envirotech APM 550, sampling was carried out from November 2021 to June 2022. The sampler was positioned indoors in urban dwellings in the Indian city of Lucknow. A total of 24 homes were chosen. The study also evaluated climatic conditions and identified influences on the concentration of the particle pollution. According to the findings, winter time $PM_{2.5}$ concentrations were higher than summer time ones. The average indoor $PM_{2.5}$ concentration during the winter was discovered to be 228.62 ± 29.5 $\mu g/m^3$, whereas the concentration during the summer was noted to be 137.18 ± 21.3 $\mu g/m^3$. Health risks assessment (HRA) on children under the age of 18 ranged from $0.06 * 10^{-6}$ in the winter to $0.026 * 10^{-6}$ in the summer.

Keywords Indoor air pollution · Particulate matter ($PM_{2.5}$) · Health risk assessment

1 Background Information

North India's major issue is air pollution. Indoor air pollution (IAP) is significantly linked to human health since most urban people spend a lot of time indoors, and it has a direct impact on children's health [1, 4]. An important metric to measure household air pollution is the concentration of Particulate Matter with a diameter

Farheen Zehra—Presenting Author

F. Zehra · S. Dwivedi · A. J. Lawrence (✉)
Department of Chemistry, Isabella Thoburn College, Lucknow, India
e-mail: alfred_lawrence@yahoo.com

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Table 1 The average concentration of $PM_{2.5}$ in winter and summer seasons

Particulate matter (PM)	Winter average concentration	Summer average concentration
$PM_{2.5}$	$228.62 \pm 29.5\ \mu g/m^3$	$137.18 \pm 21.3\ \mu g/m^3$

of 2.5 m ($PM_{2.5}$). In this study, the amount of PAHs in the particulate matter and emission sources around the city will be determined ($PM_{2.5}$).

2 Methods and Methodology

The industrial, residential, and commercial areas were monitored during the winter and summer season (November 2021–June 2022). $PM_{2.5}$ samples were collected through a GF/A 47 mm filter paper with the help of APM 550, Envirotech sampler at a flow rate of 17.5 L per minute for 8 h.

2.1 Meteorological Parameters

The dispersion and dilution of air pollutants emitted into the atmosphere are significantly influenced by weather factors, including temperature, rainfall, relative humidity, wind speed and direction, and solar radiation. The installation of automatic weather stations by the Central Pollution Control Board, Lucknow was used to collect meteorological data for the city (Table 1 and Figs. 1, 2).

3 Health Risk Assessment

This study evaluated the health risks associated with inhaling airborne particulate-related PAHs (Polyaromatic hydrocarbons). Exposure to substances regarded to have carcinogenic properties increases the probability of developing tumorous disorders, which is referred to as incremental lifetime cancer risk (ILCR) [3]. When exposed continuously to chemicals, LADD reveals the quantity of probable chemical consumption per kg of body weight per day which may have a negative impact on health. LADD and Cancer risk were calculated using the Eqs. (1) and (2) [2] (Table 2).

$$\text{Lifetime average daily dose (LADD)} = \frac{\text{Cs} \times \text{IR} \times \text{CF} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT}} \quad (1)$$

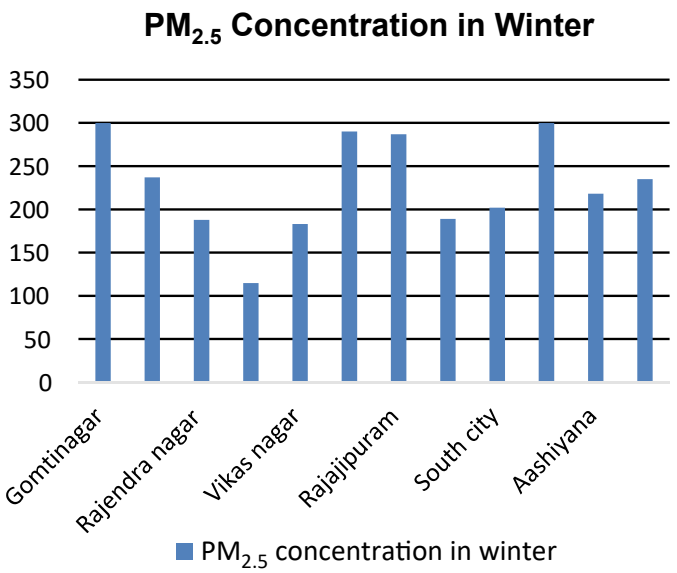

Fig. 1 $PM_{2.5}$ concentrartion in winter season in different microenvironments

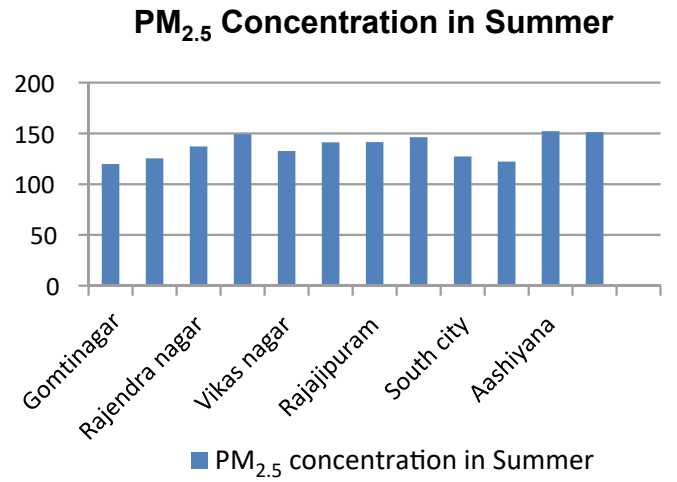

Fig. 2 $PM_{2.5}$ concentrartion in summer season in different microenvironments

Table 2 LADD and Cancer risk associated with PAHs in Seasonal variations

Polyaromatic hydrocarbons (PAHs)	Concentrations of PAHs in (ng/m^3)		LADD $\left(mg\ kg^{-1}\ day^{-1}\right) = \frac{Cs \times IR \times CF \times EF \times ED}{Bw \times AT}$		Cancer risk = LADD × Cancer slope factor (CSF)	
	Winter	Summer	Winter	Summer	Winter	Summer
B[a]P	3.25	1.07	0.18×10^{-6}	0.06×10^{-6}	0.68×10^{-6}	0.22×10^{-6}
Pyr	6.99	4.20	0.39×10^{-6}	0.24×10^{-6}	1.49×10^{-6}	0.91×10^{-6}
Phe	4.24	2.50	0.24×10^{-6}	0.14×10^{-6}	0.92×10^{-6}	0.54×10^{-6}
Ant	8.7	6.75	0.49×10^{-6}	0.38×10^{-6}	1.90×10^{-6}	1.47×10^{-6}

where, Cs−Concentration of the particulate matter in (mg/kg)
IR−Inhalation rate $\left(m^3/day\right)$
CF−Conversion Factor
EF−Exposure frequency (days/year)
ED − Exposure duration (year)
BW−Body weight (kg)
AT−Average timing (days)

$$\text{Cancer risk} = \text{LADD} \times \text{Cancer slope Factor (CSF)} \tag{2}$$

4 Conclusion

This study concludes that there is an immediate need to address the issue of Particulate matter ($PM_{2.5}$) and related toxicity in different indoor microenvironments. Its estimated Children's health risks are thought to be significantly higher in the winter than in the summer.

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Investigation of Indoor Air Quality and Passenger's Exposure in Underground Rapid Transit System

Amit Passi, S. M. Shiva Nagendra, and M. P. Maiya

Abstract A Metro system, also known as a subway/rapid transit system (RTS), is a high-capacity urban transport facility. The present study investigated indoor air quality and passengers' exposure to PM, TVOC, CO_2, and bacteria. Monitoring was conducted from Mar-Jun 2019. Four underground metro stations were selected. Data were collected for seven successive days in each station and inside trains. PM, TVOC, and bacteria concentrations were 2–5 folds the regulatory limits specified by WHO and EPA. In metro stations, the concentrations of PM_{10} and $PM_{2.5}$ were in the range of 22.55 ± 3.21 to 74.23 ± 8.87 and 16.94 ± 1.89 to 49.39 ± 7.41 μg/m^3, respectively. The concentrations of TVOC surpassed the regulatory limit in all stations with the range of 210 ± 41 to 614 ± 37 ppb. The maximum concentration of CO_2 was 567 ± 32 ppm. Further, the concentrations of bacteria were substantially high in all stations in the range of 1487 ± 951 to 2573 ± 691 CFU/m^3. Moreover, the personal exposure of passengers to air pollutants was 5–9 folds in underground and 2–3 folds in aboveground stations than in-train exposure. Passenger activities and infiltration were significant contributors to elevated pollutant concentrations. The lower concentrations of CO_2 indicate a good amount of air circulation, while critical concentrations of other air pollutants indicate filthy air.

Keywords Indoor air quality · Passengers exposure · Underground rapid transit system · Subway

A. Passi (✉) · S. M. S. Nagendra
Department of Civil Engineering, Indian Institute of Technology Madras, Chennai, India
e-mail: amitpassi@alumni.iitm.ac.in

S. M. S. Nagendra
e-mail: snagendra@iitm.ac.in

M. P. Maiya
Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai, India
e-mail: mpmaiya@iitm.ac.in

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1 Introduction

A metro system is a high-capacity urban transport facility. Across the world, approximately 170 million passengers regularly travel the metro for their day-to-day activities in more than 56 countries. The subway system is substantially helping regulatory bodies in reducing road traffic congestion and resultant toxic emissions. But the design features of the subway metro systems, such as underground construction, compact space, and an airtight environment, have emerged as the new challenges of IAQ. It consists of limited ventilation and a high density of passengers per unit area. Due to the convenience of the least travel time and an air-conditioned environment, commuter footfalls have increased severalfold in the number of metro stations in both urban and suburban areas. By avoiding congestion and reducing gasoline consumption, the metro transit system ensures safe and economical transportation to urban communities globally [23]. The metro ridership has continuously increased over recent years. In most developed nations, the metro rail systems are the primary mode of local transportation.

Some existing studies on indoor air quality inside subway metro stations reported the influence of surrounding environmental conditions, train travel direction, travel route, and the number of passengers [5, 11]. Several studies were conducted to identify PM exposure in subway stations and trains. The studies reported that PM (particulate matter) concentrations in the subway were up to tenfold higher than in the ambient environment [2, 3, 15]. The air pollutant concentrations were contributed from indoor and ambient environments. Metro tunnels and passenger activities were the prime sources of indoors, whereas infiltration of outdoor vehicular exhaust emissions was the prime source outdoors [3, 13, 14]. More than 80% of existing global studies surpassed the WHO guidelines of 45 and 15 $\mu g/m^3$ for PM_{10} and $PM_{2.5}$, respectively [21]. Subway metro trains run with electric traction. Thus, emission sources and source composition are entirely different. Also, some recent research studies concentrated on gaseous and biological air pollutants showed the influence of TVOC (total volatile organic compound) and CO_2 (carbon dioxide) on IAQ deterioration inside subway stations and trains [1, 5, 7, 12, 16, 20, 24]. Besides, a good correlation was found between passenger density, indoor temperature, and bacteria count in underground metro stations [8, 10, 18].

This research work studied station indoor air quality and passengers' exposure to PM, TVOC, CO_2, and bacteria in Chennai's rapid transit system in India. Exposure characteristics were presented with the variation in real-time subway environmental state of affairs, such as the density of passengers, type of environment, temporal variation, and spatial variation. The first section explains the research approach regarding field study design and bacteria sampling. Later, results and discussion are presented.

2 Materials and Methods

2.1 Field Study

Chennai's rapid transit system is the fourth-largest metro network in India; it started its operation in June 2015 and consisted of AG (aboveground) and UG (underground) metro lines. It comprises two metro lines with a total operating network of 54.65 km. Metro trains in the Chennai metro system work with electric traction, and each train has four air-conditioned coaches. Both lines in the metro system connect the urban areas in Chennai city. Both metro lines change their route from AG level to UG level. Metro lines presented with light color represent the AG route, dark color represents the UG route, and rounded points on each line indicate the current operating metro station (Fig. 1). Field measurement and sampling were conducted in March–June 2019. Four underground metro stations were selected along metro line 1. Selected stations present different characteristics. Also, In-train measurements were performed along metro line 2. The IAQ parameters monitored were PM_{10}, $PM_{2.5}$, CO_2, TVOC, and Bacteria. IAQ monitoring and sampling on metro platforms and inside metro train coaches were conducted in the real-time scenario under normal operating conditions of the metro system.

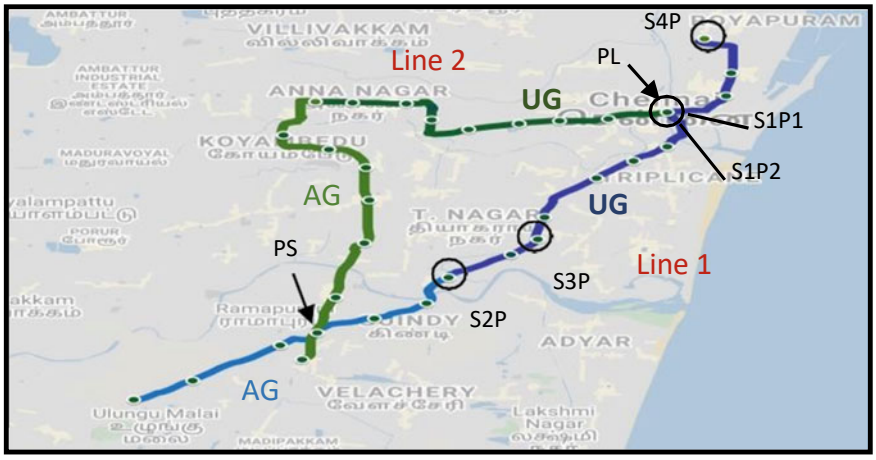

Fig. 1 Map of Chennai rapid transit system

2.2 Monitoring Instruments, Sampling Methods, and Data Quality

PM_{10}, $PM_{2.5}$, and PM_1 mass concentrations were measured using the dust spectrometer Grimm 1.109, which works with the light scattering principle. A portable IAQ meter measured CO_2 based on NDIR (non-dispersive infrared radiation) sensor. TVOC concentration was measured using PID (photoionization detection) sensor-based instrument Phocheck ion science. MAS-100 NT microbiological sampler was used for bacteria sample collection with the principle of impaction. Bacteria samples were collected using TSA (trypticase soy agar) with a sample airflow rate of 50 L, and the final results were reported in units of CFU/m^3. All monitoring instruments were calibrated before sampling. Before the start of sampling, instruments were kept ON for half an hour to stabilize. Sampling inlets were cleaned regularly to maintain proper flow. Multiples of three samples were collected to maintain the precision and reliability of data. The standard deviation of all duplicate samples was within the 10% range.

3 Results

3.1 IAQ Characteristics in Subway Stations

Indoor air pollutant concentrations in subway stations are summarized in Table 1. The table shows 24 h average data measured for a week in each station. To assess the IAQ, time-averaged data were compared with respective regulatory guidelines such as WHO (World Health Organization) $PM_{10} = 45$ μg/m^3, $PM_{2.5} = 15$ μg/m^3, Bacteria = 1000 CFU/m^3; ISHRAE (Indian Society of Heating, Refrigeration, and Air-conditioning Engineers) TVOC = 200 ppb; and ASHRAE (American Society of Heating, Refrigeration, and Air-conditioning Engineers) $CO_2 = 1000$ ppm.

The time-averaged concentrations of PM_{10} surpassed the WHO guideline in S1P1 and S1P2. In contrast, the $PM_{2.5}$, TVOC, and Bacteria concentrations exceeded the regulatory guidelines in all station platforms recommended by WHO and ISHRAE,

Table 1 Indoor air pollutant concentrations in station platforms of RTS

Station Platform	PM10 (μg/m^3)	PM2.5 (μg/m^3)	TVOC (ppb)	CO_2 (ppm)	Bacteria (CFU/m^3)
S1P1	74.23 ± 8.87	49.39 ± 7.41	614 ± 37	553 ± 24	2573 ± 691
S1P2	58.00 ± 5.11	40.08 ± 3.25	533 ± 6	567 ± 32	1530 ± 127
S2P	33.35 ± 10.95	20.58 ± 5.30	356 ± 26	500 ± 7	1636 ± 325
S3P	37.71 ± 6.55	28.12 ± 3.09	210 ± 41	499 ± 15	1487 ± 951
S4P	39.79 ± 3.42	25.04 ± 2.70	358 ± 22	517 ± 26	1603 ± 652

respectively. The air pollutant concentrations were 1.29–1.65, 1.38–3.29, 1.05–3.07, and 1.49–2.57 times higher than the safe exposure levels for PM_{10}, $PM_{2.5}$, TVOC, and Bacteria, respectively. The concentrations of CO_2 were well below the recommended ASHRAE guideline of 1000 ppm. It indicates good air circulation or air exchange in the metro stations; however, high pollutant concentrations indoors indicate the exchange of polluted air from outdoors. Figure 2 presents the IAQ characteristics in underground RTS.

3.2 Personal Exposure in Underground RTS

Personal exposure represents passengers' exposure along metro lines (platforms and inside trains) while traveling from the origin station to the destination station. To assess the passengers' exposure, train trips were conducted from PS to PL (Fig. 1). A total of 9 trips were conducted along metro line 2. The average time of travel on each trip along the metro line was (inside the train—36 min and at the origin and destination station platforms—12 min each). Figure 3 presents the passengers' exposure in underground RTS.

Observations from Fig. 3 indicate that inside metro trains, the concentrations of TVOC were two to threefold higher than the ISHRAE recommended limit of 200 ppb. The concentrations of PM and CO_2 were within the safe exposure limits inside trains. It also shows the effectiveness of in-train air-conditioning systems in removing particles. At the same time, the significant-high concentration of TVOC inside coaches indicated the least effective filtration system with gaseous pollutants. The concentration of TVOC may be attributed due to outdoor road traffic emissions. Instead, a significant amount of TVOCs are produced due to high passenger density per unit area (i.e., passenger metabolism). Further, the spatial variation of air pollutants presented that PM concentration in AG metro station was ~2 times higher and in UG metro station which was 5–9 times higher compared to in-train concentration. However, PM concentration inside metro trains was low, but the total particle mass contained 70–90% of particles of fine range, i.e., less than 2.5 μm. Exposure to fine size particles, even with a low concentration range, may be hazardous due to direct penetration in the passenger's lung system. Figure 4 presents the PM ratio along the metro line. The ratio of fine PM to coarse PM was highest inside the train, followed by AG station and UG station. Thus, the air filtration system inside metro trains was effective in removing coarse particles but not much effective in removing fine-range particles. Fine PM concentration highly depends on train operations, frequency, and ventilation system [14].

Also, bacteria concentrations were measured along the metro line in three different environments; AG station platform, inside train, and UG station platform. The concentrations of bacteria were found to be highest in the UG station platform (1530 $\pm$ 424), followed by inside train (1276 $\pm$ 349) and then the AG station platform (338 $\pm$ 65) CFU/m^3. The bacteria concentrations have surpassed the WHO recommended limit of 1000 CFU/m^3 in the UG station platform and inside trains. Past literature

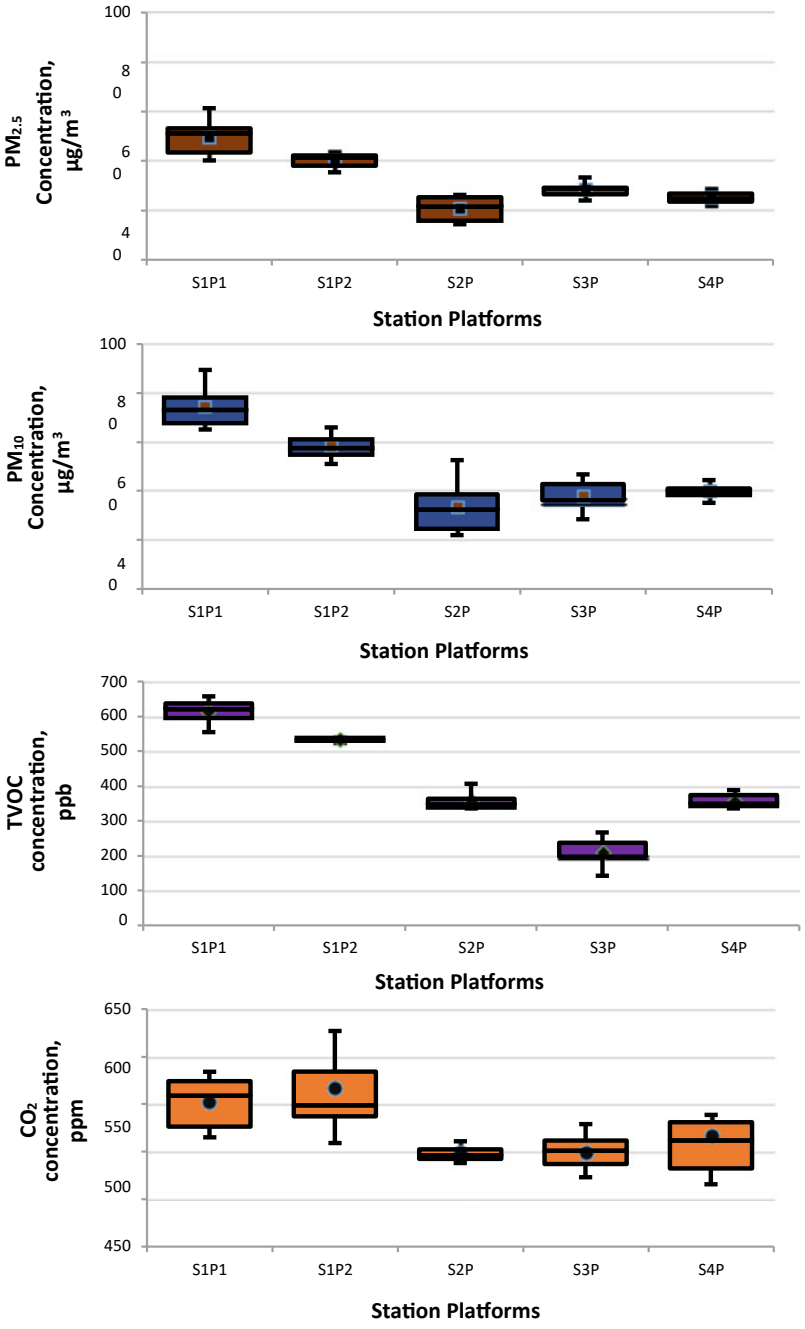

Fig. 2 Indoor air pollutant characteristics in underground metro station platforms

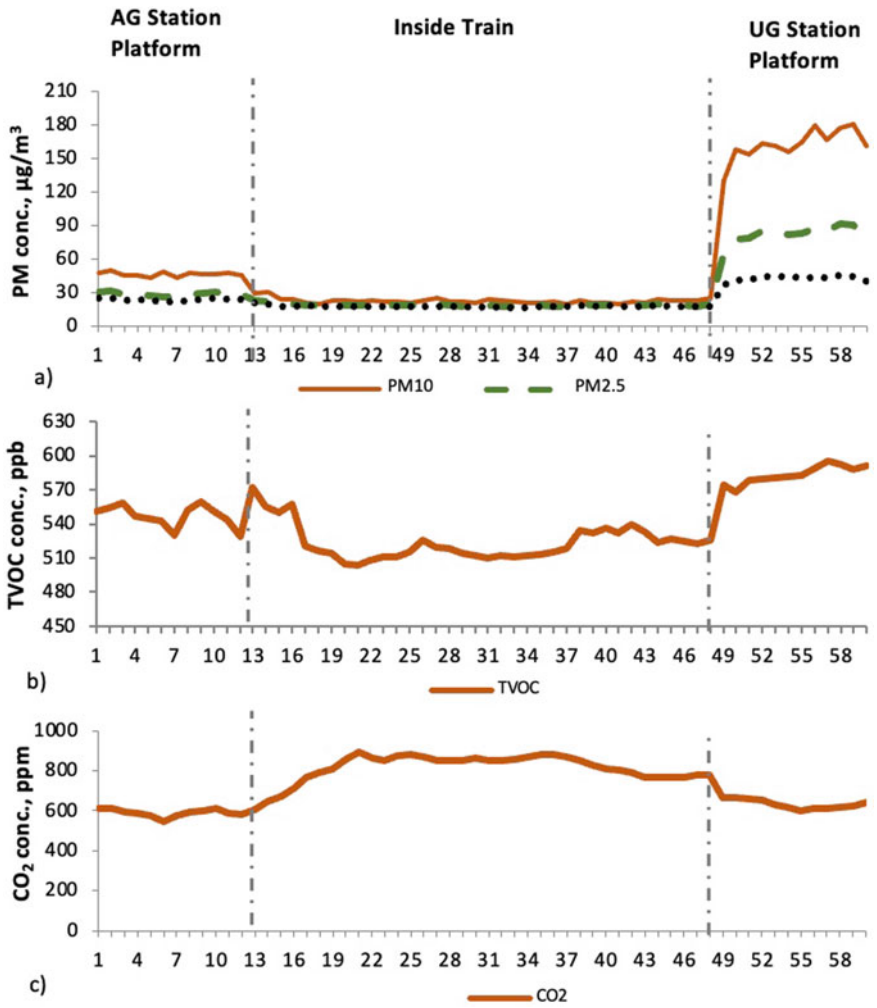

Fig. 3 Passengers personal exposure in underground RTS n platforms

showed that high bacteria concentrations in underground stations and inside trains contributed due to increased passenger density and a compact environment [7].

4 Discussion

Rapid transit systems have been developing at a fast pace globally. In India, the urban rail mass-rapid transit system plays a crucial role in intracity transportation. Per the latest report published on metro systems in India (2021), on average, 2636 million

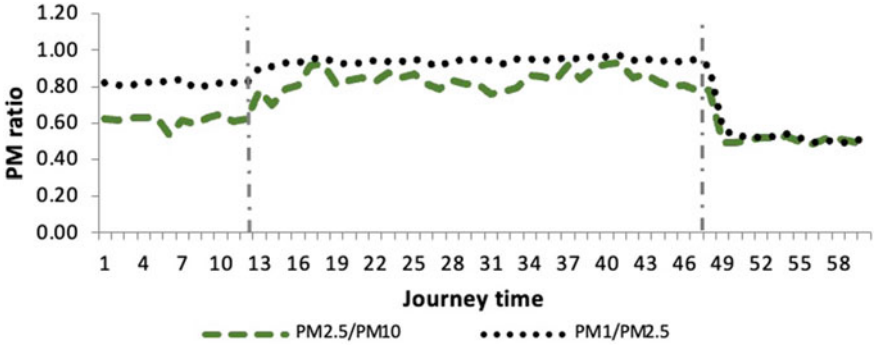

Fig. 4 PM ratios along the metro line in underground RTS

passengers travel annually through 585 metro stations across India's 15 mega-urban cities. The first metro rail system was started in 1984 in Kolkata, West Bengal. The Delhi metro system is the largest in India, with a current operational length of 348.51 km, followed by Hyderabad, Bengaluru, and Chennai. In most metropolitan cities (with a population of more than 2 million) like Bangalore, Chennai, Pune, Ahmedabad, Surat, etc., a 700 km+ metro network is in the development stage (either construction is in progress or proposed for construction). India's daily average ridership in metro transit systems is >5 million [22]. China is the Rank 1 country in developing the subway metro network. It has 42 metro systems with a total operational length of 6641.3 km. Currently, at Rank 5 out of 58, India has 15 metro systems with a total operating length of 731.75 km.

Due to the subway system's intrinsic characteristics, various indoor and outdoor sources contribute to air pollutants in RTS. The Prime Source of pollutants generation indoors is a tunnel. The diverse train operations such as wear of train tires and brake pads, friction between rails and wheels, vaporization of metals due to sparking of electric wires, emissions from pantograph and catenaries, and lubricants used during service of train lines, contribute to air pollutant concentrations [14, 21]. Also, passenger and train activities cause the resuspension of air pollutants in the air and keep up the high accumulation of air pollutants throughout the day [6, 12]. In addition, various passenger activities such as talking, coughing, sneezing, and shouting cause microbial transmission, which might be the reason for high bacterial concentrations on station platforms and inside trains. Other than passenger activities, HVAC systems are another cause of microbial contamination if not maintained properly [4]. Further, some studies reported the contribution of a volatile organic compound from passengers' metabolism, especially carbonyl compounds such as acetone, acetaldehyde, and acetate after expired exhalation. The concentration of these compounds increased with passenger numbers in the train coach [9, 19].

Furthermore, various factors impact air pollutant concentrations in subway stations: station geometry, HVAC system, platform depth, station locality, passenger density, train frequency, internal hygiene, and the outdoor environment—the design

of tunnel and platform influence pollutant concentrations considerably. Stations with narrow tunnel designs were found to have high air pollutant accumulation and the least dispersion [21] thus, high air pollutants were transported to the platform area after the train's arrival upon the opening of platform screen doors (PSD). The proper functioning of the HVAC systems is crucial to provide fresh air exchange and removing pollutants. The poorly maintained HVAC system causes blockage of air filters, which start giving breed to microorganisms after saturation and pollute indoor subway space [4]. The depth of the underground platform impacts the interaction of air pollutants with fresh ambient air. Station platforms with less depth interact highly with fresh ambient air compared to high-depth platforms [17]. Further, the locality of stations in high-trafficked areas causes high air pollutants infiltration. High passenger density increases the activity rate, thus resulting in high resuspension of air pollutants. Furthermore, internal hygiene plays an important role. Regular cleaning and maintenance activities of stations would help reduce indoor air pollutants. The ventilation rate in stations and trains should be established as an exchange rate per passenger. ASHRAE recommends that the air exchange rate should be maintained at 8L/s/person in vehicles, waiting rooms, and public transportation platforms to ensure optimum comfort.

5 Conclusions

The underground rapid transit systems or subways are complex environments. Their design and operation characteristics have a significant influence on the generation and accumulation of air pollutants. PM, TVOC, CO_2, and bacteria concentrations were measured in four underground metro stations and trains in Chennai RTS. The concentrations of PM, TVOC, and bacteria were found to be two to fivefold higher than the regulatory limits stipulated by WHO and ISHRAE, respectively. The concentrations ranged from 33.35–74.23 $\mu g/m^3$, 20.58–49.39 $\mu g/m^3$, 210–614 ppb, and 1486–2573 CFU/m^3, respectively. The personal exposure assessment indicated high exposure to TVOC and bacteria, whereas the PM exposure was within limits; It shows the effectiveness of in-train air-conditioning systems in removing particles. However, HVAC systems are not capable of removing TVOC and bacterial contamination. The improperly maintained HVAC system and passenger activities were found to be a significant cause of bacterial spread. However, CO_2 concentrations were found within the ASHRAE 62.1 limits of 1000 ppm. It indicates the good exchange of air, whereas high pollutant concentrations indoors indicate the exchange of polluted air from outdoors. In addition to indoor and outdoor sources of air pollutants, various factors impact air pollutant concentrations, such as subway design, depth of the platform, the density of passengers, frequency of trains, station locality, internal hygiene, and outdoor environment. Therefore, there is a need to improve the existing ventilation system, HVAC filtration systems, and station design to improve the IAQ of subways or RTS.

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Indoor Environmental Quality Assessment in a Newly Renovated Office Building in Delhi City

Sunil Gulia, Prachi Goyal, and S. K. Goyal

Abstract Healthy indoor environmental quality in the offices is a key factor for good health and productive work output. The ventilation facilities, construction materials and design of the buildings are the key factors to influence the indoor environmental quality, i.e., thermal comfort and pollutant concentrations. The present study attempted to evaluate the indoor environmental quality of a newly renovated office building in Naraina Industrial area using sensor based monitors. The study measured $PM_{2.5}$, relative humidity and temperature in different indoor micro-environments of the building including canteen area. The monitoring is carried out in indoor as well as outdoor environment using real time sensors based affordable monitor during one week period in September, 2022. The data analysis includes pollutant concentrations with and without operation of the ventilation system, indoor/outdoor ratio of pollutants, indoor air quality during working and non-working hours etc. The study also emphasized on the emission of pollutants due to cooking practices in the canteen area. The findings of the study highlight the effect of ventilation rate in the office building, office and canteen activities and infiltration of outdoor pollution.

Keywords Fine particulate matter · Indoor/Outdoor ratio · Office canteen · Indian cooking practice

1 Introduction

Breathing in clean air is the precondition for the survival of a healthy life. But with the rapid industrialization, development and changes in the living standards; natural factors and more of anthropogenic activities have rendered the ambient and indoor air unfit for intake [1, 9, 10]. Indoor air pollution in particular has not been discussed much in India due to non-availability of standards as well as monitoring guidelines unlike ambient air. Air quality in homes, institutions, hospitals, and other

S. Gulia (✉) · P. Goyal · S. K. Goyal
Delhi Zonal Centre, CSIR-National Environmental Engineering Research Institute (NEERI), Naraina, Delhi 110028, India
e-mail: s_gulia@neeri.res.in

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public buildings where people spend their lives should be pollutant free for the healthy survival [2, 5]. The indoor air pollution includes the occurrence of dangerous materials/agent such as carbon monoxide, sulphur dioxide, nitrogen oxides, VOCs and various micro-organisms [3, 4, 8]. Numerous sources are present in indoor spaces which again vary based on types of building and its use. In residential buildings, household emission (kitchen emission) is the major source of air pollution whereas in office buildings, the level of indoor pollution is generally less as there is no direct kitchen emission and thus, comparatively less exposure spectrum. However, there can be other sources which continuously emit pollutants both particulate matter and gases. Some of the sources in office building are (i) emission from cleaning practices; (ii) occupant-related sources such as smoking, office equipment, canteen activities, paper products and dirt/pollens; and (iii) newly built building i.e., construction adhesives, carpets, tiles, plywood/compressed wood, wall panels, etc. [6, 7]. In addition to the indoor sources, infiltration from outdoor pollution is one the major reasons for poor indoor air quality in the buildings. It is also observed that the frequent lack of causal connections between subjective complaints and certain indoor pollutants are being neglected which are usually followed by costly restoration and rehabilitation measures.

The present study is an attempt to assess the particulate matter ($PM_{2.5}$) pollutant along with thermal comfort parameters in a newly renovated office building located in one of the Industrial areas in Delhi. The study compared the $PM_{2.5}$ levels in different indoor environments in office building including canteen and compared with outdoor pollutant concentrations in terms of Indoor/Outdoor ratio and correlation analysis. Further, Pollutant levels are correlated with types of activities in indoor environment and their volume. In the end, efforts have been made to evaluate the emission from cooking activities inside the canteen area.

2 Materials and Methodology

The office building considered in the present study is located in the Naraina industrial area in Delhi where most of the activities belong to printing industries and retail of Iron sheets. The area is highly crowded witnessing continuous movement of heavy diesel trucks which are being used in the transport of Iron/Steel. There are not much combustion related activities or emission from stacks observed in the area. The building is 20 years old and renovated with modern infrastructure recently (3 months before the monitoring). It is a double storey building with total height of 7–8 m above the ground level. The building is also surrounded by the low income population. The details of indoor spaces, sensor locations and possible sources are given in Table 1 and shown in the form of photographs in Plate 1.

The monitoring was carried out during September 9–16, 2022 at 7 indoor spaces and 1 at roof using affordable sensor based air quality monitors. The AQ monitor is selected through a rigorous calibration process by comparing four different make sensor based monitors with validated portable monitor and continuous ambient air

Table 1 AQ monitoring locations and possible sources

S. No	Sensor code	Location Name & its description	Use of indoor space and related activities	Expected pollution load wrt to reception area
1	S1	Canteen (2–3 m away from cook stove) 1st floor	Cooking emission, emission from LPG, Cleaning/Sweeping of floor, Dusting activities, Newly Painted Walls	High
2	S2	canteen (Adjacent to cook stove) 1st floor	Cooking emission, emission from LPG, Cleaning/Sweeping of floor, Dusting activities	High
3	S3	Canteen sitting area (common area separated by wall & door from kitchen) 1st floor	Cleaning/Sweeping of floor, Dusting, Microwave, Oven, Painted Walls, re-suspension of dust due to movement of staffs, office staff used to sit during lunch time	Low
4	S4	Office room 1 (OR-1) (Regular movement of staffs) 1st floor	Cleaning/Sweeping of floor, Dusting, Xerox Machine, movement of people frequent here; Air Conditioned room	Low
5	S5	Reception (Regular movement of staffs- Higher than OR-1) 1st floor	Large area, connected with stairs and open window; Connected with toilet door; Cleaning/ Sweeping of floor 2–3 times in a day, Dusting, High movement of staff & visitors	Reference room
6	S6	Office room 2 (OR-2) 3–4 staff siting 1st floor	Closed room, 2–3 staffs siting area, Air Conditioned room, closed room	Low
7	S7	Office room 3 (OR-3) single staff sitting ground floor	Closed room, 1 staff siting area, closed, Air Conditioned room, ground floor	Low
8	S8	Roof 1st floor roof	Frequent Open burning, Kitchen exhaust, diesel Locomotive movement, Vehicles movement in the surround area	High

quality stations in the previous work of the author which is under consideration of publication. The device is capable of monitoring particulate matter along with ambient temperature and relative humidity. It is light scattering based sensor mounted in a compact steel case and portable in nature. It can operate at 0–50 °C and 10–95% relative humidity conditions. The device needs calibration on an yearly basis to remove the drift that comes due to aging effect. The measurement range of the sensor is 1–2000 $\mu g/m^3$ with time resolution of 40 s.

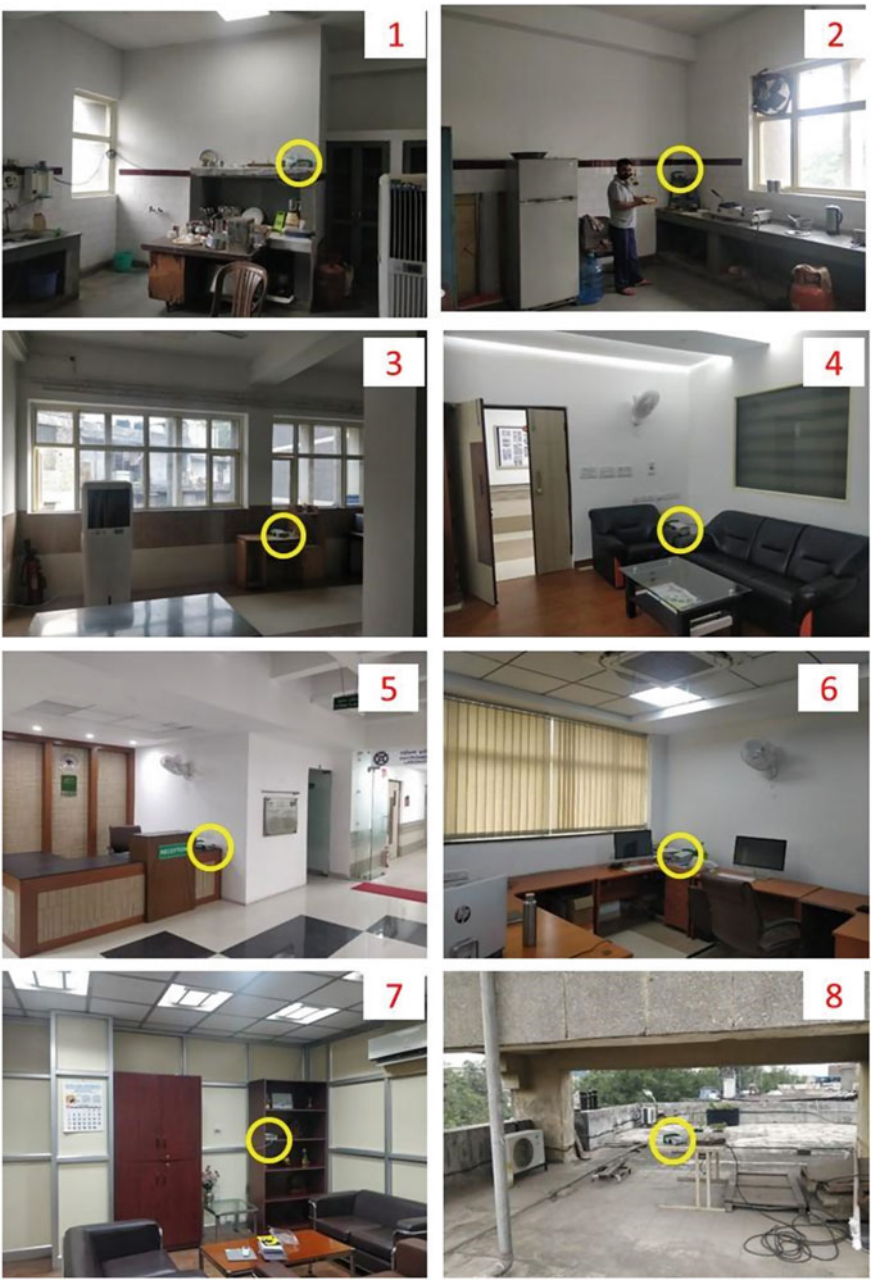

Plate 1 Photographs showing locations of AQ monitor and indoor spaces

3 Results and Discussion

3.1 $PM_{2.5}$ Concentration in Indoor and Outdoor Environments of the Building

The statistical summary (average and standard deviation) of $PM_{2.5}$ concentrations along with temperature and relative humidity are given in Table 2. The average concentrations of $PM_{2.5}$ were found to be 28 $\mu g/m^3$ at S1 (4–5 m away from cook stove) and 24 $\mu g/m^3$ at S2 (near cook stove) sensor which are located in Canteen. The higher value at S1 compared to S2 might be due to vertical rise of smoke from the cook stove due to buoyancy and settling away as reflected by S1. Whereas temperature was found higher at S2 as compared to S1 and vice versa for RH which is due to cook stove heating. In the canteen sitting area, the concentration was comparatively low i.e., 19 $\mu g/m^3$ as this area is separated from the cooking area by a wall with closed door whereas temperature is similar to kitchen area, but relative humidity is less. Further, the average $PM_{2.5}$ concentrations in office rooms were in the range of 23–28 $\mu g/m^3$ which is found slightly lower as compared to the reception area i.e., 30 $\mu g/m^3$, respectively. It is also observed that there is not much change in temperature and relative humidity between them. The average $PM_{2.5}$ concentration at roof was also found more or less in a similar range as found in indoor spaces i.e., 28 $\mu g/m^3$. Further, the average concentration of $PM_{2.5}$ was derived from hourly data of CAAQMS located at IITM Campus in Pusa (which is 3.5 km as per arial distance from the study site) in east side and the level was found to be 28.3 ± 18 $\mu g/m^3$ which is well matching with the roof sensor's observation. The correlation coefficient value between CAAQMS and Sensor monitored $PM_{2.5}$ concentrations were found to be significant i.e., 0.63. This significant correlation and more or less similar average $PM_{2.5}$ concentration develop the confidence that the sensor can provide reliable data and measurement can be used for evaluation of effectiveness of management strategies/control action.

Time series plot of hourly average $PM_{2.5}$ concentration in different Indoor spaces and roof of the building is presented in Fig. 1.

3.2 Indoor-Outdoor (I/O) $PM_{2.5}$ Concentration Ratio

Ratio of indoor and outdoor concentrations (I/O ratio) was calculated using hourly average data for the study period for each indoor sensor and is given in Fig. 2. The I/O values were found > 1 for sensors located at Canteen (S1), Reception (S5) and Office room (S7) and minimum for sensors located at the canteen siting area.

Table 2 Summary of $PM_{2.5}$ and thermal parameters at different locations

Sensor number	Sensor locations	Daily average ± standard deviation		
		$PM_{2.5}$ ($\mu g/m^3$)	Temperature (^1C)	Relative humidity (%)
S1	Canteen	28 ± 18	34 ± 2	61 ± 5
S2	Canteen	24 ± 16	35 ± 2	59 ± 5
S3	Canteen sitting area	19 ± 13	35 ± 2	56 ± 6
S4	Office room 1 (OR-1)	23 ± 11	32 ± 2	65 ± 15
S5	Reception	30 ± 20	32 ± 2	62 ± 6
S6	Office Room 2 (OR-2)	26 ± 16	30 ± 4	58 ± 6
S7	Office Room 3 (OR-3)	28 ± 15	31 ± 2	57 ± 7
S8	Roof	28 ± 13	31 ± 4	67 ± 13
9	CAAQMS, IITM Pusa	28 ± 18	–	–

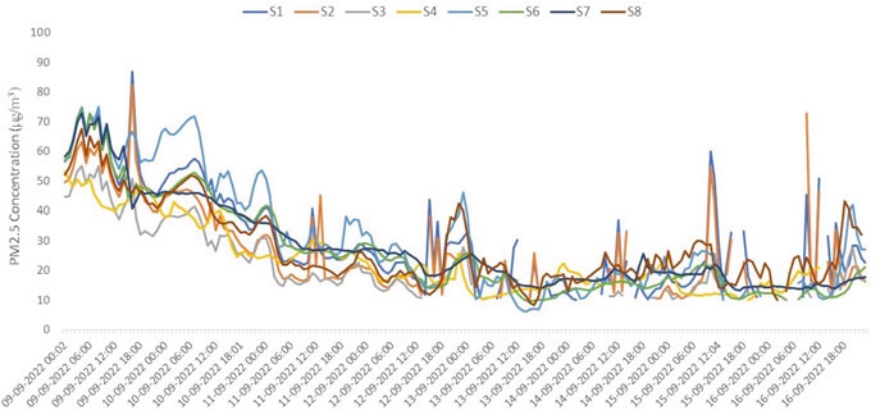

Fig. 1 Time series plot of hourly average $PM_{2.5}$ concentration in different Indoor spaces and roof of the building

3.3 Diurnal Profile of Indoor and Outdoor $PM_{2.5}$

The pollution related activities in the indoor as well as outdoor environment changes throughout the day and accordingly pollution levels vary. With respect to indoor activities in the office building, the office operates from 9:00 am to 6:00 pm in a typical working day; where generally cleaning and dusting takes place during morning hours, whereas in canteen, cooking occurs during 12:00–01:00 pm only

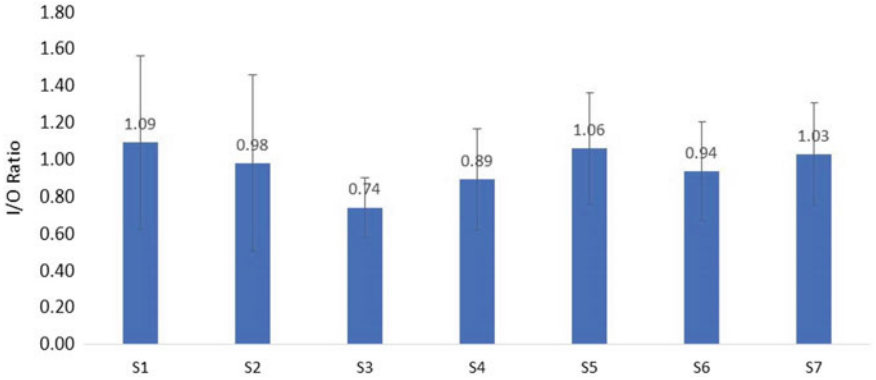

Fig. 2 I/O ratio of different indoor spaces of the building

(one hour) along with tea making during the whole day. During night time and on weekends; the activities are negligible in the office building. Considering these variables, further diurnal data analysis was performed to see the variations in the pollution level. Figure 3 shows the diurnal profile of $PM_{2.5}$ during weekdays and weekend period for each sensor.

The variations are observed in $PM_{2.5}$ values during the weekday compared to weekends in all indoor sensors which directly reflects the influence of activities. The pattern in the reception area (S5) is more or less similar on weekdays and weekends which might be due to influence from the outside area as this area is connected with stairs as well as open window, however, the concentration was higher during the weekends compared to weekdays which fully depends on the outside activities as reflected in the roof sensor (S8) and CAAQMS.

Earlier in 2018, a similar kind of study was conducted, wherein $PM_{2.5}$ monitoring was carried out for three days during August 23–25. The monitoring results indicate that average and standard deviation values of $PM_{2.5}$ were found to be 32 ± 5 $\mu g/m^3$ in Admin room, 33 ± 4 $\mu g/m^3$, in staff room and 57 ± 9 $\mu g/m^3$ in canteen (Mishra et al., 2018). It is inferred that $PM_{2.5}$ concentration were found less in the renovated building which might be due to an efficient ventilation system. The building indoor spaces are renovated with modern furniture and small cabins are replaced with large open spaces. Proper spaces are created to keep the files, old reports etc. The pantry/canteen area are kept separate.

Further, $PM_{2.5}$ monitoring is being carried out during the post-monsoon season from 3rd–10th November 2022 at the terrace (S8) and indoor in the staff room (S6). The average concentration and standard deviation of $PM_{2.5}$ were found to be 194 $\pm$ 118 $\mu g/m^3$ by S8 (Outdoor Environment) and 163 $\pm$ 84 $\mu g/m^3$ by S6 (Indoor environment). The average I/O ratio of the hourly average $PM_{2.5}$ concentration was found to be 0.99 which is comparatively higher from the monsoon period i.e., 0.94. This change might be due to poor ventilation in the Indoor environment during November due to non-operation of the air conditioning system. Further, the average and standard deviation concentrations of $PM_{2.5}$ at CAAQMS, Pusa were found to be 192 ± 111 $\mu g/m^3$ which is matching with S8 data.

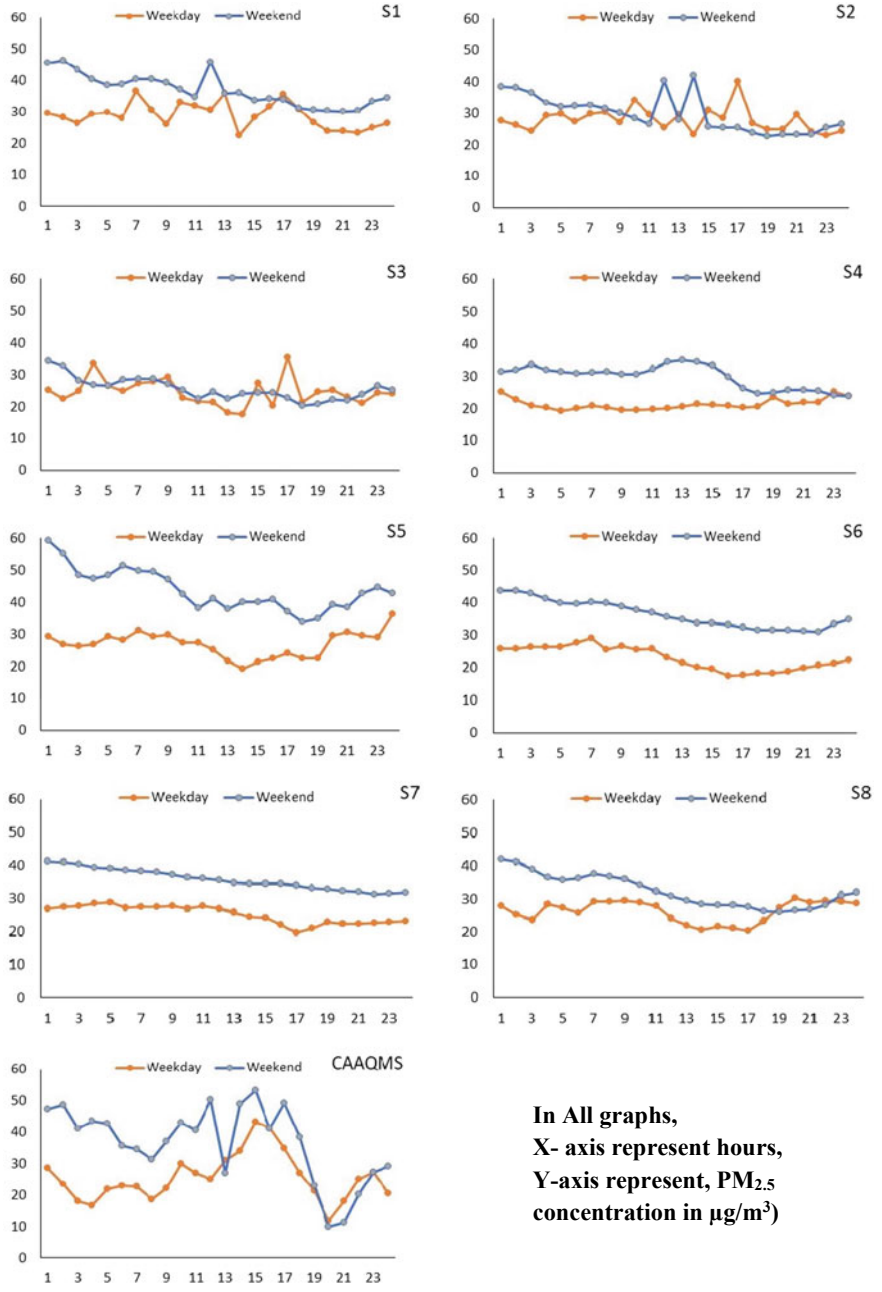

Fig. 3 Diurnal Profile of $PM_{2.5}$ during weekday and weekend in indoor and outdoor environment

4 Conclusion

Indoor air quality is a major concern as people spend most of their time indoor either in homes or workplace. The indoor air quality can be influenced through a number of factors including infiltration from outside air which again vary in mechanical and naturally ventilated buildings. Now a days, most of the offices are mechanical ventilated buildings. The present study also analysed the fine particulate matter concentration in different rooms of one office building along with canteen and outside area and correlated with activities based on one week data of September 2022.

The $PM_{2.5}$ concentrations were found higher in the canteen area compared to other office rooms. However, the $PM_{2.5}$ concentration was found higher at the reception area which might be due to continuous movement of staff/visitors compared to other indoor spaces. The average $PM_{2.5}$ concentration measured by the sensor at the Roof of the building and CAAQMS at Pusa campus are well matched. The $PM_{2.5}$ concentration in few indoor spaces was found to be slightly more than the outdoor environment. These indoor spaces are canteen, reception and office room at ground floor whereas other the air conditioned office room has low indoor $PM_{2.5}$ than outdoor. The diurnal profile of $PM_{2.5}$ concentration shows high variations during weekdays compared to weekends which reflect the influence of office activities.

The study gives some preliminary analysis of fine particulate matter in a newly renovated and painted building whereas other gaseous pollutant might also be studied, especially, VOCs. The painted walls and adhesives from new furniture may emit various types of VOCs. Additionally, the cooking emission in the canteen should be studied in detail with comprehensive monitoring using robust air quality sensors for particulate as well as gaseous pollutants and emission rate should be calculated from this monitored data. The sensor monitored $PM_{2.5}$ matched with the CAAQMS data, however, detailed monitoring covering all seasons could improve the understanding of the performance of the sensors and their application in indoor as well as outdoor spaces.

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Indoor Particulate Matter Pollution on Oxidative Stress Pathways: Role of Chemical and Biological Constituents

Milindkumar Yashvant Bhatkar, Shreya Roy, Ritwika Roy, and P. Gursumeeran Satsangi

Abstract The present study aimed to evaluate the relationship between physico-chemical characteristics and toxicological assessment of indoor PM bound chemical and biological constituents. The average concentration of both indoor PM_{10} and $PM_{2.5}$ exceeded the NAAQS standards of India. Metals of geogenic origin (Fe and Mn) are predominant in PM_{10} samples, while the metals of anthropogenic origin (Ni, Co, Cd, Pb, Cu, Cr, and Zn) were dominant in $PM_{2.5}$. Among all analyszd metals, Fe exhibited the maximum concentrations in both sized PM followed by Mn, pb, Cr, Cu and Ni suggesting considerable health risk to the exposed inhabitants due to their ability to generate reactive oxygen species through Fenton's reaction, mainly responsible for causing PM toxicity. Commonly isolated bacteria and fungi identified in the indoor environment were *Bacillus sp., Staphylococcus aureus, Pseudomonas aeruginosa, Aspergillus sp. and Penicillium sp.,* respectively. Amongst them, *Pseudomonas aeruginosa* and *Aspergillus sp.* were found to be predominant in both sized PM revealing a significant health risk due to their association with various respiratory tract infections. The cytotoxic profile of indoor PM and their constituents determined by MTT assay on A549 cells exhibited a significant decrease in cell viability indicating the cytotoxic behavior of particles. Oxidative reactivity of indoor PM in terms of DTT assay showed considerable DTT depletion suggesting the oxidative nature of PM. Results of the present study will be effectual to raise awareness and address the better indoor air quality for the residents.

Keywords Indoor PM · Metals · Microbes · Reactive oxygen species · Cytotoxicity

M. Y. Bhatkar · S. Roy · R. Roy · P. G. Satsangi (✉)
Department of Chemistry, Savitribai Phule Pune University, Pune 411007, India
e-mail: pgsatsangi@unipune.ac.in

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1 Introduction

Indoor air quality depends on many contributing factors *viz.* individual home characteristics, routine habits and personal activities. As compared to ambient particulate pollution, indoor air pollution is always less explored in terms of sources and health effects [1]. It should be noted that humans spend the majority of their time in (approximately, 90%) different indoor conditions such as homes, offices, schools [2]. These indoor environments are rich in particulate concentration due to routine activities performed by individuals. However, spending a plenty amount of time in various indoor settings, ultimately increases the inhalation rate of particles. Particulate matter (PM) is a heterogeneous mixture of many constituents like dust, metals, bioaerosols, carbonaceous matter including VOCs and PAHs. PM bounded with bioaerosols and metals have considerable adverse health outcomes. Human respiratory tract inflammation, asthma, influenza, chronic obstructive pulmonary disease (COPD) and oxidative stress can be considered major indicators for bioaerosol-bound microbe exposure [3, 4]. Similarly, metals bound with PM are capable of inducing malfunctioning and disturb cellular activities. Considering Fe, excess concentration is responsible for initiating Fenton's reactions in human body by catalyzing the conversion of hydrogen peroxide to hydroxyl free radicals [5]. Production of these radicals is accounted by the oxidation of ferrous ions (Fe^{2+}) with hydrogen peroxide. The unstable nature of these free radicals makes them highly toxic, having the capability of reducing disulfide bonds present in proteins. Thus, it is necessary to take into account the toxicological profiling of these PM, which is considered a crucial process for evaluating their health effects. In view of this, the present study was aimed to investigate the role of bioaerosols and metal concentration for inducing toxicity to PM, collected from the indoor atmosphere of urban houses of Pune. Results obtained in this study will be useful for spreading awareness and addressing the need for better air quality for residents of Pune city.

2 Materials and Methodology

2.1 Sampling and Extraction Procedures

In the present study, three houses based on different characteristics i.e., construction, living standards, etc. were selected. Samples of PM_{10} (N=36) and $PM_{2.5}$ (N=36) were collected from June, 2021 to May, 2022 by Mini Vol TAS (Airmetrics, USA) with a constant flow rate of 5 LPM in Pune. A detailed survey of these selected houses is reported in Table 1. Properly desiccated (for 48 hrs), sterilized, pre- weighed nucleopore filters were used for sample collection. Post-sampling, these filters were stored in a refrigerator unit at 4 °C. For extraction, PM filters were cut into two halves; one portion was digested in 10 ml of HNO_3 for 2 h on a hot plate followed by dilution was used for the analysis of total metal content by ICP-AES (ARCOS, Spectro,

Table 1 Household characteristics of selected sampling locations

Particulars	Pune		
	H1	H2	H3
Building characteristics	Bricks, plastered walls and well painted	Built with bricks, cemented but not painted	Built with bricks with plastered walls
Cooking gas usage	L.P.G	L.P.G	L.P.G
Other activities	Incenses sticks, mosquito vaporizers	Tobacco smoking, Mosquito vaporizers	Tobacco smoking, Incenses sticks
Ventilation	Window and exhaust fan	Windows	Windows, AC, exhaust fan
Pets/Plants	Dog/Yes	No/Yes	No/yes
Outdoor influence	Road dust and dump yard	Vehicular emissions, construction activities and road dust	Vehicular emissions
No. of occupants	2	4	3
Floor type	Tiles	Old tiles	Tiles
Temperature (°C)	25.8	26.9	24.5
RH (%)	51.3	57.5	52.7

Germany) The second portion was transferred to sterile culture tubes containing a mixture of 0.1% sterile peptone water and 0.01% Tween 80, vortexed for about 5 h and stored at 4 °C in the refrigerator. Temperature (°C) and relative humidity (%) were simultaneously measured by using an Aeroqual air quality monitor (IQM 60) which is having a flow rate of 1.0 ± 0.05 LPM).

2.2 Cultivation of Microbes Associated with PM and Their Toxicological Profiling

Fungal and bacterial isolates were cultivated on potato dextrose agar (PDA) and nutrient agar, respectively. 0.4 $\mu g ml^{-1}$ Chloramphenicol and 0.5 $\mu g ml^{-1}$ Cyclohexamide were added to inhibit bacterial and fungal growth, respectively. On sterile petri plates poured with required culture media, 50 µl of each microbial preparation was spread-plated in triplicates. An incubation period of 3 and 7 days for bacterial and fungal growth, respectively was followed for each petri plate. Manual counting of culturable microbial colonies in the form of average colony-forming units (CFU) was done for each incubated petri plate.

When the antioxidant power of the human body is unable to nullify the harmful effects of excessive ROS generated, this untoward situation is termed as oxidative stress, which is the ultimate mechanism of PM toxicity [6]. Dithiothreitol assay can be considered a promising approach towards quantification of oxidative stress. Collected PM samples were incubated with DTT for about 30 min at 37 °C. After vortexing for 15 min, 0.5 ml of trichloroacetic acid as a quenching agent was added, further, this reaction mixture was treated with 5, 5-dithiobis-(2- nitro benzoic acid) (DTNB, 10 mM) to form 2-nitro-5-thiobenzoate (TNB). Formation of TNB was measured at 412 nm by using a UV–Visible spectrophotometer (Shimadzu UV-2501PC).

Combined visualization of cell viability, cytotoxic effect and predominant microbial species can be achieved by MTT[3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide] assay. PM samples in triplicate were treated with A549 cells for 24 h. Then, MTT solution is added and incubated for 3 h. After centrifugation media was removed and DMSO was added. Finally, absorbance was measured at 570 nm by a well plate reader (PerkinElmer EnSpire 2300).

2.3 Quality Control

From the initial phases of the reported research work, precautions were taken to rule out any possibility of error. All the weighing activities and laboratory analyses were performed in triplicates. The flow rate of the sampling instrument was checked every time before sampling. Glass-wares and reagents used were of proper grades and cleaning measures were followed throughout the study period. Toxicological assays and microbial analysis were performed under aseptic conditions. Field blanks were analyzed periodically to reduce any chances of uncertainty in the upcoming analysis.

3 Results and Discussion

Annual concentration of both, $PM_{2.5}$ and PM_{10} were 82.6 ± 2.7 μgm^{-3} and 105.1 ± 7.08 μgm^{-3}, respectively during the study period. Average annual concentration for all the three houses (H1, H2 and H3) has exceeded the annual average standard of NAAQS specified by CPCB, which is 60 μgm^{-3} (PM_{10}) and 40 μgm^{-3} ($PM_{2.5}$) (Fig. 1). Similarly, standards fixed by United States Environmental Protection Agency (USEPA) are 15 μgm^{-3} ($PM_{2.5}$) and 50 μgm^{-3} (PM_{10}). On comparing our measured PM values with the USEPA standard, these are 5.5 ($PM_{2.5}$) and 2.1 (PM_{10}) times higher than the set values. Indoor $PM_{2.5}$mass concentration for H2 was found to be highest among all the three houses, recorded as 85.4 μgm^{-3}. In case of PM_{10}, H3 witnessed the highest particulate count as 112.4 μgm^{-3}, followed by H2 and H1. Sources responsible for higher mass concentrations in H2 and H3 may include nearby construction activities, vehicular emissions and lack of ventilation.

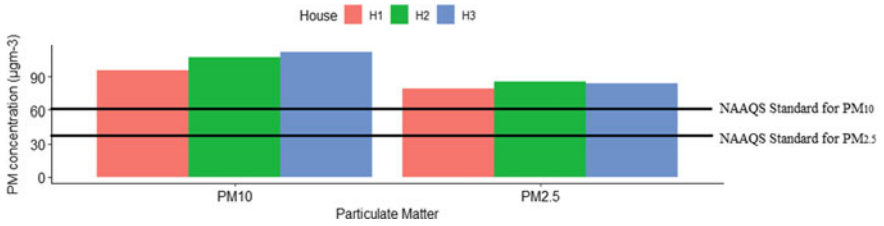

Fig. 1 Average annual concentration of PM

From these house, commonly isolated bacteria and fungi were Bacillus sp., Staphylococcus aureus, Pseudomonas aeruginosa, Aspergillus sp., and Penicillium sp., respectively. Amongst them, Pseudomonas aeruginosa, and Aspergillus sp. were found to be predominant in both sized PM revealing a significant health risk due to their association with various respiratory tract infections. Quantitative analysis for total culturable bacteria (TCB) revealed that the average TCB associated with $PM_{2.5}$ was 1325 ± 150 CFU m^{-3} and the concentration of TCB bound with PM_{10} was 1878 ± 187 CFU m^{-3}. In H2, level of TCB associated with $PM_{2.5}$ and PM_{10} were exhibited as 1165 ± 137 CFU m^{-3} and 1290 ± 266 CFU m^{-3} respectively. High CFU count for the bacterial species can be attributed to the number of individuals staying in H2. Individual routine activities i.e., talking, coughing, cooking and sneezing can be correlated with higher concentration of bacterial species in H2. Average fungal load observed in H2 was higher than H1 and H3, the key reason behind this can be natural ventilation. Only source for air ventilation in H2 was through windows which may increase the levels of fungal loads because of high wind flow from outdoor environment which leads to higher air exchange between outdoor and indoor environments. Walls of H2 were not painted and presence of cracks and leaks may increase the air flow, which may encourage the fungal growth in the indoor environment of H2.

Individual response to particularly inhaled microbe is diverse in nature, thus there is no provision for minimum standard values for inhalable microbes and their health effects. Therefore, outcomes from the current study were compared with familiar research works done in India and guidelines provided by WHO. Microbial concentrations recorded in this study were above the decided values provided by WHO. This study clearly specifies the increased level of microbial pollution in indoor environments of Pune. Identification of microbes in the indoor environment was done on the basis of their morphology and further confirmed by the gene sequencing.

The annual average concentrations of metals *viz.* Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb and Zn in both PM samples were analyzed and showcased in Fig. 2a, b. Based on the concentrations, metals are categorized as crustal (Fe), trace (Co, Mn, Zn and Cu) and carcinogenic (Pb, Ni, Cr and Cd) [7]. Furthermore, based on their origin we can segregate metals as geogenic (Fe and Mn) and anthropogenic (Ni, Co, Cd, Pb, Cu, Cr and Zn). As evident from the Fig. 2, that the metals of geogenic origin were predominant in PM10, whereas PM2.5 samples were rich in metals of anthropogenic origin. Fe is having the highest annual average concentration of 1.152 µgm^{-3} ($PM_{2.5}$)

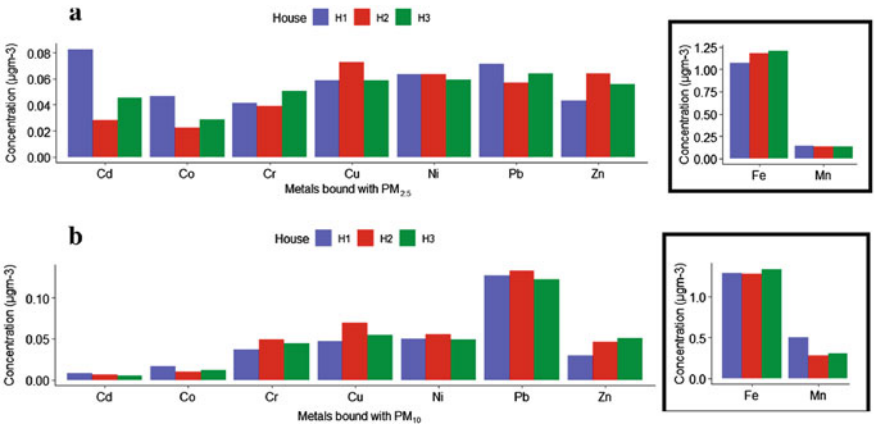

Fig. 2 **a** Average annual concentration of metals in $PM_{2.5}$. **b** Average annual concentration of metals in PM_{10}

and 1.299 μgm^{-3} (PM_{10}) due to its crustal origin. Another abundant metal in both PM was Mn, with annual average concentration of 0.139 μgm^{-3} ($PM_{2.5}$) and 0.363 μgm^{-3} (PM_{10}).

Reactive oxygen species (ROS) play a vital role in causing potential health. Numerous studies determining the oxidative potential of various components of PM have escalated and the most common method for quantification is through the DTT assay. Figure 3 shows the DTT loss of the PM_{10} and $PM_{2.5}$ samples of all the houses. Average DTT loss for $PM_{2.5}$ and PM_{10} was found to be 0.0349 µM and 0.0411 µM, respectively. Higher DTT loss in PM_{10} samples are corroborated with high concentrations of bioaerosol and metals found in this size fraction range. The concentration of redox active metals mainly Fe, Mn are more than non-redox metals *viz.* Cd and Co indicating significant risk for the exposed population. Further, MTT assay was also performed on indoor PM samples and cell viability was found to be significantly decreased as compared to the control. Finding from the present study indicates the proposing role of chemical and biological constituents in inducing the oxidative stress ultimately causing the significant health risk to the exposed population.

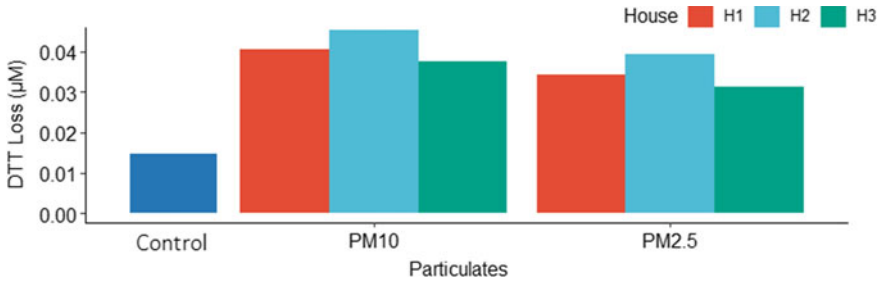

Fig. 3 Average DTT loss for PM samples

4 Conclusion

In summary, the present study revealed the combined effect of metals bound with PM and bioaerosols collected from three urban households in Pune. On a conclusive note, these microbial constituents are dependent on household characteristics, personal activities, routine habits of residents and as well as outdoor activities going on in close vicinity of these households. Associated species of microbes are proven for their ability to cause severe health conditions i.e., acute and chronic diseases. Detailed toxicological profiling of these PM may assist the policymakers to frame future guidelines regarding the health hazards of bioaerosols. These particulates are having a complex composition and thus it is of much importance to investigate both culturable and non-culturable microbial species. Therefore, it should be noted that a complete analysis of these microbes must be considered for estimating the overall harmful effects of these PM. Similar research studies should be encouraged to understand more about the air that we breathe, which will ultimately help to build more safe future for mankind.

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Determination of AER, Ventilation Rate and Indoor Air Quality Index for a Community Kitchen

Naragam Bhanu Sree, Aditya Kumar Patra, Penchala Abhishek, and Nazneen

Abstract In recent year's indoor air quality has gained much attention throughout the globe. It was ranked as the top five risks to public health. People spend most of their time indoors, it might be their home, workplace or while commuting. They are exposed to different micro environments without knowing that they are inhaling substantially high concentrations of different indoor air pollutants (IAPs). In developing countries, IAP concentrations are generally found high due to poor ventilation and numerous indoor sources. Poor IAQ can severely damage the mental, physical and social ability of a person, which can affect the working efficiency and result in loss in overall productivity. The present study focused on the determination of air exchange rate (AER), ventilation rate (VR) Q, and indoor air quality index (IAQI) for the community kitchen. The study was conducted for 3 days from 18-10-2022 to 20-10-2022. In this study, different pollutants like PM10, PM2.5, PM1, TVOCS, CO_2, CO, O_3, NO_2 were studied. Comfort parameters temperature and relative humidity were also monitored. The levels of all the pollutants, comfort parameters were shown higher on 20-10-22 when cooking activities like frying potato, frying fish took place have crossed the WHO guidelines 2009. The AER value varied from 0.9915 to 0.9906 h^{-1}. Lowest value was observed on the highly polluted day i.e. 20-10-2022. Similarly, the VR varied from 0.8262 to 0.8254 lit/s/m^2. This VR has shown that buildings have fallen to category III i.e. high polluting buildings according to ventilation rate for non-residential buildings (European Standard, EN 15,251). The indoor air quality index (IAQI) is calculated based on 5 criteria pollutants PM10, PM2.5, CO, O_3, NO_2 showed that the health condition of the workers falls into the very severe to poor category (NAQI 2014). Further the study suggests the measures to enhance IAQ that can be practiced in the community kitchen which were observed during the study.

N. B. Sree (✉) · Nazneen
School of Environmental Science and Engineering, Indian Institute of Technology Kharagpur, Kharagpur, India
e-mail: naragam.bhanusree@kgpian.iitkgp.ac.in

A. K. Patra · P. Abhishek
Department of Mining Engineering, Indian Institute of Technology Kharagpur, Kharagpur, India

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Keywords Community kitchen · PM10 · PM2.5 · PM1 · TVOCS · CO_2 · CO · O_3 · NO_2 · AER · VR · IAQI

1 Introduction

People spend 75–90% of their time in different microenvironments such as residential homes, schools, offices, recreational places, restaurants and saloons. The time spent indoors has increased greatly during the pandemic situation with toddlers spending almost all their time at home. It is going to remain at a higher level even after the pandemic is over because of continuance of online mode for many activities such as business and teaching. It's often believed that outdoor air is more polluted and indoor air is cleaner, which is not the case in the real world. Indoor air is highly polluted; sometimes pollutant levels indoors can exceed 100 times those outdoors. The pollutants that enter from outdoors often don't get flushed out from indoors due to restricted ventilation indoors. According to EPA 1986, the levels of pollutants can be 2–5 times higher indoors than outdoors (Include reference). Indoor environments act as reaction vessels for many secondary pollutants, leading to many health impacts of the persons exposed to it. Poor IAQ can severely damage the mental, physical and social ability of a person, which can affect the working efficiency and result in loss in overall productivity. The present study focussed on the determination of air exchange rate (AER), ventilation rate (VR) Q, and indoor air quality index for the community kitchen.

2 Methodology

2.1 Site Description

The microenvironment considered in this study a large community mess, consisting of a kitchen and dining hall, was considered to study the indoor air quality. The community mess located in RP hall, IIT Kharagpur. The mess is surrounded by greenery giving a good ambience. Everyday cooking was prepared for 1000 students consisting of 19 workers constantly working in morning and night shifts. Kitchen has a natural ventilation system but the exhaust fans provided were not working. The kitchen is divided into a number of partitions and the instruments are placed at the section where major activities take place.

Table 1 Instrument used in this study

Instruments	Parameters examined for	Instrument description
OPC (Optical Particle Counter)	Particle mass concentration	PC 11D and OPC 1.108, GRIMM Aerosol Technik GmbH & Co. KG, Germany
Graywolf IAQ monitor	TVOCS, CO,CO_2, O_3, NO_2, T, RH	Graywolf sensing solutions, Shelton USA

2.2 Instrumentation

Real time air samples were collected for four days with different variations. The details of the instruments were shown in Table 1. To understand the concentrations of PM and gasses a setup Grimm 11D and gray wolf were placed in the kitchen for four days from 6.30 a.m. to 12 p.m., located at the major section of a partitioned room.

3 Results and Discussions

3.1 Particulate Matter Concentrations in Kitchen

Higher levels of particulate matter were found on 20-10-2022. The mean levels were 322.96 ± 254.17, 191.77 ± 136.11, 132.19 ± 64.89 $\mu g\ m^{-3}$ PM10, PM 2.5 and PM1 respectively. The levels could be due to the frying of different eatables like potato and fish. On 18-10-2022 the mean levels are 183.39 ± 74.77, 116.71 ± 40.01, 96.25 ± 32.21 $\mu g\ m^{-3}$. On 19-10-2022 the levels are 179.43 ± 76.86, 112.73 ± 47.12, 90.67 ± 25.0 $\mu g\ m^{-3}$. The first two days were shown to be nearly equal when only vegetables were cooked. The coarser PM levels are 40% higher when fish frying and potato frying has happened. The Fig. 1 shows the timeseries of pollutants and the lower graphs is on 18-10-2022, middle graphs on 19-10-2022 and upper graphs on 20-10-2022.

3.2 Gaseous Matter Concentrations in Kitchen

3.2.1 TVOCs

The levels of TVOCs ranged from a minimum value of 464–4039 $\mu g\ m^{-3}$. The minimum value was observed on 18-10-22 when vegetables were cooked. The maximum values were observed on fish frying day. This might also be due to the use of a high amount of detergents to clean vessels and floors. The mean TVOCs of

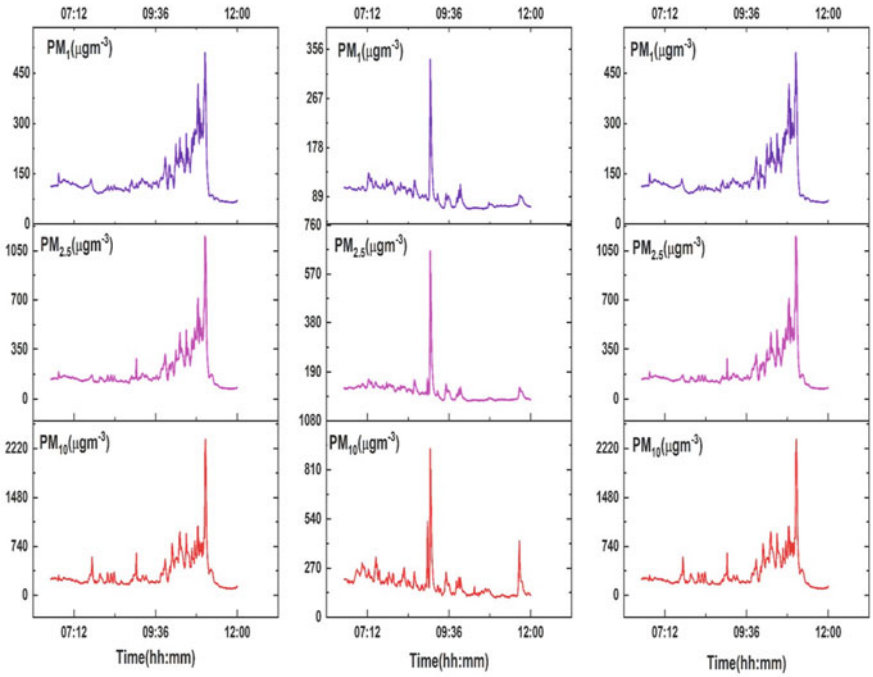

Fig. 1 Time series for PM from 18-10-2022 to 20-10-2022

1913 ± 910.84 µg m^{-3} were observed on 20-10-22. WHO guidelines 2010 suggest that 400 µg $m^{-3}$is the tolerable range of TVOCs.

3.2.2 Carbon Monoxide

The levels of the CO varied from a minimum of 4.5–90 mg m^{-3}. The mean levels on a peak day were 40.93 ± 19.45 mg m^{-3}. This shows the staff working there has minimum exposure to CO of 7 mg m^{-3} throughout their working hours as per WHO. Long term exposure of the limit can cause cardiac health.

3.2.3 Ozone

The levels of the O_3 varied from a minimum of 19.67 µg m^{-3} to maximum 365.48 µg m^{-3}. The mean levels on a peak day were 131.82 ± 85.42 µg m^{-3} which was above WHO guidelines 2010. The staff even reported sick building syndrome symptoms like eye irritation, burning.

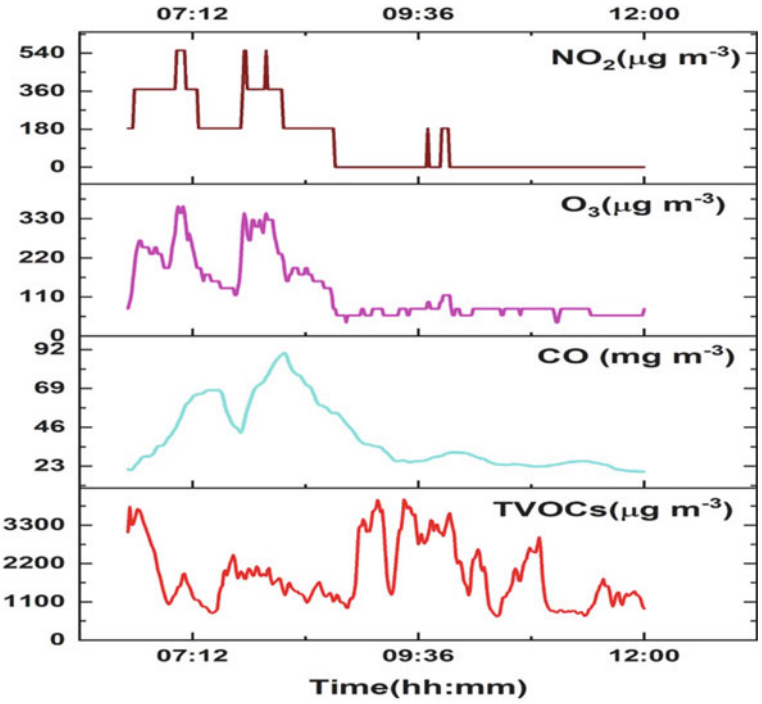

Fig. 2 Shows the time series of gaseous pollutants on peakday 20-10-2022

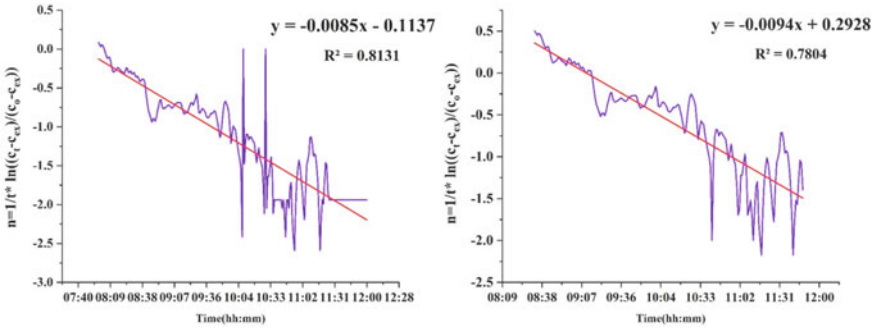

Fig. 3 Shows the decay curve on 18-10-2022 and 20-10-2022

3.2.4 Nitrogen Dioxide

The levels of the NO_2 varied from a minimum of 0 to 553.16 $\mu g\ m^{-3}$. The mean levels on a peak day were $125.66 \pm 160.32\ \mu g\ m^{-3}$. The NO_2 mean values exceeded thrice the annual average as per WHO which should be 40 $\mu g\ m^{-3}$. The NO_2 readings were not continuous; sometimes they are 0 and this could be because the instrument cannot

detect diffusion principle. This happened when ozone readings have come down. The below figure shows the variation of the typical variation of gaseous pollutants with time on a peak day 20-10- 2022.

3.3 Carbon Dioxide

The rate of change in the concentration of CO_2 depends on the concentration of CO_2 in the in-flowing air, the concentration of CO_2 in the out-flowing air, and the internal generation rate. The CO_2 concentrations during the entire study ranged from a minimum value of 310 ppm to a maximum of 1258 ppm, sometimes exceeding the ASHRAE standards 900 ppm.

3.3.1 Air Exchange Rate

The AER for the kitchen present just before the auditorium was calculated by the CO_2 decay test. The CO_2 readings were taken from the starting of the experiment and continued until the values reach the outdoor value or the constant value. The slope of the graph gives the AER value figure. Then the air change rate $n = (Q/V)$, is given by the logarithmic gradient of the tracer gas concentration curve, as follows:

From the above equation the decay rate for the kitchen is calculated. The AER value varied from 0.9944 to 0.9955 h^{-1}. The lowest value was observed on the highly polluted day i.e. 20-10-2022. Similarly, the VR varied from 0.8286 to 0.8295 lit/s/m^2 (area of the kitchen is 364.98 m^2). This VR has shown that buildings have fallen to category III i.e. high polluting buildings according to the ventilation rate for non-residential buildings (European Standard, EN 15251).

3.4 Comfort Parameters

The comfort parameters temperature varied from 30 to 32 °C which should be in the range of 20–23.6 °C for winter according to ASHRAE standards. The relative humidity varied from 80 to 83% which was supposed to be 30–65% that was also higher than ASHRAE standards.

3.5 Indoor Air Quality Index

The air quality index (AQI) is an index for reporting air quality on a daily basis. The AQI is based on the measurement of PM2.5 and PM10, O_3, NO_2, SO_2, CO, NH_3 and Pb emissions. These raw measurements are converted into a separate AQI

Table 2 Shows the IAQI for various days

DATE	PM10	PM2.5	CO	O_3	NO_2	IAQI	Responsible pollutant	IAQI category
18-10-2022	155	290	187	98	113	290	PM2.5	Poor
19-10-2022	153	276	175	92	118	276	PM2.5	Poor
20-10-2022	273	355	500	145	146	500	CO	Very severe

value for each pollutant using standard formulae developed. Sub-index function represents the relationship between the pollutant concentration X*i* and corresponding sub index I*i*. It may take a variety of forms such as linear, non-linear and segmented linear. Usually, segmented linear functions are used. The sub-index (*Ip*) for a given pollutant concentration (*Cp*) is calculated using the following equation (based on 'linear segmented principle'). The same AQI for ambient air is applied to indoors to find IAQI.

$$I_p = \frac{(Ihi - Ilo)}{BPhi - BPlo}(Cp - BPlo) + Ilo$$

BPhi Breakpoint concentration greater or equal to given concentration
BPlo Breakpoint concentration smaller or equal to given concentration
Ihi AQI value corresponding to *BPhi*
Ilo AQI value corresponding to *BPlo*

In the present study, the indoor air quality index was calculated on the basis of 5 criteria pollutants: PM10, PM2.5, CO, O_3, NO_2 shown in the table below. The health condition of the workers falls into the very severe to poor category [5].

4 Conclusion

The present study focused on determination of air exchange rate (AER), ventilation rate (VR) Q, and indoor air quality index (IAQI) for the community kitchen. The study was conducted for 3 days from 18-10-2022 to 20-10-2022. In this study, different pollutants like PM10, PM2.5, PM1, TVOCS, CO_2, CO, O_3, NO_2 were studied. Comfort parameters temperature and relative humidity were also monitored. The levels of all the pollutants were shown higher on 20-10-22 when cooking activities like frying potato, frying fish took place. All the values crossed WHO 2009 guidelines [1–3]. The AER value varied from 0.9915 to 0.9906 h^{-1}. The lowest value was observed on the highly polluted day i.e. 20-10-2022. Similarly, the VR varied from 0.8262 to 0.8254 lit/s/m^2. This VR has shown that buildings have fallen to category III i.e. high polluting buildings according to the ventilation rate for non-residential buildings [4]. The indoor air quality index (IAQI) calculated based on 5 criteria pollutants PM10, PM2.5, CO, O_3, NO_2 showed that the health condition of

the workers falls into the poor to very severe category [5, 6]. Both indexes indicate that the health becomes vulnerable to workers causing respiratory and cardiac issues.

The exhaust fans provided in the kitchen were not working. The working of the fans will definitely reduce the pollutants load. This will not only enhance indoor air quality but also enhances the comfort parameters RH, Temperature. The windows were kept open all the time and there are some table fans which were not on in winters. These table fans might be used during summers to maintain a comfortable temperature. A summer study might be useful to understand the indoor air quality and comfort parameters.

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Low-Cost Interventions that Reduce Particle Levels Indoors Are Viable Options to Enhance the Operating Efficiency of Occupants

Shubham Rathi, Anubha Goel, and Deepshikha Ola

Abstract Indoor Air Quality (IAQ) is now well recognized as impacting employee work efficiency. Poor indoor air quality can lead to productivity problems and absence from work. To examine IAQ conditions inside offices in an academic institute, IIT Kanpur, real-time monitoring of particulate matter (PM) was conducted during office hours (10 am to 5 pm). Particulate levels inside five offices on different floors of a multi-storeyed building were monitored over three consecutive days. All offices are on the same side of the building and have 3–6 permanent staff each. Office occupants were given a questionnaire survey to obtain feedback on health-related discomfort indoors (sleepiness, headache, and eye irritation). Only one location (Office A on the first floor) marginally met the current WHO guidelines for PM_{10} (45 $\mu g/m^3$), and all others far exceeded it. At least one-fifth of the staff in the four offices that do not meet the WHO guidelines complained about health-related discomfort. Mass (due to PM_{10}) retained in the trachea-bronchi (TB) of the lungs of office (these four) occupants (using the Multiple-Path Particle Dosimetry (MPPD) model) was 50% (average) higher than that in the case of staff in office A. The office with the highest number of printing appliances shows the highest concentration of fine-particulate matter (PM_1) and confirms the influence of indoor sources on IAQ. Air purifiers are low-cost interventions that can improve IAQ. Achieving the WHO guidelines inside offices will reduce particle mass retained on the TB up to a staggering 56%. Meeting guidelines may increase the efficiency of workers in these offices by 12–45%.

Keywords Health-benefit analysis · Indoor-air quality · Questionnaire survey · MPPD · Office spaces

Shubham Rathi—Presenting author

S. Rathi · A. Goel (✉)
Indian Institute of Technology Kanpur, Kanpur, UP, India
e-mail: anubha@iitk.ac.in

D. Ola
University of Cincinnati, Cincinnati, OH, USA

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1 Introduction

Years of research have shed significant light on the relationship between indoor air quality (IAQ) and ventilation in offices worldwide. The link of good IAQ to occupant productivity, health, and well-being is now well-accepted [2, 5, 11]. Offices with poor indoor air quality have been linked to sick building syndrome symptoms (SBS). In such cases, employee discomfort, dissatisfaction with the perceived air quality, and reduced performance [1, 10, 12] have been recorded. Most studies have examined the IAQ inside schools, and information about the situation inside offices in academic institutions in India is limited. This preliminary study was conducted on the academic campus of IIT Kanpur in India to gain knowledge of particle distribution indoors and estimate health benefits by meeting the required guidelines. Indoor locations frequented by staff and students were selected. This study's findings will be expanded to implement suggested interventions at identified indoor hotspots, which will be followed by monitoring the effectiveness of mitigation measures.

2 Methodology

The six-story Faculty Building (FB), which has the maximum number of offices inside the academic area of the IIT Kanpur campus, was selected for our study. In April 2019, a questionnaire survey in offices and real-time air quality monitoring was conducted. Data collected on particulate matter levels indoors was analyzed for particle deposition fraction inside the lungs using the MPPD model. This section provides information with the details, data analysis, and modelling parameters.

2.1 Sampling Site Description

In the current study, five offices in the FB spread across four floors represent today's common office types and have been numbered alphabetically (Office A on the 1st Floor to Office E on the 6th floor). Office types vary from small (faculty offices) to large (departmental and Sectional offices). All the selected offices are located on the same side of FB and were selected based on occupant agreement for the study. Permanent occupancy and floor area are also listed in Table 1. Sampling details are noted in the next section.

The movement of people inside departmental offices, mainly students, faculty, and staff, is continuous throughout the sampling period and varies over 40–60 people per day apart from permanent staff. The only faculty room in this study, Office C, with the least floor area, had minimal visitors during the sampling period (around 5–10 people). Commercial printers and photocopiers were placed inside all the offices and were used regularly except Office C, which had a small personal printer. Windows

Table 1 Office details and occupancy

Office names	A	B	C	D	E
FB floor number	1st	3rd	3rd	4th	6th
Office type	Section office	Departmental office	Faculty office	Departmental office	Departmental office
Floor area (m^2)	61.31	44.13	23.23	29.26	55.56
Permanent occupancy (#)	6	5	3	4	5

were closed in all offices during the sampling period. However, departmental offices had a higher frequency of opening and closing doors.

2.1.1 Instrumentation for Measurement of Indoor Air Quality Parameters

Real-time measurements of size-segregated particle mass concentration (PM_{10}, $PM_{3,}$ and PM_1) in the selected offices using an Optical Particle Sizer (OPS, Maker: TSI, Model: 3330). The sampling inside offices was done in April 2019 for 7 h (10 am to 5 pm) over three days in each case.

2.2 Questionnaire Survey to Assess Occupants' Perception of Their Environment

The questionnaire survey (QS) is an effective and efficient method of learning how the occupants perceive indoor conditions, including thermal comfort and IAQ [6, 11]. The QS focused on how people experienced offices and asked about symptoms people generally experience inside a "sick building" (headaches, eye irritation and sneezing) [8]. The QS was distributed to employees and visitors during the study period.

2.3 MPPD Modelling for Particle Deposition in TB Region of Lungs

The Eulerian Multiple Path Particle Dosimetry or MPPD model (version 3.04) was used to calculate the percent change in the mass of coarse particulates deposited in the human respiratory system's Trachea Bronchi (TB). The Chemical Industry

Institute of Toxicology and the Dutch National Institute for Public Health and the Environment developed this model.

We adopted the human age-specific symmetric lung model to calculate particle deposition in the TB region. The exposure scenario for an employee sitting in an office for 7 h (10 am to 5 pm) for one day was considered. The model was applied to respirable particulates with a density of 1.4 g/cm^3, and a geometric standard deviation (GSD) of 3.00 was assumed. The default parameters selected for the model of an adult at rest [i.e., upright body orientation, respiratory frequency of 12 breaths min^{-1}, functional reserve capacity (FRC) of 3300 mL, upper respiratory tract (URT) volume of 50 mL at a fixed tidal volume of 625 mL, the inspiratory fraction of 0.5, and nasal route breathing].

3 Results and Discussion

3.1 Trends in Particle Mass Distribution Inside Offices (PM_{10}, PM_3, and PM_1)

Table 2 displays the typical particle mass concentration inside each office. The average concentration for PM_{10}, PM_3 and PM_1 particles exhibits the following trend:

In terms of floor level: fourth > sixth > third > first. OR
In terms of Office name: D > E > C > B > A

PM_{10} concentration only in Office A was within the acceptable range. It was below (marginally) the (World Health Organisation) WHO-recommended indoor limit of 45 μg/m^3. Office D, where the PM levels were twice as high as Office A, had the highest PM_{10} concentration. For the two locations on the same floor (third), the smaller faculty office with the least number of visitors, Office C, had average PM_{10}

Table 2 Peak and average (±SD) particles levels inside office spaces (all values are in μg/m^3)

	Office	**A**	**B**	**C**	**D**	**E**
PM_{10}	Peak	96.99	145.83	123.49	190.82	193.12
	Avg	44.61 ±16.37	55.20 ±16.24	62.85 ±17.79	101.43 ±23.77	71.94 ±20.01
PM_3	Peak	21.21	29.46	24.20	37.11	31.74
	Avg	14.26 ±2.31	18.77 ±4.26	19.96 ±1.55	26.23 ±4.05	21.17 ±2.02
PM_1	Peak	8.56	11.79	9.70	3.1	11.86
	Avg	4.42 ±1.65	7.23 ±2.37	8.99 ±0.21	2.48 ±0.31	6.64 ±1.97

levels higher than those in Office B, the departmntal office. However, in Office B, a higher peak concentration was seen. In Offices B and C, the observations for PM_3 and PM_1 were similar. The lowest average fine particle PM_1 levels were in Departmental Office D on the fourth floor, with the fewest permanent employees. This office also had the highest levels of respirable and coarser particles.

Dominant particle size bin. Particles in size bin 5.5–7 μm contribute more inside Offices A, C, and D, while the next size bin, 7–10 μm, is dominant inside Offices B and E.

The lower particle ratios of PM_3/PM_{10} and PM_1/PM_{10} in offices on upper floors D and E, relative to other offices, are likely due to this trend in coarser particle levels. These ratios indicate that the mass concentration in all the offices was significantly influenced (66–73%) by the quasi-coarser particles (PM_{3-10}) [9]. In all the offices, the contributions to PM_{10} by respirable (PM_3) was <15% (range: 2.5–15%), and by fine (PM_1) particle, it was <35% (26–34%).

Influence of occupant activity on particle levels. Other than fines, the concentration of particles is susceptible to resuspension by occupant movement or activity, leading to peaks in particle levels. In contrast, the occupants' activity does not impact the concentration of submicron particles. These particles enter the building from the outside or are released from office equipment.

Our findings are consistent with the study, which found that the submicron particle (PM_1) is less likely than PM_{1-3} and PM_{3-10} to be resuspended by occupant activity [7]. The authors looked at how the walking patterns of staff affected the resuspension of particulate matter (0.5–5 μm) inside an experiment chamber. Compared to particles with a diameter larger than one μm, the resuspension of particles in the size range of 0.5–1.0 μm was minimal [7].

3.2 Deposition of Coarse Particles in Lungs (TB) Attributable to Particle Exposure Inside Offices

Table 3 shows the particle mass (mg) retained in employees' lungs due to exposure to PM_{10}. The mass retained correlated with PM_{10} values and was highest for Office D and least for Office A. The four offices (B–E) that do not meet WHO guidelines have an average of 50% more particle deposition in lungs (TB) compared to office A, which marginally met the guidelines. The level of coarse particle mass in the lungs directly correlates with cases of headache reported in the questionnaire response by office occupants. It was the least for Office B, one in five employees (20%) to the maximum in Office D, three in four employees (75%).

Table 3 Coarse particle mass retained in the employees' lungs (TB) and number of employees experiencing the headache

Office	A	B	C	D	E
PM_{10} particles retained in TB region of lungs (mg)	0.00215	0.00245	0.00280	0.00450	0.00315
Employees experiencing headache (ratio)	0/6	1/5	1/3	3/4	2/5

Table 4 Change in coarse particle mass on lungs (TB) and employees' efficiency if WHO guidelines met

Office	B	C	D	E
Reduction in coarse particle mass on lungs (%)	18.48	28.40	55.63	37.45
Employees' efficiency improved (%)	12	20	45	24

3.3 Meeting WHO Guidelines, Change in Coarse Particle Deposition in Lungs (TB), and Employees' Efficiency

Table 4 shows that if indoor air quality is maintained at WHO guidelines levels, then coarse particle mass (PM_{10}) retained on the TB region of the lungs could be reduced by a staggering 56% (Office D) to 18% (Office B). Researchers have examined the influence of improved indoor air quality and suggest that healthy air quality directly contributes to staff performance. In this study, removing headache issues experienced by employees within the offices will improve work productivity. The employee working in a better (headache-free) environment can perform around 60% better in cognitive tasks [4], which may improve the efficiency of the offices by 12% (Office B) to 45% (Office D).

We suggest using simple air purifiers to reduce air pollution and maintain the WHO guideline levels indoors. Air purifier costs average around 6000–14,500 INR in the local market [3].

4 Conclusions

Particle levels inside most offices in this study are higher than indoor guidelines set by WHO. The departmental offices observed frequent quasi-RSPM (Respirable Suspended Particulate Matter) and coarser PM peaks. Personnel movement indoors is the likely cause which does not seem to affect fine particle concentration, which remained almost steady. Particle deposition inside the lungs can be drastically reduced by meeting the IAQ guidelines marginally. Using air filters is low-cost and a viable intervention that can be implemented quickly. Spending little money (air filters) on improving the office's indoor air quality can drastically improve work

efficiency. Furthermore, It is crucial to assess the ventilation condition inside offices on campus to understand better factors impacting IAQ.

During the QS, it was noted that few respondents were familiar with IAQ concepts or were aware of Sick Building Syndrome, which was a significant finding. IAQ significantly negatively impacts people's health and productivity at work. Efforts should be made to inform and raise public awareness of the causes and dangers of SBS and poor air quality.

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Quantification of Dynamic Ventilation Rates and Assessment of Occupant Thermal Comfort Inside a Naturally Ventilated Hostel Room During Wintertime in North India

Supreme Jain, Asmita Addya, and Anubha Goel

Abstract Ventilation rates significantly impact indoor thermal comfort and air quality. In this study, a week-long field measurement was conducted in a hostel room with natural ventilation on the academic campus of IIT-Kanpur, India. Indoor air temperature (T_a) and CO_2 concentration were monitored continuously in the single-occupant room during wintertime in January 2022. We evaluated the data for dynamic ventilation rates (VRs) and the relationship between air exchange rates (AERs) and thermal comfort inside the room. Considering CO_2 released by occupants as a tracer gas, the tracer gas decay method is applied to measure CO_2 concentrations for daytime and night-time decay episodes. The dynamic VRs vary from 1 to 19 L/s per person (AER—0.14–2.67 h^{-1}). The daytime VRs were approximately 45% higher than night-time. The predicted thermal conditions in the hostel room (using PPV/PMV model) were uncomfortable for approximately 22% of the total time, mainly during the night and early morning hours. A neutral temperature of 22.7 °C and a comfortable temperature range of 20.6–24.6 °C were determined (T_a = 18.6–24.8 °C). The difference between $AER_{comfortable}$ (0.14–2.67 h^{-1}) and $AER_{uncomfortable}$ (0.31–2.66 h^{-1}) was not statistically significant ($p > 0.05$). This suggests that AER is not a prominent factor affecting thermal comfort during winter in the hostel. The high diurnal variation observed in VRs highlights the need for dynamic measurement that reflects the actual dynamic characteristics. Information obtained will help plan interventions and design toward achieving better thermal conditions in the hostel environment.

S. Jain · A. Addya · A. Goel (✉)
Indian Institute of Technology, Kanpur, India
e-mail: anubha@iitk.ac.in

S. Jain
e-mail: supreme@iitk.ac.in

A. Addya
e-mail: asmitaa20@iitk.ac.in

A. Goel
CK Centre for Environmental Policy and Climate Studies, IIT, Kanpur, India

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Keywords Dynamic AER · Ventilation rate · Thermal comfort · PMV/PPD · Hostel · India · Winter

1 Introduction

Ventilation, the process of exchanging indoor air with outdoor air, removes and dilutes contaminants present indoors, leading to comfortable and healthy indoors for the occupants. It creates optimal conditions of indoor environments conducive to better work productivity. Proper ventilation is recognized as one of the most effective ways to minimize pollutant accumulation or reduce pollutants' residence time indoors, lessening the chances of sick building syndrome (SBS), which negatively affects the occupants' well-being [25]. Air exchange rate (AER), the rate at which outdoor air enters an indoor space, divided by its volume, is a standard metric to measure the ventilation rates of indoor spaces (For more details on the calculation of AER, refer to Persily [15] and McNeill et al. [20]. Ventilation can be accomplished by mechanical or natural means or a combination of both (mechanical + natural). In mechanical ventilation (MV), ventilation is achieved by using heating, ventilating, and air conditioning (HVAC) systems, which are energy-intensive and have high maintenance costs. However, natural ventilation (NV) is achieved through infiltration and is affected by occupant behaviours like opening windows and running exhaust fans. The AER in MV spaces is generally constant and is not impacted by outdoor meteorological conditions (such as outdoor temperature, wind speed, and wind direction). In contrast, AERs in spaces with NV depend on factors such as outdoor meteorological conditions, building characteristics, location of openings indoors (doors, windows), and architectural elements. Dependence on multiple factors results in frequent changes of AER in NV spaces and makes it dynamic.

Occupant satisfaction with the indoor thermal environment is another crucial parameter to maintaining comfort indoors. As per ISO 7730-1984, thermal comfort is "the condition of the mind that expresses satisfaction with the thermal environment." Indoor environmental parameters greatly influence it, including air temperature, relative humidity, mean radiant temperature, and air speed. The other factors that affect thermal comfort are occupants' activity level and clothing insulation [5]. Different studies in indoor spaces reported that thermal comfort positively impacts occupants' comfort, well-being, and productivity [11, 13, 22]. Studies also reported the association of indoor thermal comfort with ventilation [6, 18, 23].

The hostel buildings differ from office and residential dwellings in scale, use patterns, and diversity of activities. Considering that the young age group occupies hostels, study, sleep, and leisure are primary activities. With this background, of concern is the expected addition of over 3 million new seats at the higher education level in India by 2035, which implies that there will be an increase in hostel buildings for students soon. The rise in the number of seats is in keeping with the Higher education outreach in India is a primary goal of the National education policy 2020 [4]. Knowledge of AER indoors under real-world conditions to effectively manage

indoor air quality and evaluate the convenience of the occupants is essential. Prevalence of poor ventilation rates and thermal discomfort will lead to increased SBS symptoms, affecting occupants' health, productivity, and comfort [3, 7, 21].

The main objective of the current study is to investigate variations in the air exchange rates during different times of the day in a naturally ventilated hostel room and assess occupant thermal comfort using a PMV/PPD model. Week-long real-time sampling was conducted from January 5th to January 11th, 2022, inside an NV hostel room at IIT Kanpur. Data was used to determine the VRs (ventilation rates) and their association with indoor environmental parameters. The results from the current study help assess the conditions inside rooms during wintertime. The researchers, architects, administrators, and building managers will have data to plan effective mitigation measures towards a healthy hostel room with comfortable conditions for hostel residents.

2 Methods

2.1 Site Description

We conducted the sampling campaign inside the room of a six-story hostel situated inside the residential campus of IIT Kanpur, India. The sampling was conducted continuously for 136 h from January 5th to January 11th, 2022. The room was situated on the 6th floor, about 20 m above the ground level. The dimension of the room was 3.1 m × 2.7 m × 3.1 m (floor area = 8.37 m^2, volume = 25.95 m^3), with a single door (2 m × 0.8 m) and a single window (1.2 m × 0.8 m) on the opposite wall. The window and door were closed during the sampling campaign, and infiltration was the only mechanism for exchanging indoor air with outdoor air. The infiltration occurs when outdoor air penetrates the indoor environment through unintended openings in the building structure due to pressure and temperature differences between outdoors and indoors. The door was opened briefly only when the occupant left or entered the room. The occupant used a small room heater during the sampling campaign. The room heater continuously ran for 16 h (from 10:00 to 02:00 am) and was turned off for 8 h (02:00–10:00 am).

2.2 Instrumentation

We used Testo 480, the data recorder with probes, to measure the indoor air quality factors (air temperature, relative humidity, airspeed, globe temperature, and CO_2) inside the hostel room. The measuring interval of the instrument was set at one minute. The measuring probes were mounted on a tripod stand 1.5 m above the floor level (the occupant's breathing zone). The probes were placed at a location

causing the least disruption to the daily activities of the occupant. During the sampling campaign, the occupant maintained a record of her actions, mainly room occupancy and non-occupancy hours.

2.3 Calculation of Air Exchange Rate (AER) and Minimum Required Ventilation Rate

The tracer gas decay method, based on CO_2 levels measured inside the room, was utilized to compute the AER for the various CO_2 decay episodes occurring inside the hostel room. Only those decay episodes when the room was unoccupied were considered for calculating the ventilation rate. The outdoor concentration of CO_2 (average) was taken as 310 ppm for calculating AER for different periods. We used a single zone mass balance method for calculating AER. The technique involves a linear regression on the log-transformed concentration difference between the indoor and outdoor CO_2 concentrations during the decay period [15]. The linear regression slope represents the value of AER of that decay period. Linear regressions with a value of determination coefficient less than 0.9 were not considered in this study. After calculating AER, we calculated the ventilation rate from Eq. (1).

$$\text{Air exchange rate } \left(h^{-1}\right) = \text{Ventilation rate } \left(m^3/h\right)/\left(\text{Volume of space } \left(m^3\right)\right) \quad (1)$$

The minimum required ventilation rate for acceptable IAQ was calculated using Eq. (2) [2].

$$V = \left(R_p * P_z\right) + \left(R_a * A_z\right) \quad (2)$$

where V is the minimum required ventilation rate at the breathing zone (in L/s), A_z is the room floor area (8.37 m^2), P_z is the number of people in the ventilation zone (1), R_p is the outdoor air flow rate required per person (L/s person), and R_a is outdoor air flow rate needed per unit area (L/s m^2). ASHRAE standard 62.1 was referred to for values of R_p (2.5 L/s person) and R_a (0.3 L/s m^2) for the hostel room.

2.4 Thermal Comfort Analysis

The thermal comfort analysis was based on the model developed by Fanger [8, 22]. The model predicts the thermal sensation of the people and their dissatisfaction percentages with the indoor thermal environment. It is expressed through two different indices, i.e., the expected mean vote (PMV) index and the predicted percentage dissatisfied (PPD) index. This model is also known as the PMV-PPD

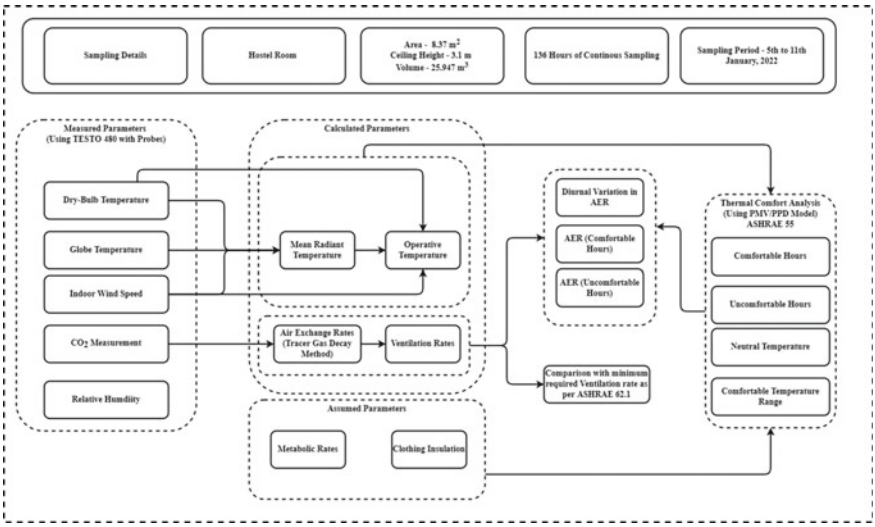

Fig. 1 Flow chart of the present study

model and is mentioned in ASHRAE standard 55. The PPD and PMV were calculated using an online tool based on the PMV-PPD model for thermal comfort analysis (CBE thermal comfort tool). The Centre for the Built Environment, University of California, Berkeley, USA, has developed the tool [26]. The CBE tool calculates PMV and PPD for indoor thermal environments. It takes the following variables as input data, indoor air temperature (°C), mean radiant temperature (°C), airspeed (m/s), relative humidity (%), the metabolic rate of the occupant (met), and clothing insulation level of the occupant (clo).

The research outline of the present study is presented as a flow chart in Fig. 1.

3 Results and Discussion

3.1 Indoor Environmental Parameters Inside the Hostel Room

The CO_2, indoor air temperature, relative humidity, indoor air speed, and globe temperature were monitored continuously for 136 h (1-min resolution) inside the hostel room. Globe temperature measures the combined effect of radiant heat, air temperature, and wind speed on human comfort. The indoor air temperature varies from 18.6 to 24.8 °C (22.1 ± 1.6 °C), whereas relative humidity ranges from 59.5 to 77.7% (67.5 ± 4.1%). The globe temperature varies from 18.7 to 24.6 °C (22.0 ± 1.5 °C), and the indoor air speed was less than 0.2 m/s during sampling hours.

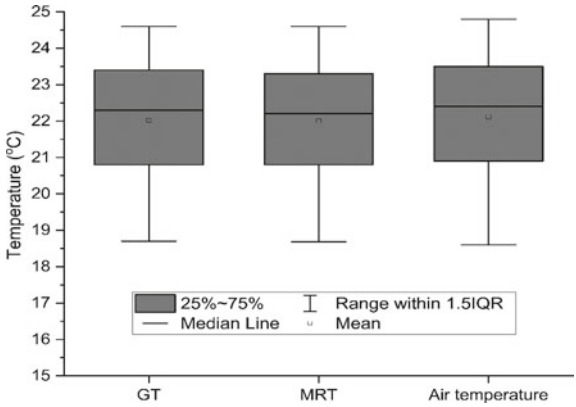

Fig. 2 Box plots of globe temperature (GT), indoor air temperature, and mean radiant temperature (MRT) during the sampling campaign

The average temperature of the surfaces surrounding a body is measured by its mean radiant temperature (MRT) and calculated using the following Eq. (3).

$$\mathrm{MRT} = [(\mathrm{GT} + 273.15)^4 + \left(2.5 * 10^8 * v_a\right)(\mathrm{GT} - T_a)]^{1/4} - 273.15 \qquad (3)$$

where GT is the globe temperature measured using the globe thermometer (°C), v_a is the indoor air speed (m/s), and T_a is the indoor air temperature (°C). The MRT was similar to GT and varied from 18.6 to 24.6 °C (22.0 ± 1.5 °C). Figure 2 represents the box plot of globe temperature (GT), mean radiant temperature (MRT), and indoor air temperature. Distributions for the three are similar.

The CO_2 concentration varies from 310 to 1022 ppm (453.6 ± 82.2 ppm) inside the hostel room. Figure 3 depicts the variation in CO_2 concentration during the sampling period.

3.1.1 Association Among Measured Indoor Parameters

The correlation (Pearson) among the measured parameters was also analysed and listed in Table 1. The correlation matrix (Table 1) clearly shows a lack of a significant statistical correlation among the indoor measured parameters.

3.2 Air Exchange Rate Inside the Hostel Room

Using metabolic CO_2 as a tracer gas, we calculated the AER for all the decay periods during the sampling hours. Decay episodes where CO_2 concentration was decaying during the non-occupancy hours totalled 35. Individual AERs for decay periods and time-weighted average (TWA) AER were also calculated. The TWA AERs were calculated with the following Eq. (4).

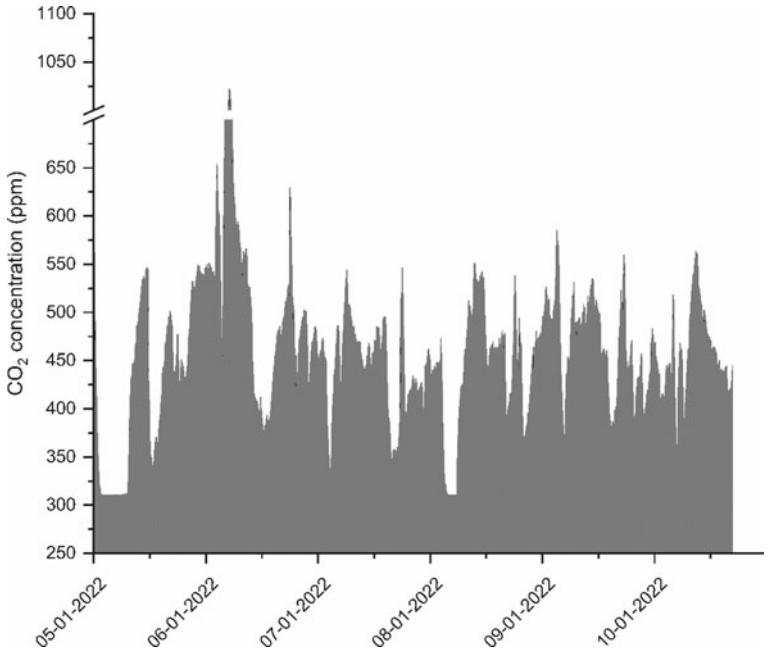

Fig. 3 Variation in indoor CO_2 concentration (ppm) during the sampling campaign

Table 1 Pearson correlation matrix between the indoor environmental parameters measured during the sampling campaign

	Air speed	CO_2 concentration	Relative humidity	Air temperature
Air speed	1.00			
CO_2 concentration	0.08	1.00		
Relative humidity	−0.16	−0.02	1.00	
Air temperature	0.10	0.15	−0.66	1.00

$$\text{TWA} = \frac{\sum_{i=1}^{n}(\text{AER}_i * T_i)}{\sum_{i=1}^{n} T_i} \tag{4}$$

where AER_i is the AER calculated for individual decay episodes, and T_i is the total decay time for that individual AER.

3.2.1 AER for Different Decay Episodes and Daily TWA AER

In the case of a non-occupied room, the AER varies from 0.14 to 2.67 h^{-1} for different decay periods ($n = 35$) during sampling hours. (Fig. 4). The daily range of AER_i is listed in Table 1. The TWA for daily AER varied from 0.23 to 2.66 h^{-1} for different

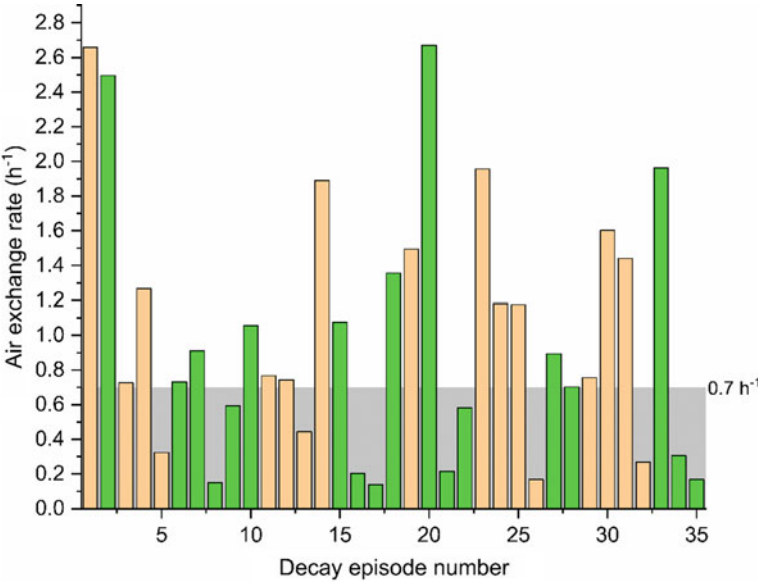

Fig. 4 Values of AERs for different decay episodes during the sampling campaign (Green bar—Night-time, Orange bar—Daytime)

sampling days ($n = 7$) and is listed in Table 2. The minimum required ventilation rate was calculated from Eq. 2 as 5.01 L/s (AER = 0.7 h^{-1}). The measured AERs were compared with the minimum required ventilation rate calculated from the ASHRAE standard 62.1 for the hostel room. Out of the total 35 AERs values, 1/3rd of the AER values fall below the minimum required AER of 0.7 h^{-1} during the sampling period, as shown in Fig. 4. However, in the case of TWA for daily AER, all sampling days, except day 7, had AER values greater than 0.7 h^{-1}, highlighting sufficient ventilation conditions. The AERs also do not meet the requirements prescribed in the National Building Code of India, which prescribes an AER value of 3 h^{-1} for rooms.

Poor ventilation conditions are related to sick building syndrome (SBS), which is well understood now. SBS describes the situations in which building occupants experience health problems such as headache, fatigue, irritation of the eyes, nose, and throat, and dry/itchy skin when they spend time in the indoor environment [12]. The symptoms, although not life-threatening, can be very unpleasant and disruptive, causing lost work time, reduced productivity, and increased discomfort [17, 24, 27]. SBS has been attributed to personal, psychosocial, and environmental factors. These symptoms are often related to poor indoor air quality, caused by various factors, including indoor chemicals, microbial contaminants, building air tightness, and dampness in the house [10, 14, 16]. Fisk et al. [9] conducted the study inside a climatic chamber. They reported that the relative prevalence of acute health symptoms (SBS) increases by 23% on the reduction of the VRs from 10 to 5 L/s per person. It decreases by 29% on improving the VRs from 10 to 25 L/s per person.

Table 2 Decay episodes considered in this study during the sampling period, daily variation in individual AERs, and TWA daily AER

	No. of decay episodes	Individual AER range (h^{-1})	TWA daily AER (h^{-1})
Day 1	1	2.66	2.66
Day 2	7	0.15–2.45	0.87
Day 3	8	0.44–1.89	0.74
Day 4	4	0.14–2.67	1.26
Day 5	7	0.17–1.96	0.79
Day 6	6	0.27–1.96	0.93
Day 7	2	0.17–0.31	0.23
Min	1	0.14	0.23
Max	8	2.67	2.66

Sundell et al. [25], in their comprehensive review of ventilation rates and health, concluded that AER in homes above 0.5 h^{-1} is associated with a reduced risk of allergic manifestations among children. Other studies also suggest similar findings that with the decrease in VRs, the prevalence of SBS increased among the occupants [3, 19, 28].

3.2.2 Comparison Between TWA and Individual AERs

We took up the case of Day 3 to compare individual AERs and TWA AER. The TWA for day 3 was 0.74 h^{-1}, greater than the minimum required AER, highlighting sufficient ventilation conditions. However, two of 8 individual AERs were less than 0.7 h^{-1}, which highlights poor ventilation conditions during day 3. The time period when the ventilation conditions are poor for the occupants cannot be emphasized through an averaging data parameter like TWA or by instantaneous AER value measured during a single time of the day. Similar observations were noticed on other sampling days, i.e., the daily TWA AER values implied sufficient ventilation conditions in the room but could not highlight the time when ventilation conditions were insufficient and less than 0.7 h^{-1}.

Implication. The daily TWA value or any other single value cannot give a clear picture of the natural ventilation conditions inside a room. The wide range of AER calculated for respective decay periods highlights that ventilation conditions are dynamic or values of AER for different decay episodes are not constant. So, the single value for a day (i.e., daily TWA) may not represent the ventilation conditions in the hostel room.

The data collected through continuous monitoring for AERs will help the building administrator to convey the results to the occupants so they will be aware of the dynamic behaviour of ventilation conditions. Identification of the period when the

ventilation conditions are insufficient will enable occupants or building administration to take possible mitigation measures to enhance the ventilation conditions at that time.

3.2.3 Diurnal Variation of AERs and TWA Diurnal AER

We calculated AER for respective decay periods and TWA AER for two periods, i.e., daytime (DT, 0800–1800 h) and night-time (NT, 1800–0800 h). The number of episodes was 17 during DT and 18 during NT. The AER ranges were 0.17–2.66 h^{-1} (DT) and 0.15–2.67 h^{-1} (NT). Figure 4 represents AER values for decay episodes of DT (orange-coloured bars) and NT (green-coloured bars). Table 3 lists the daily individual AER and TWA ranges for DT and NT.

The events where AER values are less than 0.7 h^{-1} can be classified as 'unacceptable.' Such events were about 25% during DT (4 out of 17) and increased to about 45% during NT (8 out of 18). The mean of TWA AERs during DT (1.27 h^{-1}) was approximately 45% higher than NT (0.79 h^{-1}). The results highlighted that occupants are more exposed to poor ventilation conditions during night-time. As discussed in the earlier section, the daily TWA AER for DT and NT does not show the time at which the occupants are exposed to poor ventilation conditions. Continuous monitoring, which permits the calculation of AERs at different periods, facilitates the procurement of this information.

Table 3 Time-weighted daily AERs, individual AERs, and number of decay periods considered during daytime (DT) and night-time (NT) sampling hours

	Daytime			Night-time		
	No. of decay episodes	Individual AER range (h^{-1})	TWA AER (h^{-1})	No. of decay episodes	Individual AER range (h^{-1})	TWA AER (h^{-1})
Day 1	1	2.66	2.66	NA	NA	NA
Day 2	3	0.32–1.27	0.71	4	0.15–2.50	0.92
Day 3	4	0.44–1.89	1.02	4	0.20–1.10	0.53
Day 4	1	1.50	1.50	3	0.14–2.67	1.21
Day 5	4	0.17–1.96	0.93	3	0.22–0.90	0.65
Day 6	4	0.27–1.60	0.78	2	0.70–1.96	1.20
Day 7	NA	NA	NA	2	0.17–0.31	0.23
Min	1	0.17	0.71	2	0.14	0.23
Max	4	2.66	2.66	4	2.67	1.21

3.3 Thermal Comfort Analysis

The PMV-PPD model was used to analyse the thermal comfort inside the hostel room. The PMV is an index that aims to predict the mean value of the thermal sensation votes on a 7-point thermal sensation scale expressed from −3 to +3. On the other hand, PPD is an index that establishes a quantitative relationship with the PMV and predicts the percentage of thermally dissatisfied people inside any indoor microenvironment. The CBE thermal comfort tools give the value of PMV and PPD as output parameters.

CBE Thermal comfort analysis tools used measured indoor parameters (air temperature, speed, and relative humidity) that were input parameters along with MRT, metabolic rate, and clothing level. A metabolic rate of 1 met and clothing insulation level of 1.3 clo was assumed based on the data provided by the resident for activities and clothing [1].

The PMV and PPD values from the sampling periods were critically analysed to find the comfortable hours (time at which the PMV lies between −0.5 and +0.5 and PPD is less than 10%) and uncomfortable hours (time at which PMV does not lie between −0.5 and +0.5 and PPD is greater than 10%). Data analysis permitted the calculation of the value of the neutral temperature of 22.7 °C (PMV = 0) and a comfortable temperature range of 20.6–24.6 °C. The PMV values varied from −0.56 to +0.88 (0.26 ± 0.36), whereas PPD values varied from 5 to 21.3 (9.24 ± 4.15). Figure 5 depicts the values of PMV during the sampling hours. The PMV data revealed that the thermal conditions in the hostel room were unfavourable for roughly 22% (30 h) of the total sampling time, both during DT and NT. PMV values greater than +0.5 times (PPD > 10) were reported. Because of the constant use of the heater indoors, the indoor temperature was higher than the comfortable range band.

Implication. The results highlighted that the utilization of heating systems to attain thermal comfort indoors could also cause the space to become overheated, resulting in a thermally uncomfortable environment.

3.4 AERs During Thermally Comfortable and Uncomfortable Hours

In this section, we cover the results of thermal comfort analysis from the PMV-PPD model and its association with the AER. The AERs for thermally comfortable and uncomfortable hours were grouped into two categories. The decay episodes that fall under the thermally comfortable region are categorized as $AER_{c.}$ In contrast, AER that falls into a thermally uncomfortable environment is called AER_{uc}. A quarter, or 1/4th, of measured AERs, fall into the thermally uncomfortable category. The AER_c ranged from 0.14 to 2.67 h^{-1} ($n = 26$), whereas AER_{uc} varies from 0.31 to 2.66 h^{-1} ($n = 9$). Approximately 38% ($n = 10$) of AER_c values fall under 0.7 h^{-1} suggesting *poor ventilation* conditions with a thermally comfortable environment.

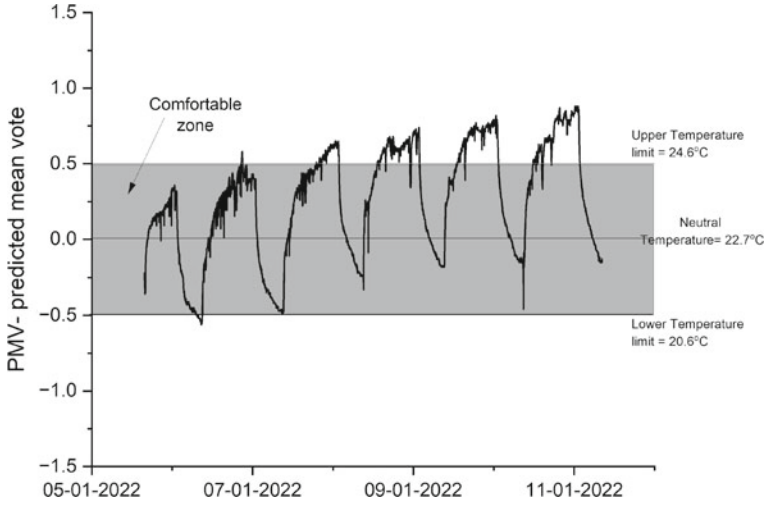

Fig. 5 Predicted PMV values during sampling hours (The grey zone shows the comfort zone with a Comfort temperature range = 20.6–24.6 °C and neutral temperature = 22.7 °C)

In contrast, 80% of the AER_{uc} values had *sufficient* ventilation conditions during the sampling period. The mean difference between AER_c and AER_{uc} was not statistically significant (independent samples *t*-test, $p > 0.05$).

The above observations highlight that thermal comfort can be achieved even in poor ventilation conditions. Similarly, sufficient ventilation conditions can be achieved in a thermally uncomfortable environment. So, during wintertime, AERs may not be an influencing factor that affects thermal comfort.

4 Conclusions

We continuously measured the indoor environmental parameters and CO_2 concentration inside the hostel room for more than 136 h during wintertime. It was observed that

- The range of individual AERs varied widely, approximately 33% of the time; the VRs were found to be less than the minimum required AER, highlighting poor ventilation conditions inside the room at different times.
- The AERs in the hostel room does not meet the requirement mentioned in the National building code of India.
- No significant statistical correlation between indoor measured parameters was observed during the sampling campaign.

The results, when examined holistically, suggest the following implications.

- Knowledge of cases when AER < minimum required will help the occupants or building managers to make data-driven decisions to improve ventilation conditions.
- The TWA of daily AERs provides values that show sufficient ventilation conditions in the room. However, it does not indicate poor ventilation conditions (when VR < minimum required) when increased airflow is needed. The use of dynamic monitoring and examination of individual AERs revealed periods of poor ventilation conditions.
- AER may not be the factor affecting thermal comfort inside the hostel room in winter.
- The discomfort hours were more than 20% of the total sampling time, mainly during the night-time and early morning hours. The difference in AER values during thermally comfortable and uncomfortable hours was not statistically significant, and AER may not affect thermal comfort inside the hostel room. Further studies in seasons other than winter are needed.

  There is a need to examine the relationship between ventilation rates and health.

5 Limitations of the Study

The present study was conducted in a single hostel room, and AER was measured continuously for only five days in a single season. In future studies, we plan to allocate longer time to understand the dynamic behaviour of air exchange in hostel rooms. The impact of outdoor environmental parameters on ventilation conditions and indoor environmental parameters needs to be examined and will be presented in our future studies.

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Investigating Student's Perception of Visual Comfort in Architecture Studios and Its Impact on Their Work Output

Tanishka Kharat and Namrata Dhamankar

Abstract Daylight plays a crucial role in the educational environment which enables better performance, learning rates and has a significant impact on the visual comfort of the students for which the classroom designs must be carefully considered. In addition to promoting a state of calm contemplation, it also makes large energy savings feasible. Having access to daylight in the buildings is essential but it is critical to control the glare risk it poses. The main objective of this study is to assess the relationship between the daylight conditions in Architecture classrooms and student's perception about it. This study also analyses the glare and its impact on visual comfort of students while performing various tasks in the design studios of Dr. Bhanuben Nanavati College of Architecture, Pune. Daylight simulation programme "Light Stanza", Interviews, observations were used to gather the data. According to the survey results, the perception of visual comfort is mostly affected by orientation, distance from windows and varies with various tasks performed at the studios. Given that the intensity and length of light exposure throughout the day affect human health, the presence of glare thus directly correlates with the student's visual discomfort.

Keywords Daylight · Perception · Glare · Architecture College · Visual Comfort

1 Introduction

The daylight greatly impacts on students' health, learning, and visual performance. Hence daylight in classrooms is a crucial element in the design of Architecture schools. The distribution of even natural light within a classroom is a significant challenge including the prevention of glare that affects the various activities conducted within the space.

T. Kharat (✉) · N. Dhamankar
Department of Architecture, Dr. Bhanuben Nanavati College of Architecture, Pune, India
e-mail: tanishka7000@gmail.com

Savitribai Phule Pune University, Pune, Maharashtra, India

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Glare occurs when a bothersome, distracting, and occasionally blinding light abruptly enters our field of vision after our eyes have adapted to a certain general brightness. Based on the glare sources, there are two distinct classes. Further classifications include absolute glare, contrast glare, and veiling reflection. Disability glare, discomfort glare, and veiling reflection are the three main categories into which the levels of glare have often been separated. The contrast between the glare source and the backdrop is often what causes discomfort glare. Problems of this nature are most frequently seen within buildings or at night in locations with low light levels and bright illumination sources. One of the typical examples of discomfort glare inside buildings is direct afternoon sunlight coming through windows [1]. The average light intensity in a space is referred to as illumination. Low lighting has been associated with slower reading, reduced focus, bad posture, and long-term visual deterioration. It has been demonstrated that an excessive change in brightness can be uncomfortable and decrease visual performance [5].

2 Literature Review

One of the key considerations that an architect would often give careful thought to when constructing a school, university, or other educational facility is the amount of daylight each of the classrooms receive. The fact that sunlight may affect student's health, state of mind, and visual performance explains why it is important for Designing classrooms that have an appropriate amount of uniformly distributed light with glare protection.

2.1 Daylight Performance and Visual Comfort

Daylighting is a strategy that occupants may use passively to improve their performance, liveliness, and visual comfort. It aids in lowering a building's total electrical energy consumption. Visual comfort is also closely tied to energy expenditure. The usage of artificial lighting due to lack of daylight may increase energy consumption. On the other hand, an abundance of natural light that is distributed unevenly may result in glare and excessive solar gain. In literature, the term "visual comfort" is often defined as the absence of discomfort, which is glare. Glare may result from inadequately sized windows [3]. However, the perception of comfortable visual conditions depends on more factors than just the absence of discomfort. These factors include illuminance level, color rendering, modeling, luminance distribution [4].

2.2 Student's Perception on Daylight

Students' perceptions of their classroom must be considered in order to assess the impact of classroom design on occupants. Students' assessments of their physical, psychological, and social environments in the classroom include ambient environment, spatial environment, and technology. Lighting is most closely related to the learning and behavior of the students out of all these characteristics. Students' performance, motivation, alertness, attention, and focus are all guaranteed by good illumination in classrooms. Students that utilize artificial illumination experience visual strain, non-visual weariness, and circadian disruption. Since children are more susceptible to the effects of the circadian system than adults are, a classroom's general illumination is crucial for achieving greater circadian entrainment. The influence of daylight in this overall illumination is quite important. Lack of sunlight in classrooms can disrupt children's hormone cycles, which can impact their ability to concentrate, annual body growth, and sick leave. Students' health, well-being, performance behavior, productivity, and even their seating preferences have all been positively impacted by daylight in classrooms [6].

2.3 Daylight in Architecture Studios

Proper Daylight illumination is extremely important in design studios as various activities are carried out throughout the day, which include reading, writing, hand drafting, use of laptops, teaching on projectors and black board, and model making and each of these activities requires a proper illumination as per the ideal working environment situations. Daylighting in a classroom is significant for overall environment and performance of students and it should also considered while designing of the Architecture buildings [4].

2.4 Factors Affecting the Natural Daylight Within a Space

Internal factors include arrangement of the furniture, glazing materials, location of furniture, sizes of windows, flooring and ceiling material. External factors influencing the amount of daylight in buildings include latitude and longitude, building form, location, landscaping, building orientation, building usage, joinery construction materials of interior walls and exterior facades, window size and position, and window components such as glass ratio, glazing materials, and shading devices. The amount of daylight in interior spaces can be calculated using the method of daylight illuminance of space (in Lux and Foot Candle units) and the daylight factor (DF) [2].

2.5 Daylight Performance Matrix

Researchers have established multiple Daylight Performance Metrics (DPMs) that determine various aspects of natural light, such as daylight availability, glare, and visual discomfort, as well as non-visual impacts of daylight, according to prior studies and articles. DPMs are classified into two types: static and dynamic, based on the analysis period (point-in-time or annual) and the sky model (standard or climate-based). These metrics are affected by location and building orientation, as well as space geometry and material optical characteristics. Design guidelines and green building grading systems describe acceptable ranges for certain daylight measures. However, some research findings show that adhering to daylight guidelines and standards may not always result in an environment that meets the visual preferences of the occupants. Therefore, these procedures and standards acknowledge the value of subjective evaluations in addition to Daylight Performance Metrics, since photometric measurements alone do not adequately capture the subjective component of lighting quality [2].

The findings of numerous studies show that the performance of the same metrics varies or is even inconsistent between investigations. Other variables that impact the level of accuracy in predicting visual comfort in the built environment might explain the disparity. Since the recommended ranges for visual comfort measurements are based on field research in certain building types and climates with general daylighting systems and a small sample size, they may not be completely applicable in various circumstances.

Previous research has attempted to bridge the gap between simulation-based daylight glare performance predictions and actual space performance. The consistency of DPMs with user perceptions and actual daylighting performance in educational buildings has been investigated in a few studies by conducting an extensive field survey in various spaces such as primary schools, offices, co-working spaces, residential areas, and so forth, and it has been concluded that the Survey documentation Analysis and Annual Sunlight Exposure are good indicators for predicting occupants' satisfaction with daylight and discomfort glare.

The aim of this study is to address the gap between simulation-based daylight glare performance predictions and actual space performance relating it to the visual comfort of the users with respect to their perception of the users in Design studios of Architecture Buildings.

3 Methodology

On reviewing some of the research works on the similar grounds that took place around the world for understanding the subject matter, the results and conclusion gave a way to the research gap for future studies. In order to address the gap, case specific study has been conducted to relate the onsite illuminance readings to the

simulation-based study of glare analysis and the student's perception on natural light with the design studios of the Architecture college. An Architecture school from Pune was selected in order to conduct the field work. Only the design studios were considered as part of the study and glare analysis. Design studios are where the students spend most of their time working and conducting various activities hence analyzing and addressing the need of the appropriate daylight is necessary. Glare analysis was conducted using a Simulation software, Light Stanza. The study was conducted to analyze the glare readings for all the design studios within the selected architectural building. The analysis was done at different time intervals within the college timings and the studios with greater fluctuating results throughout the day were further studied for the illuminance analysis. The studios with higher Glare fluctuating results were shortlisted for the study of daylight using Lux meter to verify the relation between the actual and ideal lighting conditions required to carry out various activities like Drafting, Writing, use of laptops, presentations over projector etc within the same studio. Hotspot locations from each of the selected studios were identified. Interviews were conducted of those students who spent their whole day carrying out different activities within those specific locations with maximum, minimum and average lux readings. One on One interview with the selected sample size based on visual comfort, the preferred location for carrying out activities, ability to work with daylight conditions at that specific time was analyzed to understand the perception of the students which further gave a way to the results and Conclusion. Better daylight configuration is suggested to improve the learning environment in the selected design studios.

Scope and Limitations

The selected Architecture building is a Five storey building having a total building area of 10,800 m^2, consisting of faculty rooms, cafeteria, auditorium, design studios for undergraduate and master's students, CAID labs, computer labs, common spaces, department rooms, research laboratories out of which only the Architectural design studios were considered for this study. Final year studios were not considered as students were working on the thesis project and training due to which their classrooms were not particularly occupied full time including Master's design studios as they had limited activities conducted and different furniture arrangements. Therefore, only the undergrad design studios were considered for the study as multiple activities are carried out within the space throughout the course. As highlighted in Figs. 2, 3, 4, the Study was conducted in the month of October, within a narrow field of time which were the College working hours (8:00 a.m.–3:00 p.m.) with an analysis after an interval of every three hours, for better study of varying results.

4 Case Study

Dr. Bhanuben Nanavati College of Architecture is located in Pune city in the state of Maharashtra, India. Pune has a tropical wet and dry climate, closely bordering upon a hot semi-arid climate. The warm temperatures year-round range between 27 °C (81° F) and 37 °C (99° F) (Fig. 1).

The Design studios for undergraduate students are located on the second, third and fourth floor with an orientation of SW-NE and NW-SW direction. They have an approximate range of areas varying from 122 to 138 m^2 with a ceiling height of 3 m for all the design studios as shown in Figs. 2 and 4. They can accommodate about 40–45 students per classroom, which is also the strength of the class. Figure 3 shows the classroom layout with the typical furniture arrangement within the design studios.

The glazed area of the window, the glazing material, vertical angle subtended by the sky that is visible from the center of the window, total area of room surfaces including floors, ceilings, walls and windows, average reflectance of the interior surfaces are effective factors in daylight [2]. The surface of the objects within the interiors contribute to the reflection of natural light, affecting the illuminance distribution within the space and causing discomfort to the users. On this site the study tables were made of a stainless steel support with medium density fiberboard top, the window and ventilators had clear glass with aluminum frames covered with curtains whenever required, and the floor is covered with tiles of glossy finish as seen in Figs. 5 and 6.

Fig. 1 Location of the architecture building [Google Map]

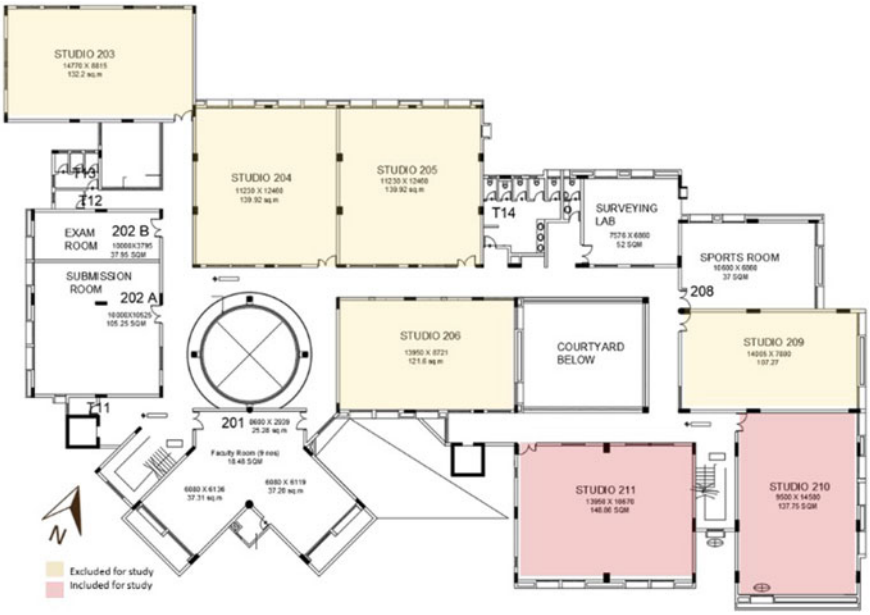

Fig. 2 Typical floor plan with marked design studios [Author]

5 Discussions

5.1 Onsite Observations by Author

As per the general observations made, students preferred switching the Artificial lights on due to the shortage of natural light in the afternoon and preferred sitting next to the wall to carry out activities like drafting, writing notes, making models, working on laptops etc. Fig. 8. Students were observed sitting next to the window only during the morning lectures and usually drew the curtains in the afternoon due to the visual discomfort. As a result, the Students did seem to change the illuminance as per the requirement of the activities they were carrying out either by switching on artificial light whenever they felt day light seem to be insufficient and drew the curtain whenever they felt the daylight is too excessive causing strain to the eyes. Over all the Studio seems to have a good distribution of daylight especially at the area where students spend most of their time.

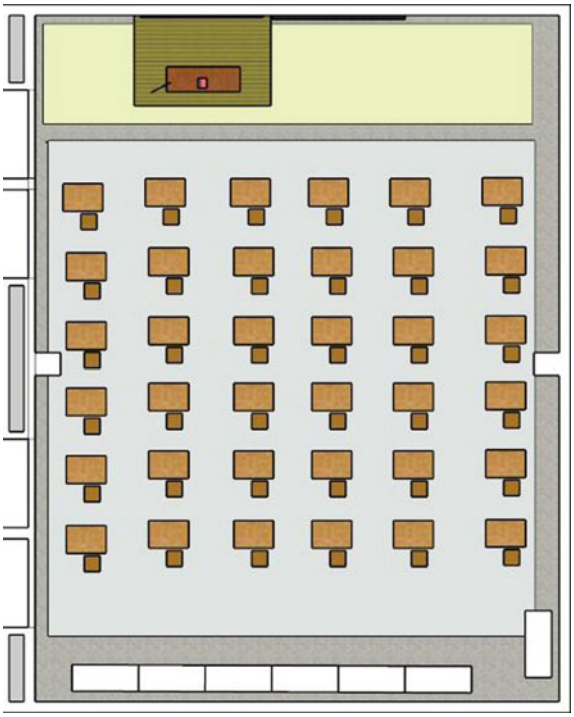

Fig. 3 The typical furniture layout [Author]

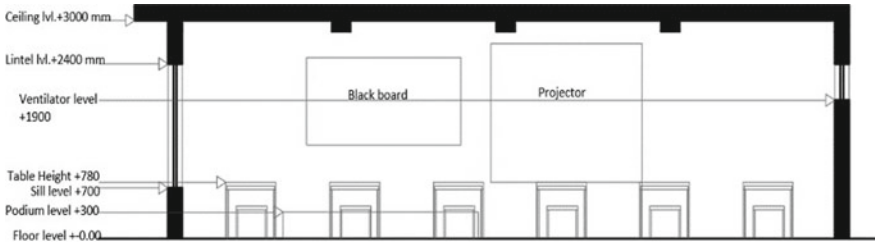

Fig. 4 Typical section of design studio [Author]

Fig. 5 Classroom photo [Author]

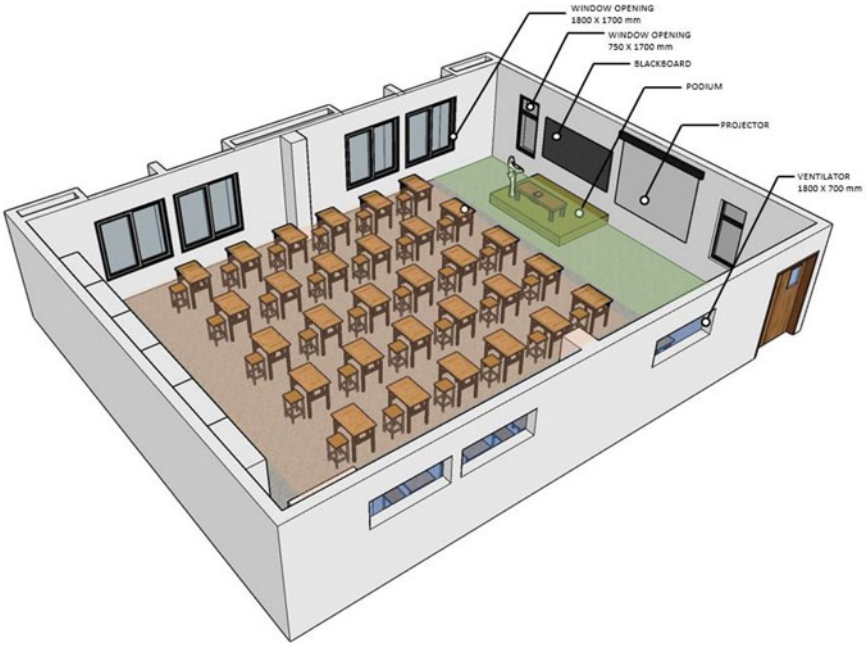

Fig. 6 A 3D model with typical furniture placement [Author]

Fig. 7 Photograph of the design studio in the afternoon [Author]

Fig. 8 Photograph of the design studio in the morning [Author]

5.2 Simulation Based Study

The Glare Analysis was conducted using a simulation software, Light stanza. Initially the SketchUp model of the complete building was made and imported into the stimulation- based software for the analysis of the glare. The analysis was conducted thrice, within the college timings after an interval of three hours to study the change in the glare at the peak.

As per the analysis the maximum glare was analyzed to be next to the windows in the afternoon Fig. 9, and moderate at the central portion of the classroom and minimum near the internal walls. The studios located to the south east direction had greater exposure to harsh afternoon sunlight with minimum foliage cover outside showing maximum glare rating during the afternoon as per the analysis. Whereas the other studios facing towards the north and north east direction showed minimum glare rating and change in the reading at different intervals of time due to their location and existence of outdoor factors such as foliage cover and surrounding buildings, hence they were excluded for the study. Out of all the design studios across the complete second floor only Studio 211 and Studio 210 showed a greater fluctuation in results; hence they were studied further for the illuminance study.

After the analysis of the third floor it was noticed that the studios had similar readings to that on the second floor which is due to the same locations on both the floors. Hence studios 310 and 311 just above the studios 210 and 211 respectively showed greater fluctuation in results. Therefore, these design studios were studied further for the illuminance study and the rest of them were excluded.

The fourth floor consisted of only one undergrad design studio and the analysis was quite different from those of the previous selected classrooms. As the location

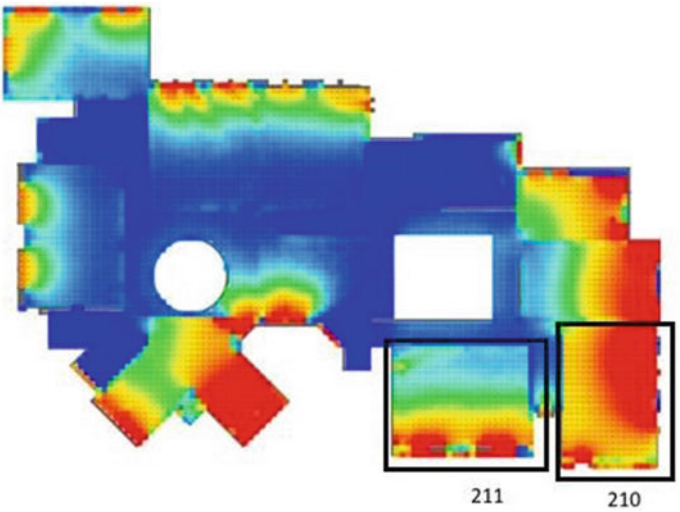

Fig. 9 Analysis at 8:00 a.m. [Author]

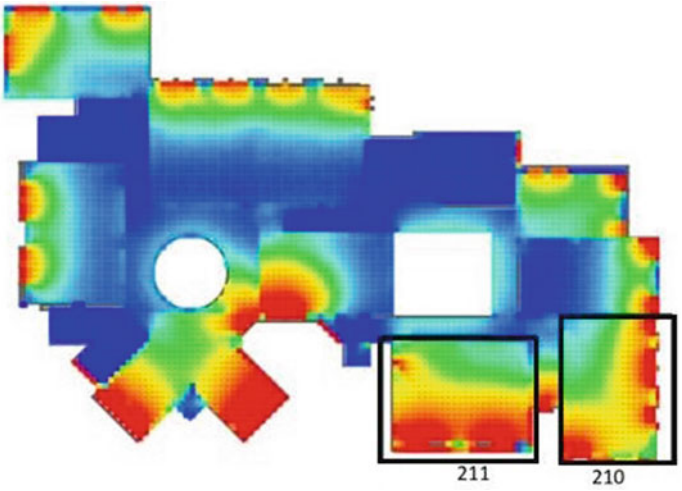

Fig. 10 Analysis at 11:00 a.m. [Author]

of the studio was such that it had less exposure to the direct harsh light with a greater surrounding cover, the glare levels next to the window were high. The location near the walls and the back of the class had minimum exposure to natural light due to which the students preferred using artificial lights to carry out the activities.

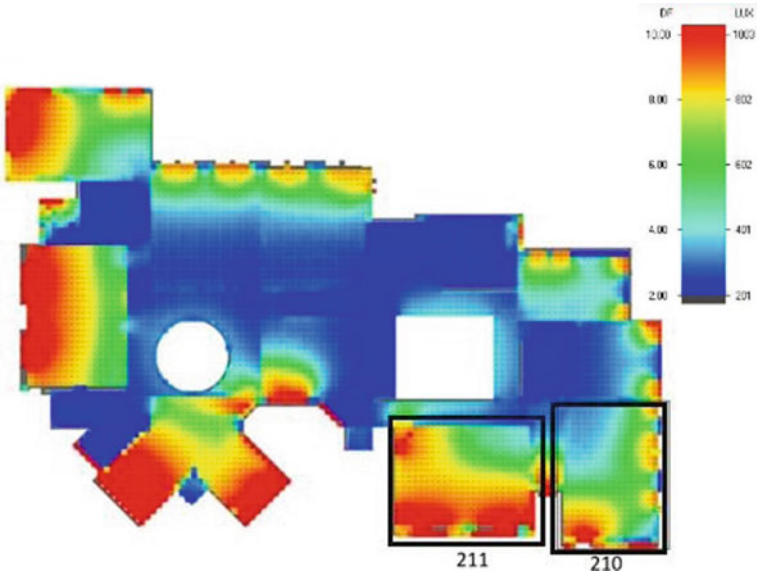

Fig. 11 Analysis at 2:00 p.m. [Author]

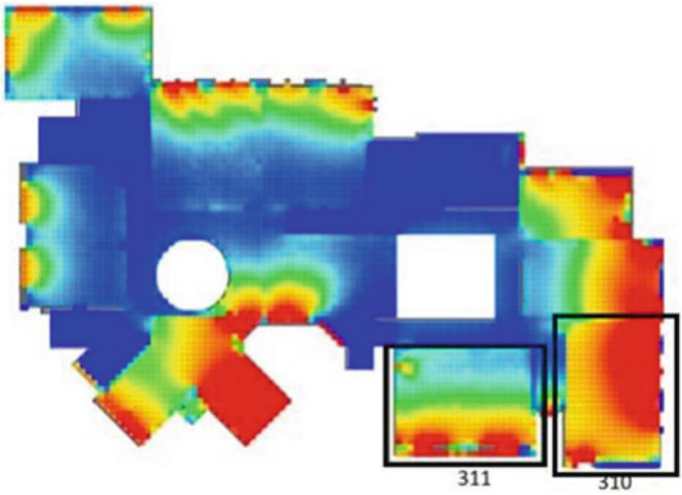

Fig. 12 Analysis at 8:00 a.m. [Author]

5.3 Field Study

There are various factors internal as well as external that affect the natural light entering the buildings. The amount of daylight within the interior spaces can be

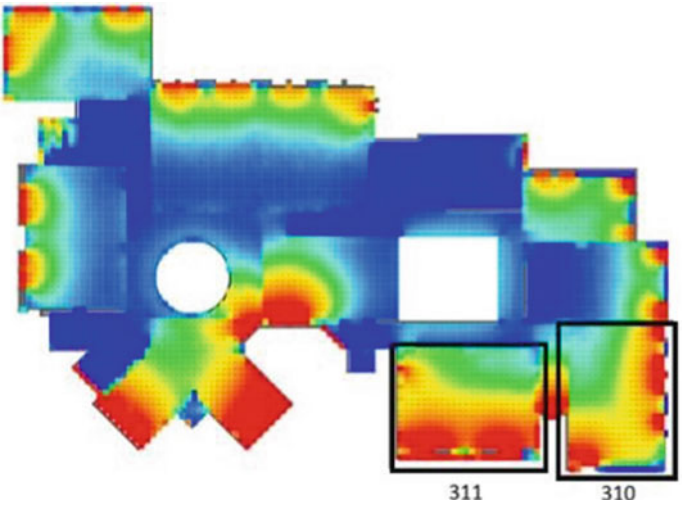

Fig. 13 Analysis at 11:00 a.m. [Author]

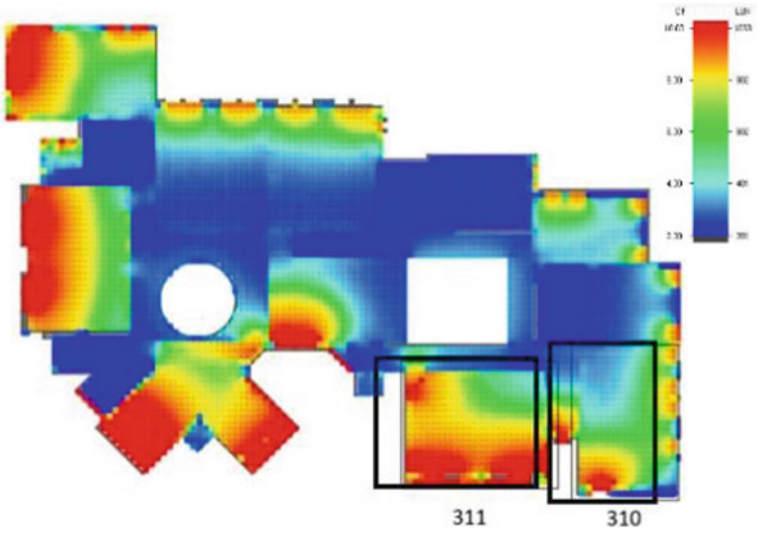

Fig. 14 Analysis at 2:00 p.m. [Author]

measured by the lux measuring instrument, Lux meter. As various activities are carried out within the studio it is important that the daylight must be enough to satisfy the ideal illuminance levels of a good working environment. After the results from the glare analysis the selected studios from each floor (210,211,310,311,406) were further studied for analysis of illuminance levels at different locations within

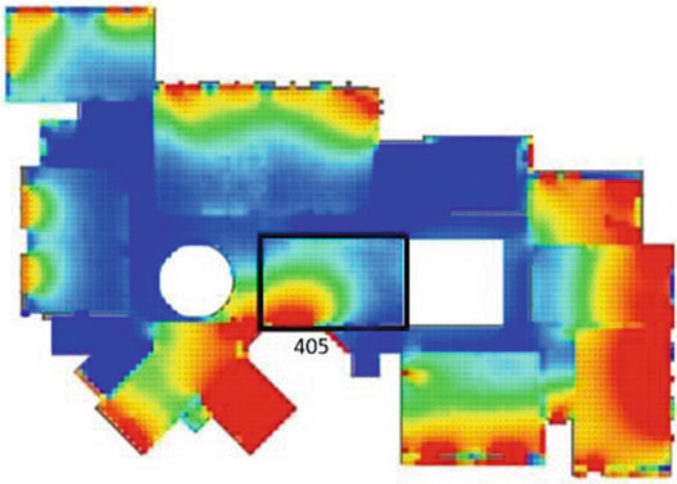

Fig. 15 Analysis at 8:00 a.m. [Author]

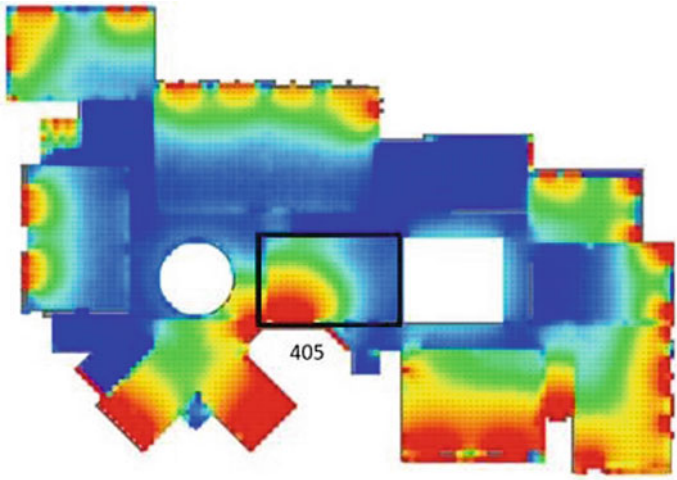

Fig. 16 Analysis at 11:00 a.m. [Author]

the respective studios and compared with the ideal illuminance conditions (Figs. 18, 19, 20).

The locations of each of the selected classrooms that showed fluctuating readings from the glare analysis were considered further to note the lux readings using the lux meter. As per the glare readings the results showed maximum variation in the afternoon as compared to that in the morning hence the lux readings were noted at 2:00 p.m. on-site. These hotspot locations in the classrooms varied as per each design studio and were chosen considering the space where students spent most of their time

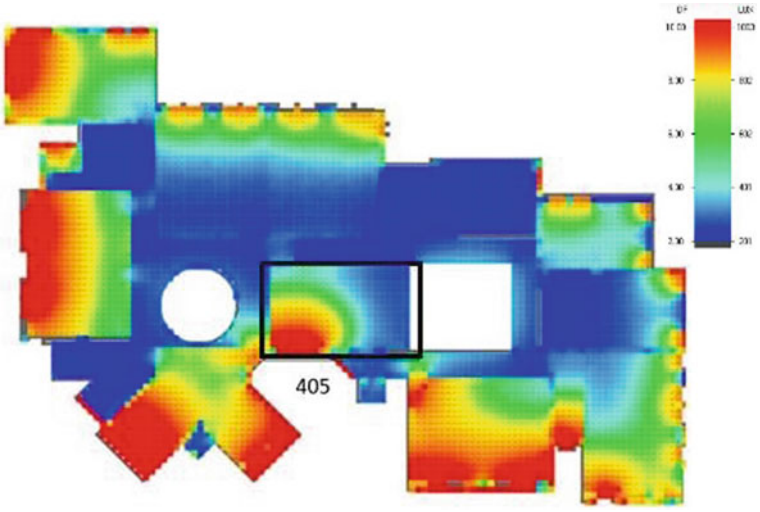

Fig. 17 Analysis at 2:00 p.m. [Author]

Fig. 18 Photograph of studio 210 [Author]

Fig. 19 Photograph of studio 211 [Author]

Fig. 20 Photograph of studio 406 [Author]

working. After the study it was noted that the lux levels were ranging from 12.2 lux to 3788 lux as seen in Fig. 22 and the maximum lux levels were noted towards the window in the afternoon. On comparing with the standard illuminance levels from CIBSE for each of the activities taking place in class, it was found that the ideal illuminance levels for activities such as hand drafting and workshop work matched with the onsite values noted near the windows and center of the rooms. However, the ideal illuminance levels for activities such as working on computers, learning through projectors and reading were matching with those on the onsite readings noted in the spaces next to the walls and back of the class.

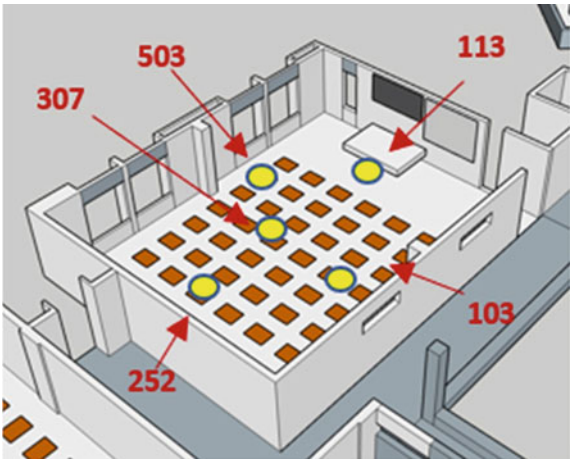

Fig. 21 Model of studio 210 with Lux readings [Author]

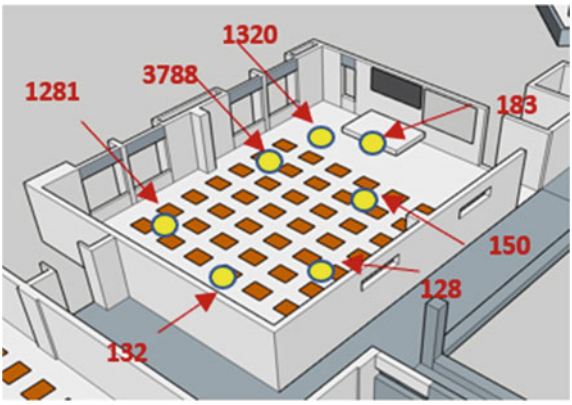

Fig. 22 Model of studio 311 with Lux readings [Author]

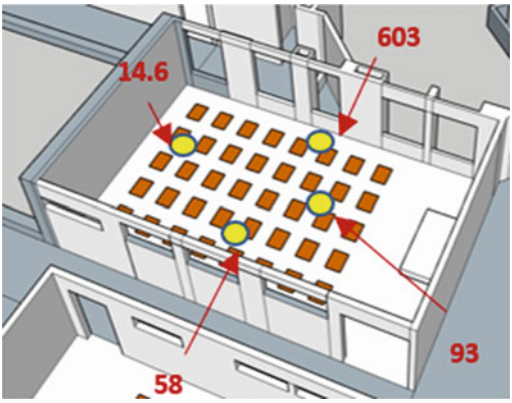

Fig. 23 Model of studio 406 with Lux readings [Author]

5.4 Student's Perception on Natural Light

Once the stimulation results and lux readings were found out the next step was to understand the student's perception for the space that they were working in carrying out different activities. Hence the one-on-one interview was conducted. The students located at those spots where the lux readings were noted were only interviewed for the perception study. As per the Hotspots within the selected design studios the distribution of sample size was such that about 5-10 students were selected from each class depending on the locations that were selected. Following the Fig. 24 shows the interview questions which were being asked selected studio wise and the data was then converted into percentage to understand the results better.

Questions	Studio 210	Studio 211	Studio 310	Studio 311	Studio 406
Sample size	**10**	**5**	**5**	**8**	**6**
Q1. Do you Agree that your classroom overall has a good uniform distribution of the light? -Yes -No	20% 80%	45% 55%	38% 62%	58% 42%	17% 83%
Q2. How would you describe daylight in your classroom? -Very Bright -Bright -Normal -Dark -Too Dark	12% 21% 45% 10% 2%	20% 23% 16% 41% 0%	23% 10% 12% 45% 0%	0% 10% 12% 55% 23%	0% 10% 12% 55% 23%
Q3. Does the light cause glare that bothers the current work? -Yes -No	80% 20%	75% 25%	74% 26%	84% 16%	62% 38%
Q4. Are you satisfied with the current lightning conditions? -Yes -No	28% 72%	20% 80%	50% 50%	45% 55%	70% 30%
Q5. Do you want to increase light to increase your visual satisfaction? -Yes -No	72% 28%	66% 34%	45% 55%	63% 37%	20% 80%
Q6. Does the light conditions effectively affect your ability to work? -Yes -No	80% 20%	40% 60%	75% 25%	67% 33%	10% 90%
Q7. Do you think the window sizes are too large ? -Yes -No	40% 60%	30% 70%	50% 50%	75% 25%	64% 36%
Q8. Where do you prefer sitting in the classroom? -Next to window -Next to Wall -Centre	64% 10% 26%	10% 15% 75%	50% 25% 25%	42% 16% 74%	100% 0% 0%

Fig. 24 Questions the participants were asked during one-on-one interview [Author]

The Questions asked were to do more with the glare and overall illuminance level in the classrooms. They were asked to rate the overall daylight distribution, satisfaction with the light and discomfort experienced rate using Likert scale in order to understand their perception. As a result it was seen that the students' perception had direct relation with results derived from the analysis of the luminance and glare analysis. Students working on those particular spots didn't feel visual comfort where the lux levels didn't match the ideal illuminance and were having higher glare readings.

On the spots that had minimum illuminance level as per the stands and analysis, students felt the need to switch on the artificial lights in order to meet the illuminance level for the activity that they were conducting. As compared to all the studied classrooms which received the harsh afternoon having maximum exposure to heat, studio 406 with better coverage had better illuminance levels as per the student's perception.

Daylight in the classrooms has an essential effect on the learning environment. As per the Glare Analysis it is clear that almost all of the studios selected for study receive harsh sunlight in the afternoon which affects the visual comfort of the students. The illuminance readings make it clear that the distribution of daylight within the classrooms is not even throughout. The readings when compared to the standard illuminance guide the existing lighting that is appropriate for laptop work, projector displays, teaching on blackboard except for the hand drafting activity. As per the perception of the students, they feel that there is a need for artificial lights to be used in order to meet their work requirements as the natural light is not enough for the same. The purpose of the study was to develop a relationship between glare analysis, the illuminance study as well as the perception of the students, As per the study there is strong connection between the results obtained. After conducting the simulation based and instrument-based analysis the results get confirmed by understanding the perception of the students. As students spend most of their time in the design studios it is important to understand their perception considering all the factors that affect the workability of the students.

6 Conclusion

The results of the study indicated that the low illuminance levels within the design studios highly affect the workability and interest of students. Appropriate orientation of the classroom becomes the most important external factor to consider before planning the classroom and in order to make the existing learning environments visually comfortable external shading devices must be used to avoid the harsh sunlight as well as control the amount of light entering into the studios as per the requirements of the needs of the activities conducted by the students. In general, classrooms should get as much daylight as possible and designers must control the illumination of areas within the student's field of vision. Effective use of daylight in classrooms can help the educational buildings realize the significance of energy saving and conservation. Future studies can focus on the other indoor factors such as furniture layouts, material for surfaces, orientations, and angle which may influence the glare and impact the work output of the University students.

Appendix

The design studios for undergraduate students are located on the second, third and fourth floor. Following images show the floor plans marked with design studios included and excluded for the study (Figs. 25, 26, 27, 28, 29, 30, 31, 32, 33, 34).

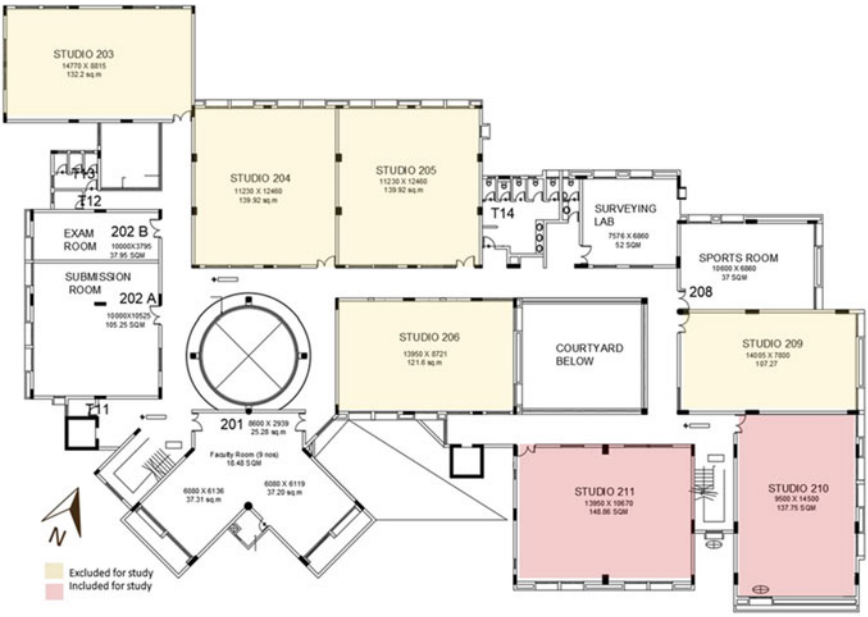

Fig. 25 Second floor plan with marked design studios [Author]

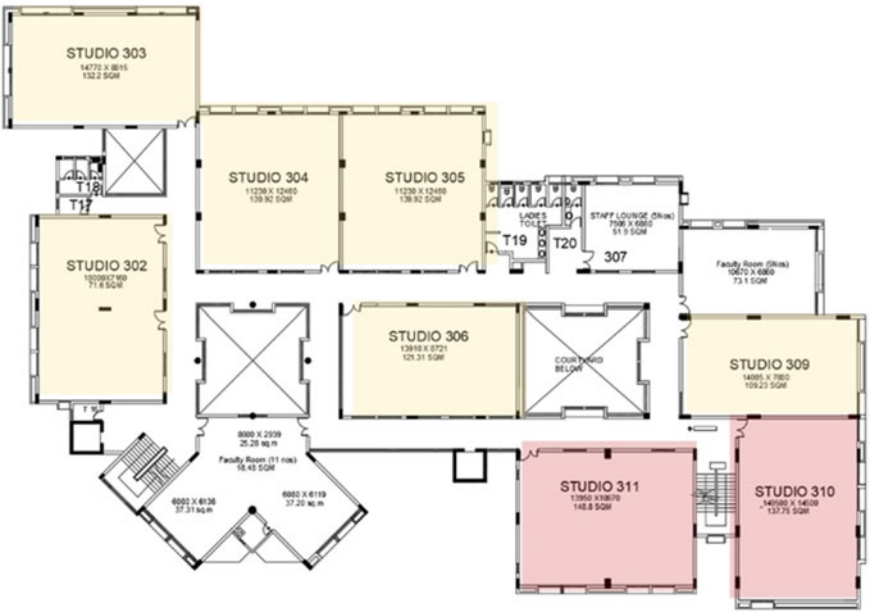

Fig. 26 Third floor plan with marked design studios [Author]

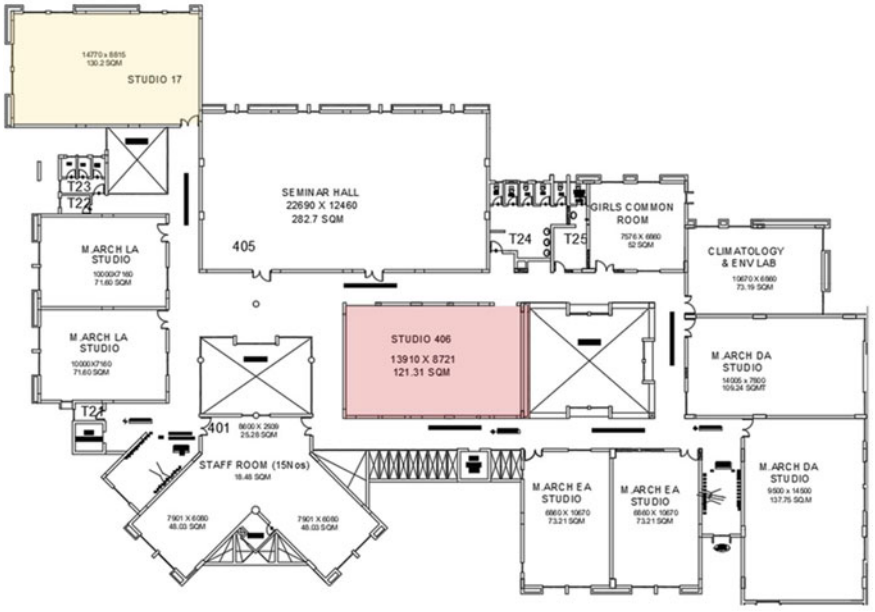

Fig. 27 Fourth floor plan with marked design studios [Author]

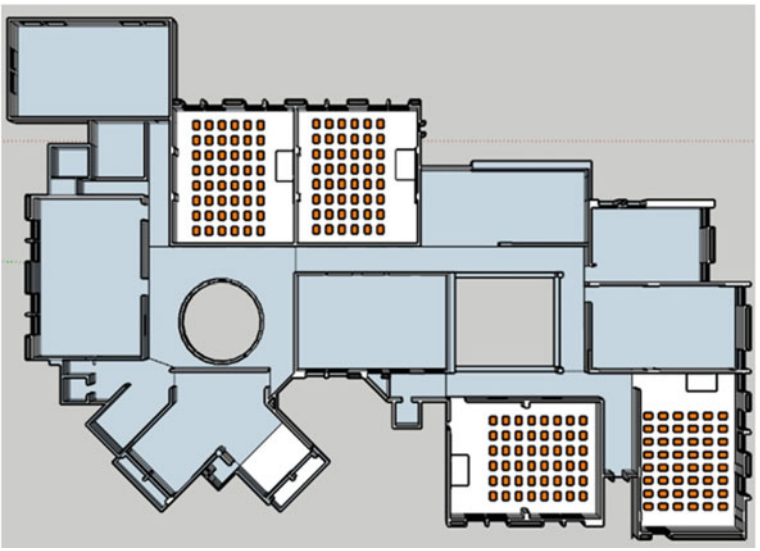

Fig. 28 Typical Furniture layout of the UG design studios [Author]

Fig. 29 Photograph of studio 310 [Author]

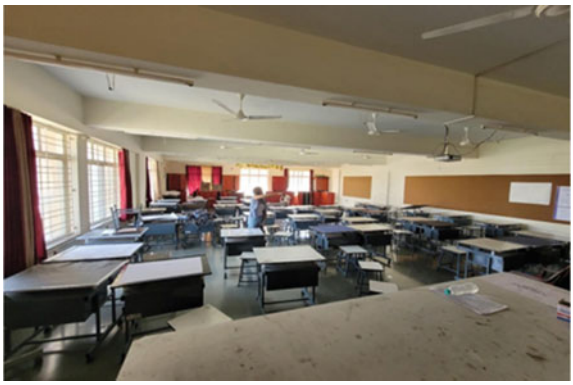

Fig. 30 Photograph of studio 311 [Author]

Fig. 31 Lux meter readings [Author]

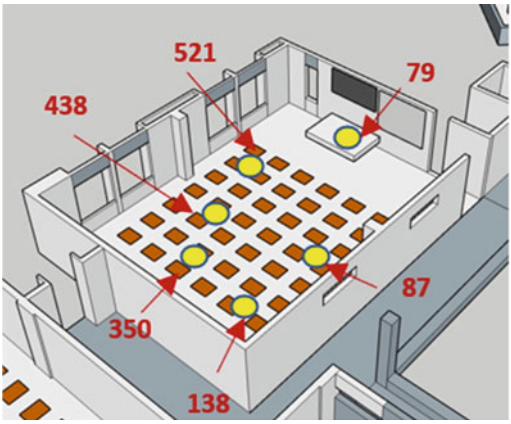

Fig. 32 Model of studio 310 with Lux readings [Author]

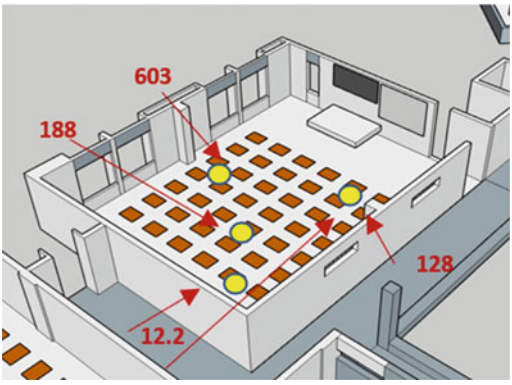

Fig. 33 Model of studio 211 with Lux readings [Author]

Questions	Studio 210	Studio 211	Studio 310	Studio 311	Studio 406
Sample size	**10**	**5**	**5**	**8**	**6**
Q1.Do you Agree that your classroom overall has a good uniform distribution of the light? -Yes -No					
Q2. How would you describe daylight in your classroom? -Very Bright -Bright -Normal -Dark -Too Dark					
Q3. Does the light cause glare that bothers the current work? -Yes -No					
Q4. Are you satisfied with the current lightning conditions? -Yes -No					
Q5. Do you want to increase light to increase your visual satisfaction? -Yes -No					
Q6. Does the light conditions effectively affect your ability to work? -Yes -No					
Q7. Do you think the window sizes are too large ? -Yes -No					
Q8. Where do you prefer sitting in the classroom? -Next to window -Next to Wall -Centre					

Fig. 34 Blank Questionnaire for the interview of the participants [Author]

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A Review of Antimicrobial Air Filters over Normal Air Filters: Unique Insights on SARS-CoV-2 Virus Deactivation

Ravi Kaushik, Sandeep Tripathi, and Suryasarathi Bose

Abstract In this study, we discuss the benefits of "antimicrobial air filters" over "normal air filters" for protection against airborne pathogens and air pollutants developed in the laboratory of IISc Bangalore and IIT Kanpur. While normal air filters work on a capture mechanism to become a breeding ground for captured germs, antimicrobial air filters are coated with bio-polymers and polycationic polymers that can deactivate the germs. The formation of ROS (reactive oxygen species) i.e. H_2O_2 leads to the deactivation of germs. Polymers being used, in this study are a safe and sustainable alternative to heavy metal (Ag/Cu) doped coating that has proven toxic to humans. The antimicrobial filters are tested to deactivate micro-organisms, such as Escherichia Coli, Staphylococcus Aureus, Influenza, MS2 Bacteriophage, Aspergillus brasiliensis, and SARS-CoV-2 (delta variant). It was also proven that normal filters have a negative reduction which implies the growth of microorganisms. Structural and filtration integrity of anti-microbial air filters were upheld without affecting the filter's porosity and initial pressure drop. There was no statistically significant difference in pressure drop and filtration efficiency observed between coated and uncoated filters. Furthermore, the coated air filters maintained antimicrobial activity throughout the operational lifetime with regenerative ROS formation. Antimicrobial air filters pave the way for better protection against infection spread and air pollutants. It prevents the air filter to become a breeding ground for germs using bio-polymers that are biodegradable and non-toxic.

Keywords Infection spread · Air filters · Environment-friendly · Antimicrobial coating

R. Kaushik (✉) · S. Tripathi
Airth Research Pvt Ltd., New Delhi, India
e-mail: ravi.kaushik.c2019@iitbombay.org

R. Kaushik · S. Tripathi · S. Bose
IISc, Bengaluru, India

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1 Introduction

In recent years, the risk of infections caused by air pollutants and airborne diseases are increasing among people rapidly. More than 6.6 million people died due to COVID-19 by end of June 2022, globally (WHO report). Similarly, more than 7 million deaths happened globally due to air pollution in the year 2018 (WHO report). In India, air pollution causes a loss of 150 billion USD annually (Greenpeace). Also, humans lose more than 2.6 years of their life due to air pollution (Centre for Science and Environment). There have been using a number of air filters for the prevention of the deadly effects of air pollutants. HEPA filters are able to trap viruses, bacteria, fungi etc. at high velocities [1]. However, these air filters in different filtration systems are effectively capturing pathogenic microorganisms from the indoor air environment but they remain viable and proliferate on the filter media. Therefore the filter becomes a breeding ground for microorganisms and behaves as a source of contamination in the indoor air environment [2–4]. Since there is the risk of filters acting as a secondary infection spread in the indoor air environment, and in response to the COVID-19 pandemic, there has been an increase in demand for novel antimicrobial technologies to prevent transmission. The incorporation of heavy metal (Ag/Cu) nanoparticles into meshes for filters imparts an antimicrobial effect [5], but they are proven toxic to humans [6].

The objective of this literature review is to analyze the efficacy of antimicrobial air filters coated with a plant-based biopolymer and polycationic polymer.

The stability and durability of the filter are examined with the production ROS to deactivate germs and the efficacy against gram-positive bacteria, gram-negative bacteria, fungi and viruses are assessed in detail.

2 Materials and Methods

Polycationic polymers and Plant-based biopolymers are processed with chemical reagents of analytical grade and used without any further purification.

2.1 Preparation

1. Solution A: The liquid polycationic polymer of a certain volume is processed.
2. Solution B: (a) Plant-based biopolymer is prepared then a defined weight percentage was taken and mixed with a certain volume of distilled water.
   (b) It is heated and stirred maintaining a certain temperature for an optimum time period.
3. Thus, a certain proportion of solution A is mixed with a defined proportion of solution B, and then the concoction is ready to be coated over the filters.

2.2 Coating Methods

Dip coating:

Filter media submerged in the coating, then taken out and allowed to drip dry.

Air spray coating:

Compressed air applies high pressure to the coating fluid discharged from the nozzle and the fluid then collides at a high speed with the remaining air. The coating fluid is split up and slowed down at that moment due to air resistance, and then changes into a mist and reaches the depths of the material.

3 Mechanism of H_2O_2 on Microorganisms

H_2O_2 formed by the polycationic and plant-based biopolymer is an oxidizing agent, so it would seem obvious that the main mechanism of action is due to the oxidation of various available macromolecules that make up the structure and function of microorganisms, such as protein, lipids, carbohydrates, and nucleic acids (Fig. 1). Other reactive species are produced locally on the degradation of peroxide into water and oxygen during such reactions that further contribute to the overall microbicidal activity of hydrogen peroxide.

Reactive species may include $O_2^{\bullet-}$, $^{\bullet}OH$, $^{\bullet}OOH$, $^{\bullet}O$, and $^{\bullet}H$, as well as other by-products of these species, with other components of or associated with viable microorganisms.

Proteins play important roles in the surface and internal structures of cells and viruses, as well as their various functions. Aqueous solutions of hydrogen peroxide have been shown to oxidize proteins and specifically the side chains of certain amino acids that make up their structure.

- Virus mostly enveloped and non-enveloped viruses and bacteria with cell walls
- Proteins are mostly present in bacteria on the cell walls and in viruses on the enveloped structure and on the internal structure of non-enveloped viruses.

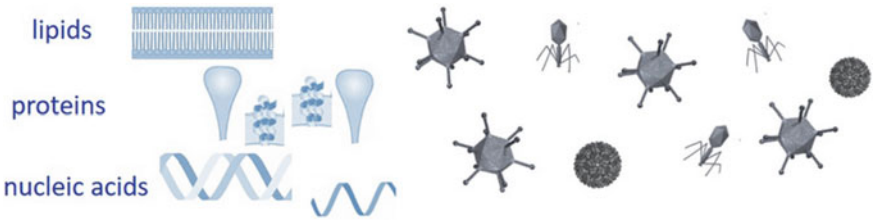


Fig. 1 Structure of lipids, proteins and nucleic acids

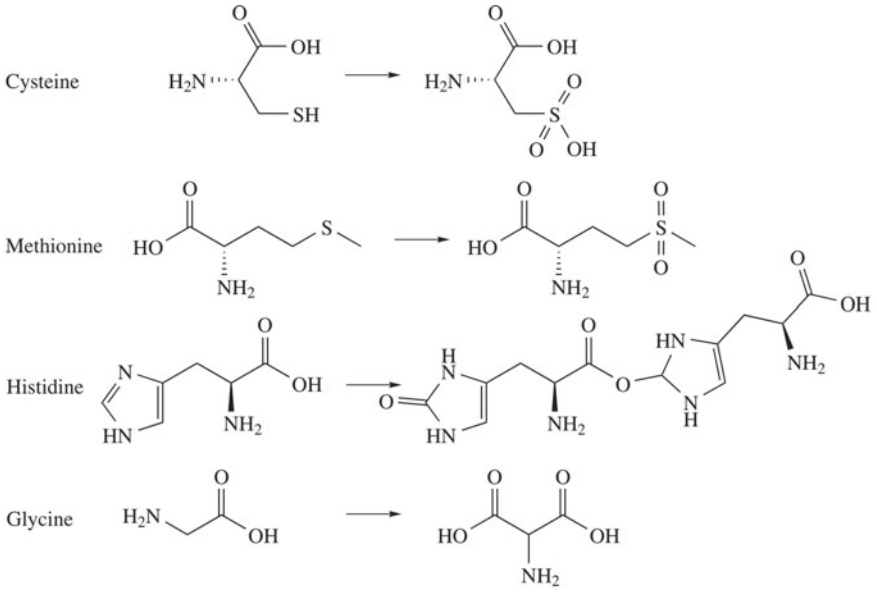


Fig. 2 Oxidation of the amino acids

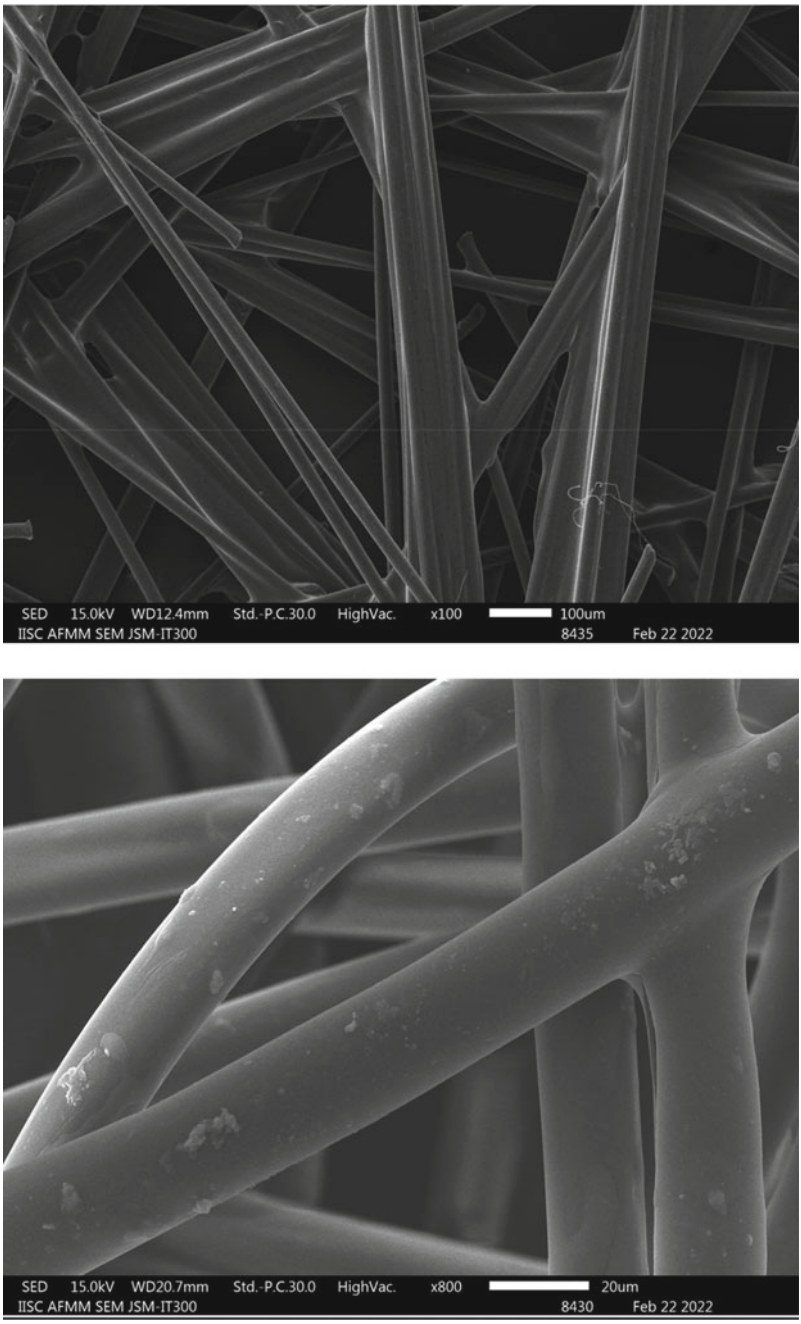
Examples: Direct oxidation of the amino acids cysteine, methionine, lysine, histidine, and glycine has been reported. The structure of the same is shown in Fig. 2.

Considering the importance of specific amino acid sequences in the structure and function of proteins, these changes could not only dramatically affect structure/function but also lead to other reactions within or between adjacent protein structures to culminate in sufficient damage to a cell/virus. Overall, proteins appear to be an important target in the antimicrobial activity of hydrogen peroxide [7].

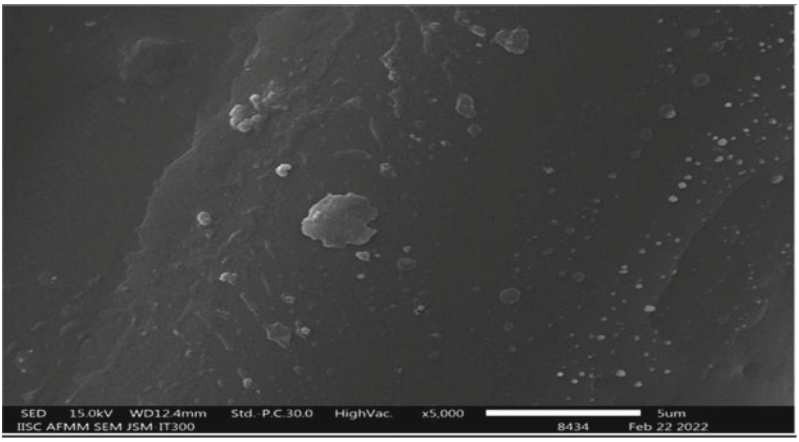
4 Characteristics Analysis

The surface morphology of composite filters sputter-coated with gold was characterized by scanning electron microscopy (SEM) Brand—Carl Zeiss Model Number—EVO18 Special Edition with an operating Voltage of 1–30 kV (Plates 1, 2 and 3).

Summary: The deposition of polymers on the fibers and no pores are closed proved at the microscopic level.



Plates 1, 2 and 3 Surface morphology of composite filters sputter-coated with gold



Plates 1, 2 and 3 (continued)

5 Antiviral Efficacy of Antimicrobial Filters over Normal Filter

5.1 Scope

The assay describes the method for measuring antiviral activity on porous textile surfaces of antiviral-treated products against specified viruses.

5.2 Test Method

A test suspension of the SARS-CoV-2 virus: Delta variant was inoculated onto the control (untreated) specimen and test (antimicrobial treated-test specimen). The surfaces loaded with virus inoculum were maintained at a specified temperature (25 °C ± 1 °C) for a contact period of 24 h. At the end of the contact time remaining infectious virus particles were recovered individually from the control (untreated) specimen and test (antimicrobial treated-test specimen) by washing the surfaces followed by vortex and agitation in the neutralizing medium. Quantification of the recovered virus particles (infectious virus particles) was done by plaque assay. The assay was performed in triplicate using 3 test specimens for each step (Tables 1, 2 and 3).

A: Dilution Factor10;

B: Dilution Factor100; the number of plaques obtained in Control (0 min in the wells for dilution factor 10 is not countable. Hence the dilution of the wells where a countable number of plaques >60 is obtained is taken for calculation.

Table 1 Virus summary

Realm	Riboviria
Order	Nidovirales
Family	Coronaviridae
Genus	Betacoronavirus
Species	COVID-19
Variant	Delta
NCBI accession number for virus isolate	MZ574052.1

Table 2 Test information

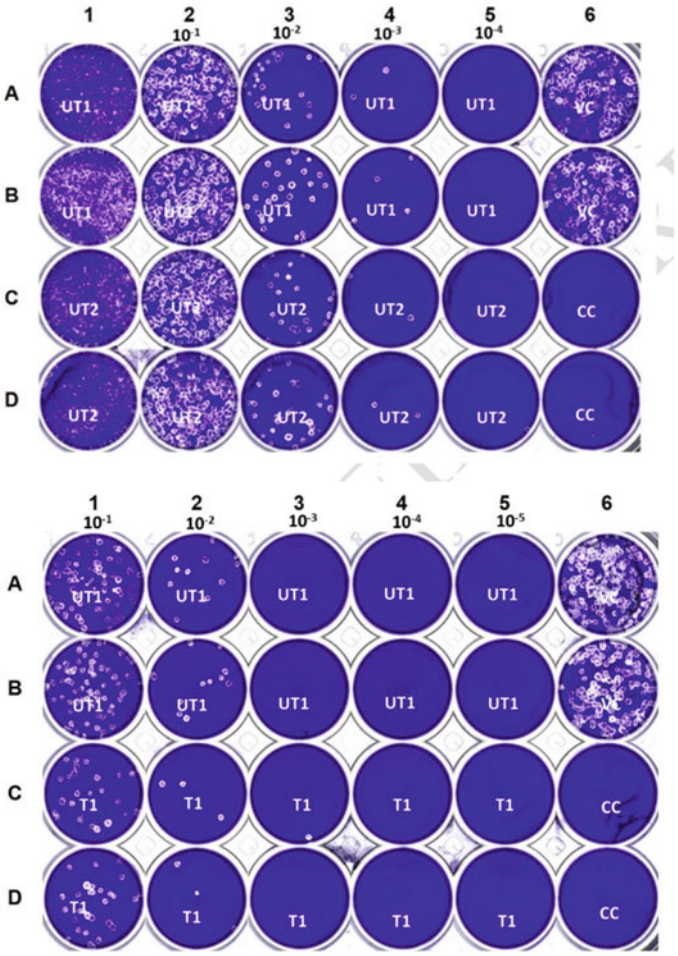
Guideline referred	ISO 18184 (Textiles: determination of antiviral activity)
Sample description	Treated and untreated specimen: (50 mm × 50 mm) and 0.22 g ± 0.05
Color	White
Specimen storage condition	Ambient
Virus used for testing	COVID 19 (SARS-CoV-2) Delta variant P4
Host cell line used for testing	Vero cell line
Volume of test inoculum used	200 µl (1.6×10^6 PFU/ml)
Test temperature	25 °C ± 1 °C
Temperature of incubation	37 °C
Contact time	24 h
Stability and appearance of the specimen during the test	200 µl of the virus specimen was absorbed immediately in the treated specimen and untreated specimen
Neutralizer used	Ice cold SCDLP media

Table 3 Antiviral assay assessment for the untreated and treated samples

	Number of plaques recovered after 24 h						Z	Vp (PFU/vial)		Mc value	Mv value
	Specimen 1		Specimen 2		Specimen 3						
Untreated	11	11	16	12	8	6	10.6	Vb	10,667	1.4	2.12
Treated	3	2	2	2	2	1	2	Vc	2000		
Control (0 min)	21	27	21	29	30	32	26.6	Va	266,667		

C: The logarithm reduction value of the infective titer of the control specimen should be ≤1 for the 2 h contact period and ≤2 for the 24 h contact period (as mentioned in ISO 18184).

The image specifies that, in comparison to the UT1 specimen, the T1 shows a reduction in the plaque count (Figs. 3 and 4).



Figs. 3 and 4 Titration of SARS-CoV2 virus: delta variant on untreated sample after immediate wash with the wash media (0-min titer: Va is calculated from this data)

The image indicates that coated filters exhibited virucidal activity against the SARS-CoV2 virus: Delta variant in comparison to the respective untreated control specimen after a contact time of 24 h (Figs. 3 and 4).

UT1: Untreated specimen (Control specimen); T1: Treated specimen; CC: Cell control; VC: Virus control.

5.3 *Verification of Cytotoxicity by Cell Sensitivity to Virus and the Inactivation of Antiviral Activity*

The purpose of the control test is to confirm the suppressive efficiency of wash media on the test specimen (Table 4).

WUT: Virus titer in PFU/ml obtained from washout neutralizing media of untreated specimen spiked with SARS-CoV2 Virus; Delta Variant.

WT: Virus titer in PFU/ml obtained from washout neutralizing media of treated specimen spiked with SARS-CoV2 Virus; Delta Variant.

As per ISO 18184, the difference in the logarithmic value of the number of plaques recovered between untreated and treated specimen in the verification of cytotoxicity by cell sensitivity assay should be ≤ 0.5.

The validity criteria for confirmation of cytotoxicity by cell sensitivity and inactivation of antiviral activity is achieved.

This image indicates, the wash media is not cytotoxic and has no effect on the cell sensitivity to the SARS-CoV2 virus: Delta Variant infection and virus inactivation as represented by plaques in 'UT' and 'C' (no specimen) wells (Fig. 5).

UT: Untreated specimen washed with medium and spiked with the SARS-CoV-2 virus: Delta Variant; T: Treated specimen washed with medium and spiked with the SARS-CoV-2 virus: Delta variant; C: Verification of cell sensitivity control (control: medium + virus without treated or untreated specimen); CC: Cell control. VC: Virus Control.

Calculations

$$P = Z \times R \tag{1}$$

P Infectivity titer (PFU/0.2 ml)
Z Arithmetic average of plaques
R Dilution Factor
W Infectivity titer (PFU/ml)

$$Vp = W \times C \tag{2}$$

Table 4 Assessment of cytotoxicity by cell sensitivity to virus and the inactivation of antiviral activity

	A number of plaques recovered						Z	W (PFU/ml)		Log (WUT)-Log (WT)
	Specimen 1		Specimen 2		Specimen 3					
Untreated	65	75	74	82	69	70	72.5	WUT	36,250	0.36
Treated	29	29	37	38	26	29	31.3	WT	15,667	

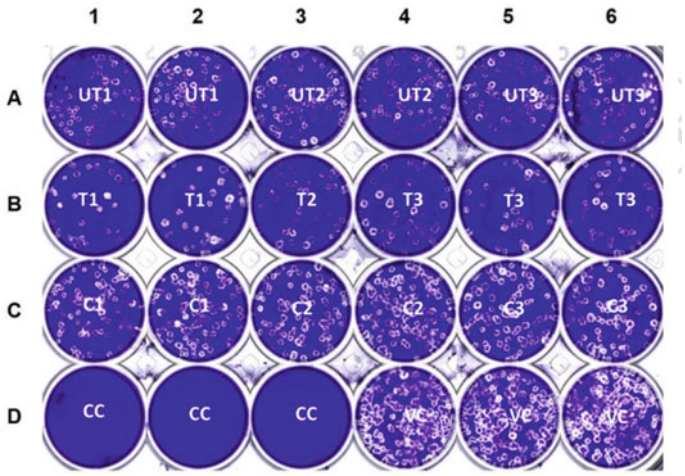


Fig. 5 Treated and untreated specimen in the verification of cytotoxic activity

Vp Infectivity titer (PFU/vial)
C is the wash-out virus suspension amount (ml)

* Logarithm reduction value of infective titer of control specimen

$$M = \lg(Va) - \lg(Vb) \tag{3}$$

M Reduction value
lg(Va) is the common logarithm average of 3 infectivity titer value immediate after inoculation of the control specimen
lg(Vb) is the common logarithm average of 3 infectivity titer value after 24 h contact with the control specimen

**Antiviral activity value

$$Mv = \lg(Va) - \lg(Vc) \tag{4}$$

Mv Antiviral value
lg(Va) is the common logarithm average of 3 infectivity titer value immediately after inoculation of the control specimen
lg(Vc) is the common logarithm average of 3 infectivity titer value after 24 h contact with the treated specimen

The antiviral activity of antimicrobial filters exhibited an antiviral activity Mv value of 2.12 which is a 99.24% reduction in virus titer against the SARS-CoV2 virus Delta variant after 24 h of contact time point.

The same procedure was repeated with other viruses as shown below.

5.4 Virus Strains and Host Cells

Influenza virus (H3N2): A/Hong Kong/8/68: ATCC VR-1679.

Host Cell: MDCK cell ATCC CCL-34; Passage No.: Cells from PN 64.

The antiviral activity of antimicrobial filters exhibited an antiviral activity Mv value of 2.33 which is a 99.53% reduction in virus titer against influenza virus after 24 h contact time point.

5.5 Test Microorganism Information

MS2 Bacteriophage (MS2) is an RNA virus of the family Leviviridae. *Escherichia coli* 15597 are the hosts for MS2 bacteriophages. Due to its environmental resistance, MS2 bacteriophages are used as a surrogate virus (particularly in place of Picornaviruses such as Poliovirus and human Norovirus) in water quality and Antimicrobial studies.

Virus: MS2 Bacteriophage.

Permissive Host Cell: *Escherichia coli* ATCC 15597.

The antiviral activity of antimicrobial filters exhibited an antiviral activity Mv value of 2.85 which is a 99.86% reduction in virus titer against MS2 Bacteriophage after 24 h of contact time point.

6 Antibacterial Efficacy and Antifungal Efficacy Method

6.1 Scope

The assay describe the method for measuring the antibacterial activity and antifungal activity on the specified gram-positive bacteria, gram-negative bacteria and fungi.

Gram-positive bacteria: *Staphylococcus aureus*—ATCC: 6538.

Gram-negative bacteria: *E. coli*—ATCC: 8739.

Fungus—*Aspergillus brilliancies*—ATCC: 16404.

6.2 Test Method

A challenge bacteria and fungus were inoculated onto the control (untreated) specimen and test (antimicrobial treated-test specimen) respectively. The Incubator was maintained at 37 °C and the specimens are kept for a contact period of 24 h. At the end of the contact time, the control (untreated) specimen and test (antimicrobial treated-test specimen) samples were surface washed followed by vortex and agitation

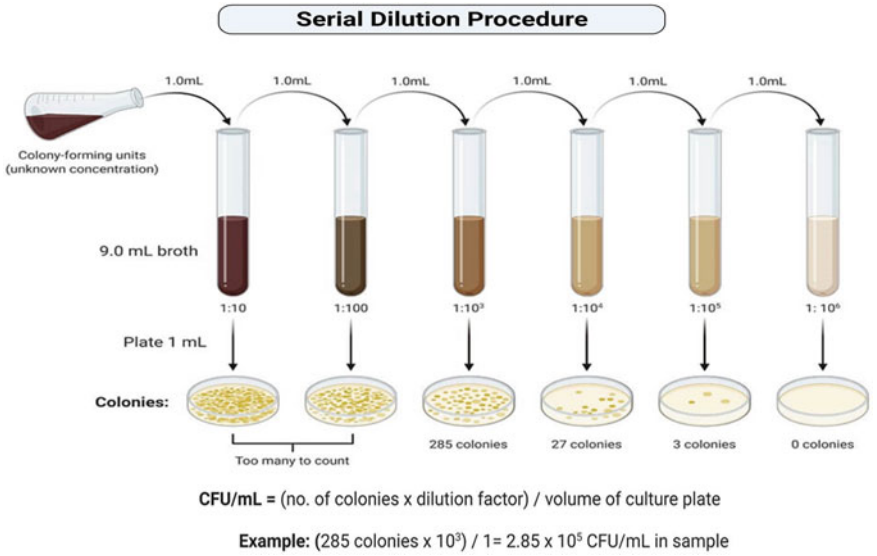


Fig. 6 Serial dilution procedure (Standard EN ISO 11737–1:2018)

in the neutralizing medium. Quantification of the recovered bacteria and fungus was done by serial dilution assay (Fig. 6).

The antibacterial activity of antimicrobial filters exhibited a 99.99% reduction against gram-positive and gram-negative bacteria after 24 h of contact time point.

The antifungal activity of antimicrobial filters exhibited a 99.71% reduction in fungus titer against Aspergillus brilliancies after 24 h of contact time point.

The antimicrobial activity on the normal filters was exhibited at a 0.30% reduction rate proving that normal filters have a negative reduction which implies the growth of microorganisms after 24 h of contact time point.

7 Pressure Drop and Filtration Efficiency Were Observed Between Coated and Uncoated Filters

Build air filter testing unit: It was assembled as a closed system with the components connected in the order that follows;

An electric fan with its related motor and electrical wiring is used for air to flow.

The filter housing with filter frame and two ports at the upstream and downstream chambers. Two ports are connected with particle counters to monitor the upstream and downstream particles.

The unit was assembled in a very clean laboratory and was leak-checked by a professional contractor to assure its integrity.

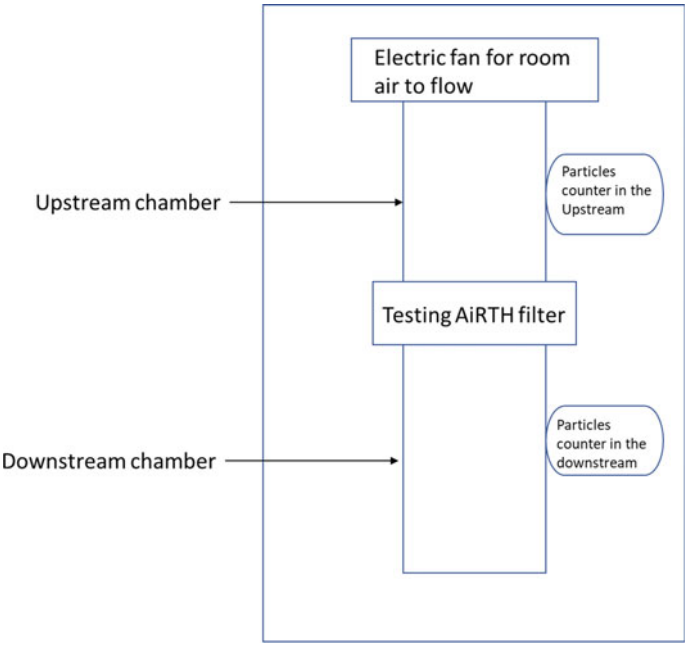


Fig. 7 AirTH filter testing

The testing filter is installed in the filter frame and then let the airflow into the unit.

The particles passed through the air filter medium were measured at the upstream and downstream chambers (Fig. 7).

Experimental set-up:

Flow rate (CFM)	Uncoated filter (Pa)	Coated filter (Pa)
100	13	14
150	26	25
200	47	43

Coated filters were found to have a marginal lesser pressure drop than normal filters.

Filtration efficiency was marginally increased for bigger particles in coated filters. Thus, there was no statistically significant difference in pressure drop and filtration efficiency observed between coated and uncoated filters (Fig. 8).

ROS generation by antimicrobial filters

To evaluate the intracellular stresses generated by antimicrobial filters on bacterial cells by studying the reactive oxygen species (ROS) production (Fig. 9).

Test organism: *Escherichia coli* ATCC 25922.

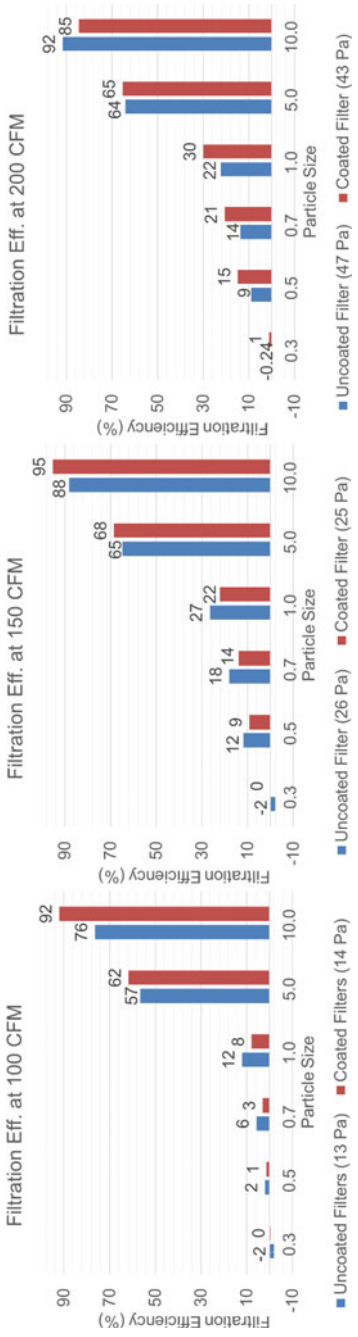


Fig. 8 Filtration efficiency of uncoated and coated filters at 100, 150, 200 CFM

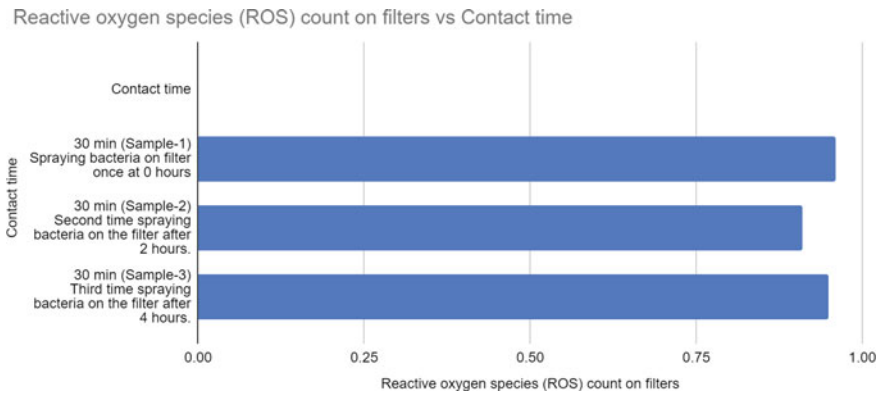


Fig. 9 Reactive oxygen species count on filters

Test procedure:

Escherichia was grown in LB broth and harvested by centrifugation and cells are re-suspended in PBS (Phosphate buffered saline) to obtain 103 CFU/ml.

100 µl of the bacterial cells were added to the 1 cm filter disk samples: These disks were (coated and uncoated) and placed in a 96-well plate.

The samples were incubated and termed as Sample-1, Sample-2 and Sample-3.

After incubation for 30 min, Sample-1 was added with 50 µl of dichlorodihydrofluorescein diacetate (DCFH-DA) dye and the sample was kept in dark for 30 min.

The fluorescence intensity was measured at the excitation wavelength of 485 nm and the emission wavelength of 528 nm using an ELISA plate reader.

After incubation for 2 h, an aliquot of 100yL of the re-suspended bacterial cells was added to Sample-2 and Sample-3 in 96 well plates and incubated.

After incubation for 30 min, Sample-2 was added with 50 pL of dichlorodihydrofluorescein diacetate (DCFH-DA) dye and kept in dark for 30 min.

The fluorescence intensity was measured at the excitation wavelength of 485 nm and the emission wavelength of 528 nm using an ELISA plate reader.

After incubation for 4 h, an aliquot of 100pL of the re-suspended bacterial cells was added and Sample-3 in 96 well plates and incubated.

After incubation for 30 min, Sample-3 is added with 50pL of dichlorodihydrofluorescein diacetate (DCFH-DA) dye and kept in dark for 30 min.

The fluorescence intensity was measured at the excitation wavelength of 485 nm and the emission wavelength of 528 nm using an ELISA plate reader.

It can be said that the bacteria were sprayed once in Sample-1, twice in Sample-2 and thrice in Sample-3.

Alongside, Sample-1, Sample-2 and Sample-3 were sprayed with the bacteria and were tested for microbial reduction at various incubation times—30 min, 2 h and 4 h.

Evaluation criteria:

The fluorescence intensity is directly correlated with the extent of ROS.

Contact time	30 min (Sample-1) Spraying bacteria on filter once at 0 h	30 min (Sample-2) Second time spraying bacteria on the filter after 2 h	30 min (Sample-3) Third time spraying bacteria on the filter after 4 h
Reactive oxygen species (ROS) count on filters	0.96	0.91	0.95
Reactive oxygen species (ROS) production (%)	96	91	95
Positive control (%)	100	100	100
Negative control			

Contact time when bacteria culture count was taken	0 h (Sample-1)	2 h (Sample-2)	4 h (Sample 3)
Culture count alone as control (count/well)	48	42	32
Culture count with coated filters (count/well)	–	1	3.5
Microbial reductions (%)	–	97.62	89

Inferences:

1. The ROS count at every interval of 30 min for the three samples plotted above shows the production of ROS at an average of 0.94 with all three samples of antimicrobial filters. Hence, it can be concluded that the production of ROS is regenerative on repeated contact with bacteria on antimicrobial filters.
2. Sample 2 and Sample 3 were tested for a microbial reduction before the bacteria were sprayed on filters after the contact time of 2 h and 4 h, showing an average of 90% reduction of bacteria concluding that the production of ROS generation that is responsible for the deactivation of Escherichia coli on antimicrobial filters.

8 Invitro Cytotoxicity Test

The purpose of this test is to prove that antimicrobial air filters are not toxic to humans. The test has been conducted as per the standard protocols ISO 10993-5:2009 (E) and ISO 10993-12:2004.

Results:

2201510/2	Neg. control	Pos. control	Growth control	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
% cell viability	-	0.582	100	78.36	78.42	77.65	76.42	73.88	73.42	73.06	73.04	73.09	70.76

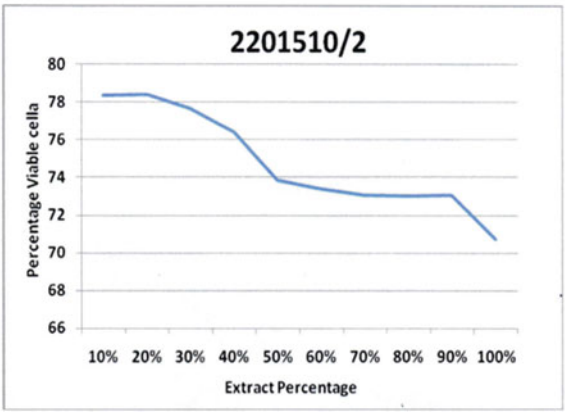


Fig. 10 Percentage of viable cells versus extract percentage

Interpretation:

1. For the assay, a concentration range from l0%- 100% was maintained.
2. At all concentrations set in the assay the sample was found to be Non-toxic to the cells (Fig. 10).

9 Results and Conclusions

Characteristic analysis using SEM showed that there is the deposition of polymers on the fibres and no pores are closed at the microscopic level. The antiviral activity of antimicrobial filters exhibited an antiviral activity value Mv value of 2.12 which is a 99.24% reduction in the virus titer against the SARS-CoV2 virus Delta variant after 24 h of contact time point. The antiviral activity of antimicrobial filters exhibited an antiviral activity Mv value of 2.33 which is a 99.53% reduction in virus titer against influenza virus after 24 h contact time point. The antiviral activity of antimicrobial filters exhibited an antiviral activity Mv value of 2.85 which is a 99.86% reduction in virus titer against MS2 Bacteriophage after 24 h of contact time point. The antibacterial activity of antimicrobial filters exhibited a 99.99% reduction against gram-positive and gram-negative bacteria after 24 h of contact time point. The antifungal activity of antimicrobial filters exhibited a 99.71% reduction in fungus titer against Aspergillus brilliancies after 24 h of contact time point. The antimicrobial activity on the normal filters was exhibited at a 0.30% reduction rate proving that

normal filters have a negative reduction which implies the growth of microorganisms after 24 h of contact time point. The pressure drop test and filtration efficiency test showed us there was no statistically significant difference in pressure drop and filtration efficiency observed between coated and uncoated filters. The ROS count at every interval of 30 min for the three samples plotted above shows the production of ROS at an average of 0.94 with all three samples of antimicrobial filters. Hence, it can be concluded that the production of ROS is regenerative on repeated contact with bacteria on antimicrobial filters. Thus the following implies the antimicrobial filters maintained antimicrobial activity throughout the operational lifetime with regenerative ROS formation. Antimicrobial air filters labeled as coated filters under the exact conditions using an in vitro toxicity test are found to be Non-toxic for the cells in culture.

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