ANALYZING INDOOR AIR QUALITY FOR PM 2.5, SECONDHAND SMOKE, INSECTS, AEROALLERGENS AND TESTING THE EFFICIENCY OF NANOTECHNOLOGY BASED AIR PURIFIERS IN MITIGATING THESE IRRITANTS

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ABSTRACT

A good air quality is essential for good health as well as to prevent the spread of diseases. In recent years, people spend 90% of their time indoors. Thus, exposure to pollutants in both occupational and residential environments have drawn much attention due to their health impacts (e.g., infections, respiratory diseases, allergies, and cancer). Indoor air can contain aeroallergens and PM 2.5 (Particulate Matter 2.5 μm). PM 2.5 is a mixture of solid and liquid particles that are suspended in the air. They can be of biological or non-biological origin. It can be composed of metals, products from fuel combustion, dust, spores and pollen and other substances. PM 2.5 can infiltrate from outdoor to indoor and some household activities like cooking, burning of wood, incense sticks, candles and smoking can also add up to indoor PM 2.5. Particulate matter with such lesser aerodynamic diameter poses a greater respiratory risk factor due to its propensity to reach deep down the lungs and enter into the bloodstream. PM 2.5 has been increasing alarmingly in all the major cities of the world. Thus, to mitigate indoor PM 2.5 concentrations, Advanced Hydrated Photocatalytic Oxidation (AHPCO®) and Air For Life Photocatalytic Oxidation (AFLPCO) technology based air purifiers were tested. It was found that AHPCO® technology could cause decay of PM 2.5, 3 times faster than the natural degradation process. Thus, reducing the time of exposure to PM 2.5 for the residents. In further

experiments, it was also found that these air purifiers were even effective against high concentration (2000 μg/m^3) of PM 2.5 under continuous airflow. Another most dreaded class-A carcinogen and avoidable indoor pollutant is Secondhand smoke (SHS). In the present work, the effect of SHS on PM 1, PM 2.5 and PM 5 concentration was studied. It was found that SHS increased the indoor PM 2.5 concentration by 20 times and PM 5 concentration by about 50 times. The air purifiers under the study were able to decrease the SHS generated PM 2.5 by 50% and PM 5 by 80%. Also, with the air purifiers, the rate of decay of PM was also increased. Besides the effect of the air purifiers on the pollutants, the insect-repellent property of the air purifiers was evaluated using *Drosophila melanogaster* as a model organism.

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INTRODUCTION

Air pollution is the presence of one or more contaminants in the atmosphere, such as dust, fumes, gas, mist, odor, smoke or vapor, in quantities and duration that can be injurious to human health. Inhaling these pollutants leads to inflammation, oxidative stress, immunosuppression, and mutagenicity in cells throughout our body, impacting the lungs, heart, brain among other organs and ultimately leading to disease.

Although there are many toxins that have adverse impacts on health, pollutants with the strongest evidence for public health concern include particulate matter (PM), carbon monoxide (CO), ozone (O_3), nitrogen dioxide (NO_2) and Sulphur dioxide (SO_2). Some pollutants are so harmful that there are no thresholds below which adverse effects do not occur. Fine particulate matter is an especially important source of health risks, as these very small particles can penetrate deep into the lungs, enter the bloodstream, and travel to organs causing systemic damage to tissues and cells. Air pollution is one of the greatest environmental risks to health. The latest estimates by the World Health Organization (WHO) and the IHME's Global Burden of Disease are very close to each other – they estimate 7 million and 6.7 million deaths per year, respectively. These deaths are attributed to both indoor and outdoor pollution. Deaths due to air pollution can be avoided by human efforts, if air pollution can be reduced to levels that would not increase the risk of developing these lethal diseases. Then, these ‘avoidable deaths’ could have been avoided. Other than mortality, exposure to air pollutants increases our risk of developing a range of diseases. These diseases fall into three major categories: cardiovascular diseases, respiratory diseases, and cancers.

The sources of air pollution consist of natural and anthropogenic origin. Anthropogenic sources of outdoor air pollution originate in a variety of human activities: the production of electricity (in particular in coal power plants), the burning of solid fuels (wood, charcoal, coal, crop waste and dung) for cooking and heating in billions of poor households; agriculture; industry; and road transport (Holman, 1999).

The largest source of *natural* air pollution is airborne dust in the world’s deserts. This form of particulate matter is a very large threat to the health of people in the arid regions of the world. A second major natural source is the smoke from wildfires in forests and grasslands. It is also being anticipated that Anthropogenic-driven warming has increased the intensity and frequency of wildfire events worldwide and the duration of wildfire seasons has been extended in recent decades (Doerr and Santín 2016). Additional natural sources of air pollution are sea spray, pollen, and volcanoes.

It is possible to reduce natural air pollution to some degree. It is certainly possible to reduce *exposure* to it – better housing, less time outdoors during periods of high concentration, and filters in the household can all make a difference.

But anthropogenic sources of air pollution are of particular interest. We can massively reduce them by changing the technologies we rely on to produce electricity, to cook our meals, to heat our homes, to produce our food, and to power our transport. According to a study by Lelieveld et al (2019) 5.5 million people die prematurely every year due to anthropogenic air pollution. This includes the air pollution caused by agriculture, residential energy use, non-fossil industrial emissions, and fossil fuel burning. Out of 5.5 million deaths 3.6 million premature deaths annually are attributable to fossil fuels in particular. This means that phasing out fossil fuels – and substituting them with clean sources of energy – would avoid 3.6 million mortality per year; this is more than 6-times the annual death toll of all murders, war deaths, and terrorist attacks combined.

Indoor Air Pollution and Health

In today's world, most people spend around 90% of their time indoors, mainly at home or at the workplace (Klepeis et al 2001). Thus, a healthy and clean indoor environment is important for the well-being of humans and their pets. It has been indicated that indoor air quality in residential areas or buildings is significantly affected by three primary factors (Mar´c, et al, 2018): (i) Outdoor air quality, (ii) human activity in buildings, and (iii) building and construction materials, equipment, and furniture. It is known that outdoor contaminant concentrations and building airtightness have a great influence on indoor air quality (IAQ), due to the possibility of transportation of contaminants from outdoors to indoors (Poupard et al, 2005). As outdoor pollutants' concentrations increase, they are transported from outdoors to the indoor environment via ventilation. Human daily activities generally cause pollution by the discharge of waste gases, tobacco smoke, pesticides, solvents, cleaning agents, particulates, dust, mold, fibers, and allergens. Humans also create favorable conditions for the development of mold, spores, bacteria, viruses, and insects, such as dust mites and roaches. Combustion sources and cooking activities contribute to carbon dioxide (CO2), sulfur dioxide (SO2), carbon monoxide (CO), nitrogen dioxide (NO2), and particulate matter (PM) emissions into indoor air environments (Linaker, 1996). In addition, equipment, such as computers, photocopy machines, printers, and other office machines, emit ozone (O3) and volatile compounds. Common building materials, such as polyvinyl chloride (PVC) floor covering, parquet, linoleum, rubber carpet, adhesive, lacquer, paint, sealant, and particle board, can shed toxic compounds (i.e., alkanes, aromatic compounds, 2-ethylhexanol, acetophenone, alkylated aromatic compounds, styrene, toluene, glycols, glycolesters, texanol, ketones, esters, siloxane, and formaldehyde) (USEPA report, 2020, Van Tran et al 2020).

According to WHO, in addition to outdoor air pollution, indoor smoke from household air pollution is a serious health risk for some 2.6 billion people who cook and heat their homes with biomass fuels and coal. Figure 1 shows annual mortality data by different groups of researchers and organizations. The WHO 2016 data shows that about 3.8 million premature deaths were attributable to indoor air pollution. Among these 3.8 million deaths: 27% are due to pneumonia, 18% from stroke, 27% from ischemic heart disease, 20% from chronic obstructive pulmonary disease (COPD), 8% from lung cancer. The studies also show that kids are more vulnerable to detrimental effects of pollution. Every day around 93% of the world's children under the age of 15 years (1.8 billion children) breathe air that is so polluted it puts their health and development at serious risk.

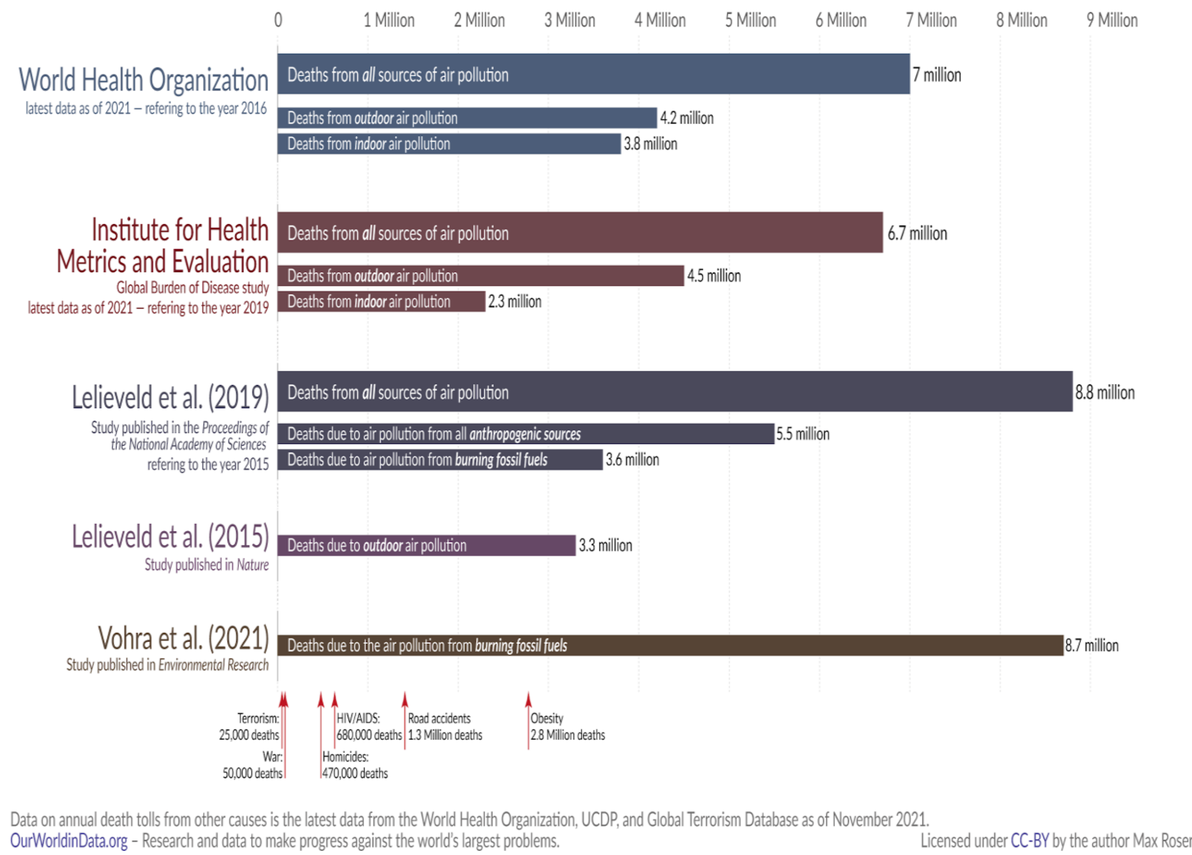


Figure. 1 Annual mortality data from different sources attributable to air pollution (Source: OurWorldData.org)

WHO estimates that in the year 2016 about 600,000 children died from acute lower respiratory infections caused by polluted air. One reason why child is particularly vulnerable to the effects of air pollution is that they breathe more rapidly than adults and so absorb more pollutants. They also live closer to the ground, where some pollutants reach peak concentrations – at a time when their brains and bodies are still developing.

Newborns and young children are also more susceptible to household air pollution in homes that regularly use polluting fuels and technologies for cooking, heating and lighting. Household air pollution is also a major source of outdoor air pollution in both urban and rural areas, accounting for up to 50% in some regions of the world. According to Lelieveld et al. (2015) one million outdoor air pollution deaths per year are caused by residential energy use and that deaths are "in addition to the 3.54 million deaths per year due to indoor air pollution from essentially the same source". The pollutant that is responsible for most air pollution deaths is particulate matter. It affects more people than any other pollutant.

There are a number of pollutants that have negative health impacts. But there is one that all studies focus on: *particulate matter*.

Particulate matter

Particulate matter – often abbreviated as PM – is everything in the air that is not a gas. These are very small particles made up of sulfate, nitrates, endotoxins, ammonia, sodium chloride, black carbon, mineral dust. PM is usually classified by its size or aerodynamic diameter into (i) coarse particles, PM 10 of diameter <10 µm; (ii) fine particles, PM 2.5 of diameter <2.5 µm; and (iii) ultrafine particles, PM 0.1 of diameter <0.1 µm. These are extremely fine particles that remain suspended in the air for longer durations. Figure 2 created by US Environmental Protection Agency (USEPA) shows that an average human hair is about 70 micrometers in diameter -making it 30 times larger than the largest fine particle. As claimed by the World Health Organization (WHO), 9 out of every 10 people in urban areas are exposed to high levels of PM 2.5 (annual average concentration >10 $\mu g/m^3$) from outdoor air pollution, and about 3 billion people using non-renewable fuels are exposed to serious indoor air pollution (World Health Organization, 2019). The Global Burden of Disease, 2015 ranks PM 2.5 as the fifth leading risk factor for death, with exposure to PM 2.5 causing 4.2 million deaths (7.6% of global deaths) and loss of 10.31 million disability-adjusted life-years (DALYs) (4.2% of global DALYs) (Cohen et al., 2017).

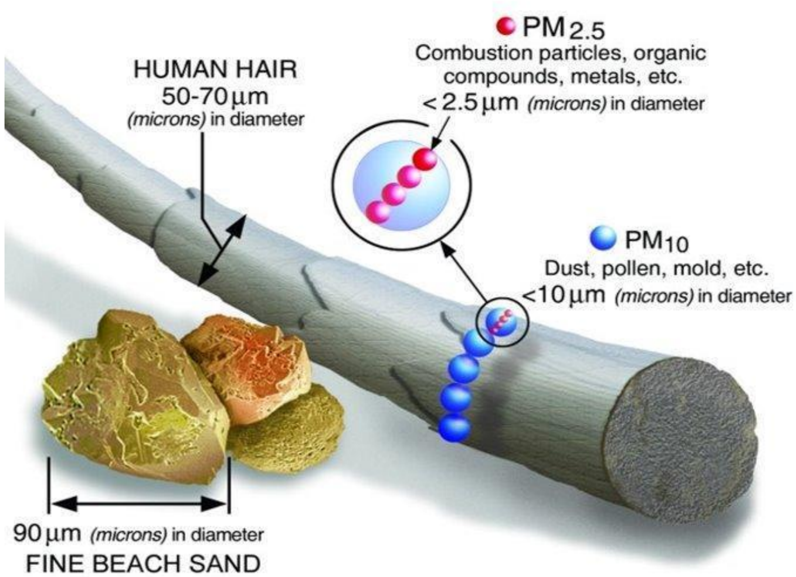


Figure 2. Comparative diagram of particulate matter size with hair (Image source: Particulate Matter (PM) Basics | US EPA)

Air quality measurements are typically reported in terms of daily or annual mean concentrations of PM particles per cubic meter of air volume (m^3). Routine air quality measurements typically describe such PM concentrations in terms of micrograms per cubic meter ($\mu g/m^3$). National air-quality standards for PM were first established in 1971. Since 1997, EPA has evaluated thousands of new studies on PM and, in September 2006, EPA revised the PM standards by lowering the level of the 24-hour $PM_{2.5}$ standard to 35 $\mu g/m^3$ and retaining the level of the annual PM 2.5 standard at 15 $\mu g/m^3$ (Figure 3). The Agency retained the 24-hour PM 10 standard of 150 $\mu g/m^3$. However, the annual PM 10 standard was revoked because of a lack of evidence establishing a link between long-term exposure to coarse particles and health problems. The secondary standards continue to be identical to the primary standards. Primary standards set limits to protect public health, including the health of "sensitive" populations such as asthmatics, children, and the elderly. Secondary standards set limits to protect public welfare, including protection against decreased visibility, damage to animals, crops, vegetation, and buildings. On December 14, 2012, EPA finalized an update to the National Ambient Air Quality Standard for PM 2.5. The annual standard was reduced from 15 $\mu g/m^3$ to 12 $\mu g/m^3$. The daily PM 2.5 standard and standards for PM 10 were retained. The revised 2012 PM standard became effective on March 18, 2013.

AQI Category	Index Values	Revised Breakpoints ($\mu g/m^3$, 24-hour average)
Good	0 - 50	0.0 – **12.0**
Moderate	51 - 100	12.1 – **35.4**
Unhealthy for Sensitive Groups	101 – 150	35.5 – **55.4**
Unhealthy	151 – 200	55.5 – 150.4
Very Unhealthy	201 – 300	150.5 – 250.4
Hazardous	301 – 400	250.5 – 350.4
Hazardous	401 – 500	350.5 – 500

Figure. 3 National Air quality standards by USEPA

According to WHO air quality guideline values for:

Fine particulate matter (PM 2.5) is

5 $\mu g/m^3$ annual mean

15 $\mu g/m^3$ 24-hour mean

Coarse particulate matter (PM 10) is

15 $\mu g/m^3$ annual mean

45 $\mu g/m^3$ 24-hour mean

PM 2.5 is used when describing pollutant levels both outdoor and indoor, where health impact from exposure considers the amount of PM 2.5 over a 24-hour period. Most studies indicate PM 2.5 at or below 12 $\mu g/m^3$ is considered healthy with little to no risk from exposure. If the level goes to or above 35 $\mu g/m^3$ during a 24-hour period, the air is considered unhealthy and can cause issues for people with existing breathing issues such as asthma. Prolonged exposure to levels above 50 $\mu g/m^3$ can lead to serious health issues and premature mortality. A study even suggested the highest hourly-averaged concentration of PM 2.5 ever recorded was 994 $\mu g/m^3$ at midnight on January 23, 2012 and the second highest was 980 $\mu g/m^3$ at midnight on February 14, 2010 (San Martini et al., 2015).

PM 2.5 and the world

Emissions from residential energy use such as heating and cooking, prevalent in India and China, have the largest impact on premature mortality globally, being even more dominant if carbonaceous particles are assumed to be most toxic. Whereas in much of the USA and in a few other countries emissions from traffic and power generation are important, in eastern USA, Europe, Russia and East Asia agricultural emissions make the largest relative contribution to PM 2.5, with the estimate of overall health impact depending on assumptions regarding particle toxicity. Figure 4 from the state of global air shows the number of deaths attributable to PM 2.5.

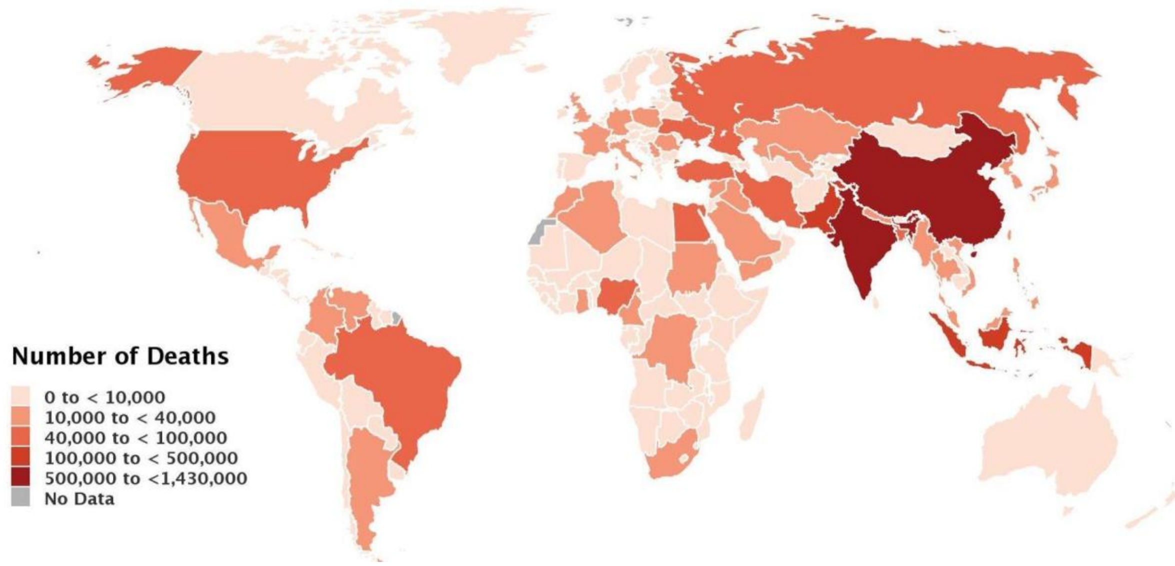


Figure 4. Number of deaths attributable to air pollution in 2019 (Image Source:https://www.stateofglobalair.org/health/pm)

Particulate Matter as Indoor Pollutant

The Indoor Air Hygiene Institute requires a PM 2.5 level of 12 $\mu g/m^3$ or less, with infrequent or no spikes of 35 $\mu g/m^3$ or higher. It has been shown that indoor PM concentrations often exceed outdoor concentrations (USEPA). Indoor PM sources include (i) Outdoor PM that enter indoor spaces through doors, windows, and "leakiness" in building structures. (ii) particles generated by indoor activities, like cleaning, cooking, smoking, burning of wood, candles, incense sticks and other activities like painting, woodworks are the main reasons why PM is generated indoors as well. Particulate matter of size 2.5 micrometers and less is more threat to health due to its penetrability into the small airways as well as alveoli (Miller et al, 2012; Brook et al, 2012) and ultimately to blood streams and other parts of the body. For cooking activity, it was shown that cooking activities enable the emission of millions of particles (~106 particles/cm^3) through the burning of oil, wood, and food and most of them are ultra-fine particles [Dennekamp et al, 2001: Yu et al., 2015). As these particles are so minute, they do not remain confined to the place they are generated, indeed they travel to every part of the house and remain suspended in the air for a longer time (Yu et al., 2015; Kim et al 2018). Meanwhile, other normal human activities, such as vacuuming, dusting and even walking, are likely to resuspend house dust and contribute to 25% of the indoor PM concentrations (Wallace, 1996). Particles of indoor origin can also include components derived from biological sources, many of which are known allergens, such as pollen from indoor plants, mold spores on windows, bacteria and viruses coming indoors with people and pets. Particles also can form indoors from complex reactions of gaseous pollutants emitted from such sources as household cleaning products and air fresheners.

PM impacts on health

According to WHO, globally, 93% of the world's children under 15 years of age are exposed to ambient fine particulate matter (PM 2.5) concentrations above WHO air quality guidelines, which include the 630 million children under 5 years of age, and 1.8 billion of children under 15 years of age. PM 10 can be visible as dust or haze with appropriate lighting whereas small particles are invisible. Large particles may affect mucous membranes and the upper airways, causing cough and tearing (Schraufnagel et al

2019), while smaller particles like PM 2.5 can enter the lung alveoli, and ultrafine particles (PM 0.1) pass through the alveolar-capillary membrane, and are readily picked up by cells, and carried via the bloodstream to expose virtually all cells in the body (Figure 5) (Pinkerton et al., 2000; Schulze et al., 2017; Yang et al., 2020)

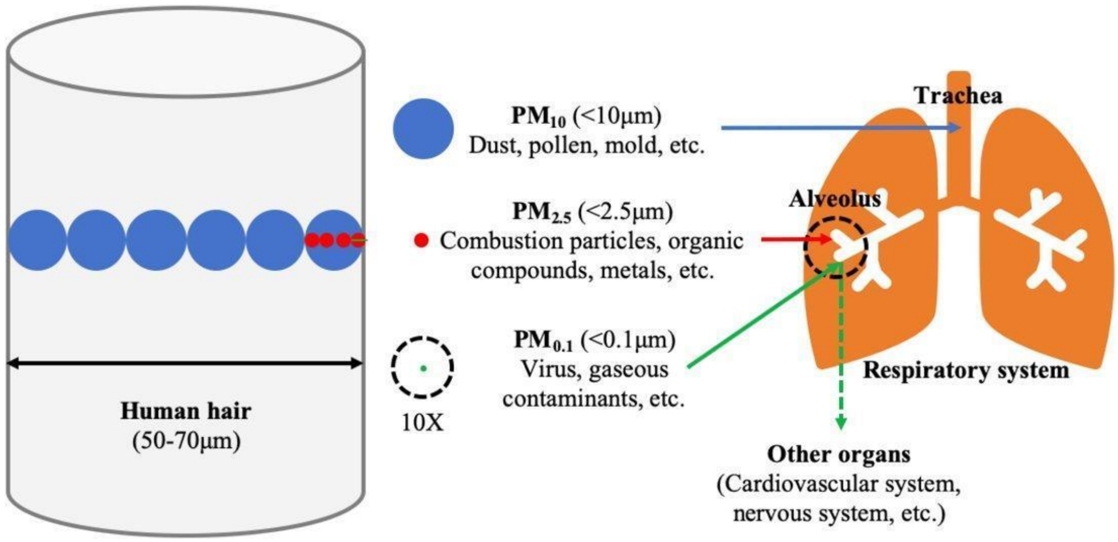


Figure 5. Effect of Particulate matter of different sizes in lungs.

Exposure to high concentrations of particulate matter, for example, can lead to reduced lung function, respiratory infections (Xing et al., 2016) and aggravated asthma from short-term exposure. Whereas long-term or chronic exposure to fine particulate matter increases a person’s risk for diseases with a longer onset, like some noncommunicable diseases including stroke, heart disease (Xing et al., 2016), chronic obstructive pulmonary disease and cancer. Thus, smaller particles have greater systemic toxicity and exposure to PM 2.5 can endanger multiple organs in the body, and even lead to systemic adverse effects (Chauhan and Johnston, 2003). Numerous clinical studies have positively correlated PM 2.5 exposure with the number of doctor’s visits for acute upper or lower respiratory infections (Strosnider et al., 2019). Several research works suggest that PM 2.5 exposure can prime the lung for greater susceptibility to pathogens by impairing the respiratory host defense. In a study, it was found that PM exposure suppressed macrophage function and slowed the pulmonary clearance of *Listeria monocytogenes* (*L. monocytogenes*) in rats (Yang et al. 2001). As it is known, the adhesion of pathogens to host cells is a prerequisite for infection. A study has reported that exposure to urban PM increased the adhesion of *S. pneumoniae* to human airway epithelial cells, possibly related to reactive oxygen species (ROS). Proximity and exposure to sources such as wildfires are becoming more prevalent. PM 2.5 exposure from wildfire smoke, for instance, is associated with increased cardiovascular events with effect estimates comparable to those with ambient PM (DeFlorio-Barker et al., 2019). Heft-Neal et al. (2018) found that in many parts of Africa, exposure to PM 2.5 is extremely high, both due to the reliance on solid fuels for cooking and dust from the African deserts (especially the Sahara). They found that a 10 $\mu g/m^3$ increase in PM 2.5 concentration is associated with a 9% rise in infant mortality. This suggests that PM 2.5 exposure is responsible for 22% of infant deaths in the studied countries; this means 449,000 infant deaths in 2015 alone. The structure and composition of the PM also play a major role in making it fatal. For example, particles that are highly acidic are more noxious. Toxic components may lie on the particle’s surface and be responsible for the tissue damage on contact. Elements such as arsenic, lead, or cadmium, or compounds such as sulfuric acid or polycyclic aromatic hydrocarbons, can be picked up during the combustion process and be carried deep into the lung on the surface of the ultrafine particles. This scenario is most relevant to particles resulting from fossil fuel combustion, especially coal combustion, which contains many heavy metal constituents and high levels of sulfur. If similar-sized particles do not contain as many toxic add-ons, they generally cause less harm (Thurston et al, 2017). PM, however, can also interact with airborne allergens as hapten carriers to trigger or even induce allergic asthma reactions in sensitized subjects (Baldacci et al, 2015; Schraufnagel et al, 2019). A recent study even suggested PM 2.5 as a potential SARS-CoV-2 carrier (Nor et al., 2021).

Prevention from PM 2.5 and air purifiers

The first step to protect from PM pollution is by avoiding the areas prone to high concentrations of PM 2.5. The EPA collects air quality data and forecasts at the Air Now website. People can check current and predicted air quality conditions of any area. If the air quality index shows elevated levels of pollutants, limit your time outdoors. Athletic activities should also be avoided in poor air conditions, since higher exertion levels increase a person's breathing rate and inhalation of pollutants. Sensitive groups of people and young kids' outdoor visits and activities should be planned at the time of the day when that area has least PM 2.5 concentrations. Outdoor high concentration of PM 2.5 also impacts inner PM 2.5 concentration as the PM infiltrates from outside to indoors. In order to prevent the outdoor PM entering indoors, one should keep windows and doors closed as much as possible and run the air conditioning. Apart from outdoor PM 2.5 there are several sources which produce indoor PM 2.5 as discussed earlier. To keep the limit over indoor PM, use the vacuum with HEPA filter to control how much dust it emits, avoid burning a wood fire or candles, incense inside, and when cooking and using the oven, make sure to allow adequate ventilation and use a good quality fume hood. These days air purifiers are emerging as promising equipment in cleaning the indoor air. Several studies suggest that some air purifiers can reduce indoor PM 2.5 by as much as 50% to 60% (Dong et al., 2019). Earlier, only HEPA based air purifiers were available in the market whose filters need to be changed timely. Nowadays more sophisticated air purifiers are available based on nanotechnology. Ionic air purifiers are the most advanced type of air purification technology. Research suggests that ionization offers numerous benefits, including improved psychological health, productivity and well-being. These are filterless air purifiers which are maintenance free. The purpose of this work was to explore the efficiency of nanotechnology based ionic air purifiers in decaying indoor PM 2.5. This work would be helpful for common people to decide whether these air purifiers are worth investing in and which ones are the better choice.

Secondhand smoke as indoor pollutant

Secondhand smoke (SHS) includes the smoke that a smoker exhales (mainstream smoke) and the smoke that comes directly from the burning tobacco product (sidestream smoke). Secondhand smoke is also called environmental tobacco smoke (ETS). Exposure to secondhand smoke is sometimes called involuntary or passive smoking. According to various reports by the US Department of Health and Services, secondhand smoke contains more than 7,000 chemicals. Hundreds of which are toxic and about 70 can cause cancer. There is no risk-free level of exposure to secondhand smoke. Secondhand smoke is classified by EPA as a Group A carcinogen.

Secondhand smoke causes numerous health problems in infants and children, including more frequent and severe asthma attacks, respiratory infections, ear infections, and sudden infant death syndrome (SIDS). Exposure to secondhand smoke during pregnancy increases the risk of having a baby with a reduced birth weight. In adults SHS can cause coronary heart disease, stroke, and lung cancer.

Smoking remains the leading cause of preventable disease, disability, and death in the U.S. Although the percentage of adults who smoke is at an all-time low in the U.S. About 34 million adults still smoke and therefore continue to be at risk of developing smoking-related diseases. Over 16 million Americans have at least one disease caused by smoking. In 2019, 21.8% of Texas high school youth reported currently using any tobacco product, including e-cigarettes. Among Texas high school youth, 4.9% reported currently smoking cigarettes. According to a study SHS exposure is estimated to have caused nearly 2.5 million deaths from 1964 to 2014 among Americans who did not smoke. From 2005-2009, an estimated 7,330 lung cancer deaths and 33,950 coronary heart disease deaths annually were attributable to secondhand smoke exposure. Nonsmokers who are exposed to secondhand smoke at home or work increase their risk of developing heart disease by 25-30% and lung cancer by 20-30%. Cotinine, a metabolite of nicotine, is used as a biomarker of recent secondhand smoke exposure. Using an established serum cotinine range of 0.05 ng/mL to 10 ng/mL, during 2017-2018, nearly one in four Americans aged ≥3 years who do not smoke were exposed to secondhand smoke (Tsai et al., 2021).

A 2011 study reported that secondhand smoke exposure can produce adverse inflammatory and respiratory effects within 60 minutes of exposure and that these effects persist for at least three hours after the exposure (Flouris and Koutedakis, 2011). Therefore, there may be compounded health effects for an employee working an eight-hour shift in a smoke-filled place, such as a restaurant or bar.

In order to estimate the effect of SHS on air quality many researchers have found that there is an increase in PM2.5 concentration followed by smoking. There are several studies which established the correlation between cigarette smoke and PM 2.5. A study by Nafees et al. (2012) demonstrates unacceptably high levels of PM 2.5 exposure associated with secondhand smoke (SHS). Another study found that smoking causes unhealthy levels of PM 2.5 concentrations, not only indoors, but also in the patios of hospitality venues. (Kaplan et al., 2019).

With planning, one can reduce their family's exposure to secondhand smoke starting with steps like not allowing smoking in your home. Always preferring smoke free facilities. Contrary to common belief, opening windows and ventilation systems doesn't eliminate exposure to secondhand smoke. Sometimes, the above mentioned prevention steps are not within the reach of a non-smoker. To eliminate such exposure mandated or voluntary smoke-free policy implementation is important. Besides this, the most easy way to get rid of smoke generated PM 2.5 is to use air purifiers. In the present study, I intended to check the efficacy of air purifiers in reducing the SHS generated PM 1, PM 2.5, PM 5.

Insects as indoor irritants

Insects pose a great harm to humanity by transmitting some dreaded diseases like Malaria and Dengue. Malaria is caused in humans by *Plasmodium* parasites (mainly *Plasmodium falciparum* and *Plasmodium vivax*) that are transmitted by the bite of *Anopheles* mosquitoes. According to UNICEF, a child dies of malaria every two minutes. In 2016, almost half of the world's population was at risk of contracting the disease — that's about 3.2 billion people. Of the 445,000 people who died of malaria that year, 290,000 of them were children under the age of five. According to WHO in 2020, there were an estimated 241 million cases of malaria worldwide and the estimated number of malaria deaths were 627,000. Studies even suggest that some children infected by the disease may experience intellectual disabilities for the rest of their lives. Thus, the irony is despite malaria being both preventable and treatable, the world is still facing millions of these avoidable deaths.

Another insect related dreaded disease is dengue. The dengue virus is transmitted to humans through the bites of infected female mosquitoes, primarily the *Aedes aegypti* mosquito and secondarily by *Aedes albopictus*. *Aedes albopictus, a secondary* dengue vector, has spread to more than 32 states in the USA, largely due to the international trade in used tyres (a breeding habitat) and other goods (e.g. lucky bamboo). *A. albopictus* is highly adaptive to colder conditions as an egg and adult making it widespread (Romi et al., 2006).

The number of dengue cases reported to WHO increased over 8 fold over the last two decades, from 505,430 cases in 2000, to over 2.4 million in 2010, and 5.2 million in 2019. And the number of deaths increased from 960 to 4032 between the year 2000 and 2015 affecting mostly younger age groups.

Despite all the governmental efforts in fighting against these dreaded diseases the number of cases are continuously increasing. So one simple solution to the problems of insects can be to use air purifiers. In a study, an indoor ozone-producing air purifier was evaluated for its repellency effects on *Aedes aegypti, Aedes albopictus, Culex quinquefasciatus, Musca domestica* and *Periplaneta americana*. They recorded about (83.23%) repellency effect against *Cx. quinquefasciatus* (Wan-Norafikah et al., 2016). In this study we want to explore the repellency effect of two nanotechnology based air purifiers.

Indoor aeroallergens

Both outdoor and indoor aeroallergens can cause allergic asthma. Major indoor aeroallergens are derived from dust mites, pet dander, pollens and fungi. Most of the fungi and pollens recovered from an indoor environment emanate from outside (Ghosh et al., 2006). However, certain species, such as *Penicillium* and *Aspergillus*, can be found in greater quantities indoors.

Pollen grains are one of the earliest identified aeroallergens and a major cause of bronchial asthma and allergic rhinitis (Singh, & Mathur. 2017). Symptoms caused by pollen allergens include sneezing, watery eyes, nasal obstruction, itchy eyes and nose, and coughing. Allergy symptoms to fungal spores also include respiratory problems, nasal-sinus congestion, watery eyes, sore throat, coughing, asthma, and skin irritations..

If indoor, these particles are distributed throughout a room within minutes and accumulate over hours. Airborne particulates will remain airborne until settling occurs or they are inhaled. Thus, the quality of the air we breathe can have a direct impact on our health. Air quality monitoring is a rapidly emerging area due to the increasing infectious diseases transmission and pollution. Monitoring indoor air helps in the assessment of indoor air quality and cause of allergies.

The best way to improve your air quality is to get rid of the sources of allergens and irritants from your home. Reducing humidity decreases dust mites and mold growth. Air conditioners help reduce humidity too. They can also prevent outdoor allergens. Besides these, air purifiers can help clean the indoor air. In the present study, air quality of some indoor areas was checked for presence of aeroallergens.

CHAPTER II

AIMS & OBJECTIVES

Aim:

Do air purifiers help in reducing the indoor particulate matter (PM) concentration and other pollutants?

Objectives:

PM 2.5 as indoor pollutant

- To test the efficacy of nanotechnology-based air purifiers IonicAir and MiniSanifier in decaying artificially generated PM 2.5 in a fiberglass chamber.
- Comparison of the PM 2.5 decaying rate of the two air purifiers with the natural decaying rate.
- Check the working efficacy of air purifiers in high concentration and low concentration of PM 2.5.
- Comparison of PM 2.5 decaying rate with and without using air purifier under no air circulation.

Secondhand smoke (SHS) generated PM as an indoor pollutant

- To compare the maximum PM 1 concentration reached during and after burning of one cigarette with and without using an air purifier in a fiberglass chamber and a closed room.
- To compare the maximum PM 2.5 concentration reached during and after burning of one cigarette with and without using air purifier in a fiberglass chamber and a closed room.
- To compare the maximum PM 5 concentration reached during and after burning of one cigarette with and without using an air purifier in a fiberglass chamber and a closed room.
- To compare the PM 1, PM 2.5, PM 5 decaying rate of two types of air purifiers with each other and with the control.

Insects as indoor irritants

- To study the *Drosophila* as a model organism for exploring the insect repellant property of Mini Sanifier.

Indoor aeroallergens

- To collect the common aeroallergens present indoors using NIOSH BC 251 cyclone aerosol sampler

CHAPTER III

MATERIALS AND METHODS

Equipment which were used during different experiments were:

(1) Lighthouse Handheld 3016 IAQ

This equipment is used to measure the Particulate matter concentration of varying sizes (Fig. 6). The number “3016” indicates a 0.3 μm minimum channel size at 0.1 CFM with up to 6 channels. The instrument uses a laser-diode light source and collection optics for particle detection. Particles scatter light from the laser diode. The collection optics collect and focus the light onto a photo diode that converts the bursts of light into electrical pulses. The pulse height is a measure of particle size. Pulses are counted and their amplitude is measured for particle sizing. Results are displayed as particle counts in the specified size channel.

(2) Air purifiers

The two air purifiers used were IonicAir™ and AFL Mini Sanifier® II. These are Ionic air purifiers. Ionization itself is a 100-year old technology. All ionic air purifiers (also called air ionizers) work by emitting ions which interact with and deactivate contaminants such as viruses & bacteria, mold, allergens, Volatile Organic Compounds (VOCs), and odors. Ionic air purifier, is a device that releases negative ions (molecules that contain an extra electron) into the air. Negative ions latch on to particles in the air, giving them an electrical charge. The electrical charge causes particles to clump together and become heavy, eventually falling from the air.

IonicAir™

IonicAir™ (Fig.7.) uses Air Oasis created Advanced Hydrated Photocatalytic Oxidation

(AHCPO®), a technology. This technology uses specific catalytic elements to produce a variety of safe, long-lasting ions. Ion generators that use AHPCO® technology create ions that travel farther and can deactivate contaminants in the air and on surfaces. Figure 8 shows the mode of action of AHPCO® technology by Air Oasis. This sophisticated technology was initially researched by NASA and further developed for commercial use by Air Oasis and others. In it, UV light shines on a photocatalyst then the water molecules in the air activate and reorganize. Ions, such as H202, are produced.

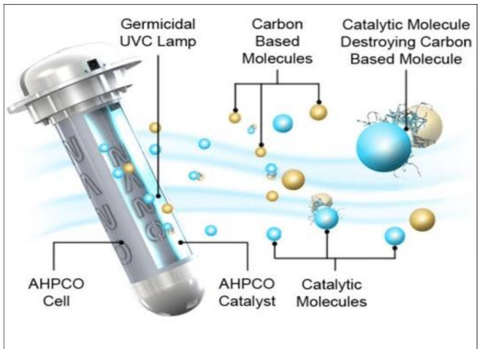


Figure. 8 Mode of action of AHPCO® technology

These ions interact with single-cell contaminants, and VOCs are broken down on a molecular level to their simplest elemental forms and Bacteria and viruses are deactivated: RNA and DNA can no longer replicate. Thus, AHPCO® ionization deactivates at a molecular level.

AFL Mini Sanifier® II

The AFL Mini Sanifier (Fig. 9) is the Filter-less, portable device for small rooms covering upto area of 330 ft^2 . It uses Air For Life Photo-Catalytic Oxidation (AFLPCO) technology. As AFLPCO emits human friendly low doses of negative ions, the air as well as nearby objects and surfaces in the room are sterilized. Photocatalytic Oxidation or PCO technology began with NASA in 1994 to purify the air in spacecraft. When NASA began planning for deep space exploration, including proposed manned missions to Mars such as the "Constellation Mission Program " in 2013, sustaining life in space for months and years at a time was necessary. Before preparing for deep space exploration, NASA

had to find an answer to ethylene gas destroying plants and vegetables in the space shuttle. Ethylene gas is the naturally occurring hormone released by plants and vegetables to signal ripening. On earth, it is naturally dispersed into the atmosphere, but in a sealed spacecraft, ethylene build up becomes toxic, killing those very same plants and vegetables if not removed. Scientists at NASA developed a new green technology called PhotoCatalytic Oxidation (PCO) to remove the ethylene gas build-up. PCO technology works by breaking down the ethylene gas into harmless Carbon Dioxide (CO_2) and Water (H_2O) by exposure to UltraViolet (UV) light in the presence of a Titanium Dioxide (TiO_2) catalyst. Further tests by NASA revealed PCO technology not only eliminated ethylene gas build up, but also destroyed all carbon-based impurities in the air such as bad odors, Volatile Organic Compounds (VOC's), Fungi, Bacteria, and Viruses.

(3) NIOSH BC 251 cyclone aerosol sampler

This is a two-stage cyclone sampler BC 251(Fig. 10), which collects aerosols in a 15 ml centrifuge tube, a 1.5 ml tube and on a backup filter. At 3.5 l/min, the BC 251 conforms to the ACGIH/ISO criterion for separation of respirable and non-respirable airborne particles, which is widely used in health-related aerosol measurements. The BC 251 has been successfully used to collect airborne influenza virus in

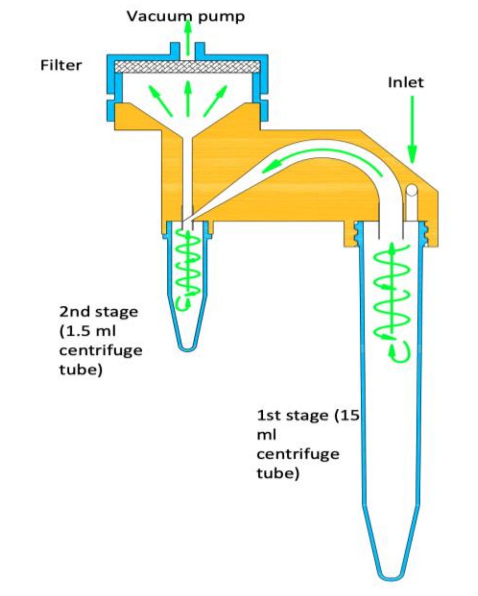
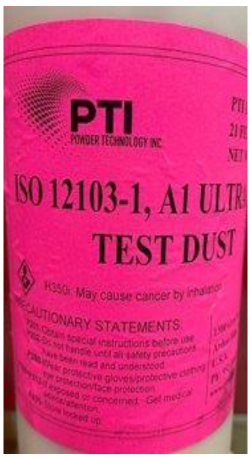


Figure 11: Diagrammatic view of cyclone sampler mode of action

healthcare facilities and from the coughs of influenza patients. A cyclone sampler works (Fig 11.) by pulling air into a round chamber and swirling it around like a cyclone.

Particles in the air are thrown against the wall of the chamber by centrifugal force, where they collect. In the NIOSH sampler, air and particles are first pulled into the sampler through the inlet on the right. Large particles (4 μm and larger) collect on the wall of the first tube. The air and uncollected particles flow out and into the second tube. Because the second tube has a smaller radius and smaller inlet nozzle (resulting in faster air flow), smaller particles (1 to 4 μm) will collect here. The smallest particles (<1 μm) pass through this tube and collect on the filter.

(4) Dust, Fan and Fiberglass chamber



Dust: The ISO 12103-1 ultrafine dust particle (Fig. 12.) with an average size of 2.75 micron (PTI Powder Tech., Minnesota) was used as a source of PM 2.5 and to create a PM 2.5 rich environment in the fiber glass chamber.

Fan: To circulate air in the chamber

Fiberglass chamber: It had three airtight lids, two on the top and one on the side to keep the equipment inside. It had a volume of 12.45ft^3. It was used for PM 2.5 related experiments and Secondhand smoke related experiments.

METHODOLOGY

(1) PM 2.5 and air purifiers

The main aim of this study was to test the efficacy of both the air purifiers, IonicAir and Mini Sanifier in decaying artificially generated PM 2.5. This experiment was done in three different variations. For all the three sets of experiments, a fiberglass chamber of volume 12.45ft^3 was used to assess the AFL Mini Sanifier and IonicAir air purifier in terms of reduction of PM 2.5. The chamber was first cleaned using Clorox wipes and allowed to dry up for 24 hours. About 2 g of dust was spread from the top lid of the chamber to create a high concentration PM 2.5 environment. In all of the experiments, temperature was maintained between 22ºC-25ºC and humidity between 20%-30%. Experiments were done in 5 replicates. For all the PM 2.5 decaying experiments data was recorded until the PM 2.5 concentration reached 30μg/m^3 as 35μg/m^3 is the acceptable range by EPA.

Experiment 1: Comparison of PM 2.5 decaying rate with and without using air purifier under no air circulation

For the first set of experiments no fan was used, this was done to create a still air environment inside the chamber. Firstly, the Lighthouse handheld was placed in the chamber. It was set at 30 mins intervals to record the change in PM 2.5 concentration. For control, no air purifier units were run inside the chamber. Then, the dust was spreaded from the top lid of the chamber. The data recorded gave the natural decay rate of PM 2.5 which was considered as control. This experiment was then repeated with IonicAir and then Mini Sanifier and the PM 2.5 decay rate of both the air purifiers (with no air circulation) were compared with control.

Experiment 2: Analyzing high concentration PM 2.5 decaying rate of air purifiers and comparing it with control

To test the working capacity of air purifiers in decaying high concentration PM 2.5, firstly a Lighthouse handheld was placed in the chamber. It was set at 30 mins intervals

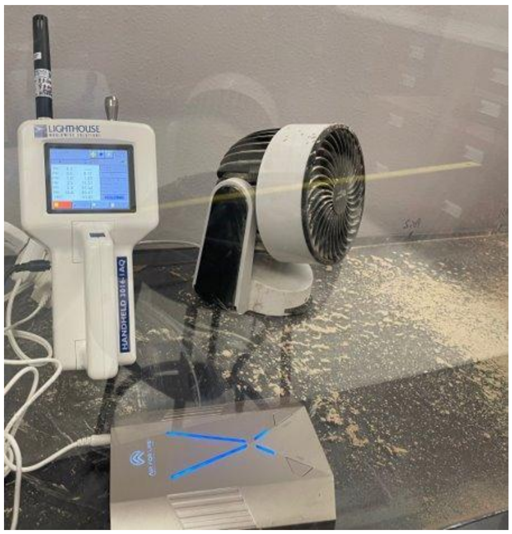


Figure 13. Lighthouse handheld, a fan, Mini Sanifier in the fiberglass chamber

to record the change in PM 2.5 concentration. A fan was also placed inside for the continuous air flow in the chamber. For control, no air purifier units were run inside the chamber. Both the equipment were turned on, then 2g dust was spreaded from the top lid of the chamber. Within one minute the chamber concentration reached 2000 $\mu g/m^3$. This concentration was ideal to start recording high concentration decay. The data recorded gave the natural decay rate of PM 2.5 which was considered as control. This experiment was repeated with IonicAir and then Mini Sanifier using the same PM 2.5 concentration range of 2000μg/m^3 -2140μg/m^3 . Time taken for PM 2.5 decaying by both the air purifiers was recorded and compared with control (Fig. 13).

Experiment 3: Analyzing low concentration PM 2.5 decaying rate of air purifiers and comparing it with control

To test the working capacity of air purifiers in decaying low concentration PM 2.5, firstly a Lighthouse handheld was placed in the chamber. It was set at 30 mins intervals to record the change in PM 2.5 concentration. A fan was also placed inside for the continuous air flow in the chamber.

Figure 14. Lighthouse handheld, a fan, IonicAir in the fiberglass chamber

For control, no air purifier units were run inside the chamber. Both the equipment were turned on, then 1g dust was spreaded from the top lid of the chamber. Once the PM 2.5 concentration was reached between 92 μg/m^3-105 μg/m^3 recording of the data was started. The data recorded with no air purifier, gave the natural decay rate of PM 2.5 which was considered as control. This experiment was repeated with IonicAir (Fig. 14) and then Mini Sanifier using the same PM 2.5 concentration range of 92 $\mu g/m^3$-105 $\mu g/m^3$. Time taken for PM 2.5 decaying by both the air purifiers was recorded and compared with control.

For further analysis and comparison of the data obtained from the three sets of experiment, rate of decay and area under the curve was calculated. Area under the curve was calculated using excel software and rate of decay was calculated by following formula:

P = Initial amount

A = Final amount

t = time

$A=P e^{rt}$

(2) Secondhand smoke (SHS) generated PM, as an indoor pollutant and air purifiers

The aim of this study was to compare the maximum PM 1, PM 2.5 and PM 5 concentration reached during and after burning of one cigarette with and without using an air purifier in a fiberglass chamber and a closed room. For this purpose three sets of experiments were done. After every run the chamber was cleaned and kept ventilated for 2-3 days before running the next set of experiments.

Experiment 1: Study of SHS generated PM1, PM2.5 and PM 5 in a fiberglass chamber

Before beginning the experiment the chamber was cleaned from inside with Clorox wipes and allowed to dry. Firstly, the Lighthouse handheld was placed in the fiberglass chamber. Then the PM 1, 2.5, 5 concentrations were recorded. These gave us the PM concentration in the chamber before the generation of secondhand smoke. The Lighthouse handheld was then set at 2 mins intervals to record the change in PM 1, 2.5, 5 concentration after SHS generation. One cigarette was placed vertically in a petri dish.

Figure. 15. Lighthouse handheld, a fan, Mini Sanifier and a burning cigarette in the fiberglass chamber

inside the chamber and lit (Fig. 15). Immediately after lighting it, the lid was closed and the data were recorded. For control, no air purifier units were run inside the chamber.

After this the same procedure was repeated with IonicAir and Mini Sanifier separately. For all the three types of experiments with and without the air purifiers the data was recorded even after 15 mins of cigarette being burnt off. Then, the maximum particulate matter concentration reached during that time period (approx. 45 min) was recorded.

Experiment 2: Study of SHS generated PM 1, PM 2.5, PM 5 in a closed room of 225 ft^2 area

The purpose of this study was to monitor the spread of PM 2.5 in the room after the SHS generation by burning one cigarette. This experiment was done with two variables: in the first setup the cigarette and the PM monitor were placed 10 feet away from each other (Fig. 16) and in the second setup the cigarette and the PM monitor were placed 15 feet from each other. The Lighthouse handheld was set at 2 mins intervals to record the change in PM 1, 2.5, 5 concentration after SHS generation. One cigarette was placed vertically in a petri dish in the closed room. After lighting it, data was recorded. For control, no air purifier units were run in the room. After this the same procedure was repeated with IonicAir and Mini Sanifier separately. For all the three types of experiments with and without the air purifiers the data was recorded even after 30 mins of cigarette being burnt off. Then, the maximum particulate matter concentration reached during that time period (approx. 45 min) was recorded. Same procedure was repeated by

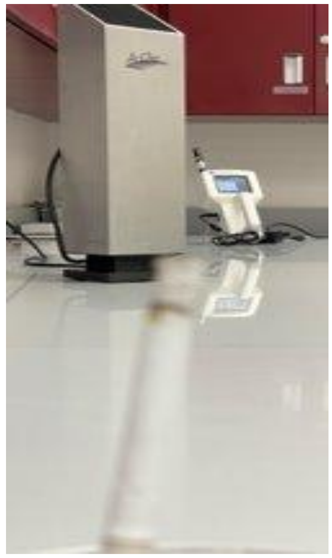


Figure. 16. IonicAir, Lighthouse handheld, and a burning cigarette placed 10 feet apart in a closed room.

placing the cigarette and the PM monitor 15 feet away from each other. For experiments with air purifiers the air purifying units were placed in between the Lighthouse handheld and the cigarette as shown in figure 16.

Experiment 3: To compare the PM 1, PM 2.5, PM 5 decaying rate of two types of air purifiers with each other and with the control.

For all the experiments done above with and without using air purifiers the time taken with and without air purifiers for PM to reach the safe concentration was recorded. This data was then used to calculate the rate of decay for PM 1, PM 2.5 and PM 5. Rate of decay was calculated by the same formula as mentioned earlier.

(3) To assess the repellent effect of Air purifiers against insects: taking *Drosophila melanogaster* as a model organism

Culture handling and maintenance: *Drosophila* (Fruit flies) were cultured on the *Drosophila* media (Fig. 17). Most stocks were successfully cultured by periodic mass transfer of adults to fresh media. Bottles were tapped on the pounding pad to shake flies away from the plug, the plug was rapidly removed, and the old culture inverted over a fresh bottle. Flies are tapped into the new vessel, or some shaken back into the old one, as necessary, and the two are rapidly separated and replunged. Good tossing technique combined with plugs that are easily removed and replaced resulted in very few escapes. Stocks were kept at room temperature and were transferred to fresh media every 3 to 4 week.

Experimental Setup

A fiber glass chamber was used in this study. The chamber had three openings. Two at the upper part of the chamber and one at the side of the chamber. The upper opening was used to release the fruit flies and the side opening was used to keep bait and the air purifier. The first set of experiments were done without the air purifier to study the behavior of the fruit flies in the chamber and the data obtained was used as control. The second set of experiments were done using an air purifier. In this setup the distance

Figure. 18. *Drosophila* experimental setup

between the air purifier and the bait was used as a variable. Mashed bananas were used as bait. For every replicate about 100 overnight starved fruit flies were released from the upper opening of the chamber. The number of flies attracted towards the bait was counted. Then the same experiment was done with the Mini Sanifier, firstly it was placed about 25 cm away from the bait and then in the subsequent experiments the distance between the air purifier and the bait was increased up to 100 cm. Once the flies were released into the chamber then the air purifier was turned on and the number of flies on the bait and in the vicinity of the air chamber was counted and the number of flies away from the bait and the air purifier was counted. The number of flies landing on the bait within 10 minutes was counted. At least 3 replicates were tested for each set in this study. Results obtained were subjected to statistical analysis. The control data were compared with data obtained after using an air purifier.

(4) Sampling Indoor Air for aeroallergens

Air sample was taken using a two-stage bioaerosol cyclone sampler by the National Institute for Occupational Safety and Health (NIOSH). The sampler was placed 1.2m from the ground on the tripod stand. The sampler collected the aeroallergen for 30 minutes. This sampler collects particles >4 μm in diameter into a 15 mL centrifuge tube, particles 1–4 μm in diameter into a 1.5 mL centrifuge tube, while particles <1 μm in diameter are collected onto a 37-mm diameter, polytetrafluoroethylene filter with 2-μm pores. After aeroallergen collection for 30 minutes, samples were analyzed following standardized techniques by using microscopes. The samples were collected in replicates of three from each closed room studied.

Statistical Analysis

Data collected was checked for completeness and then statistically analyzed. Descriptive data were represented as mean, standard deviation and range. Different levels were expressed at 95% Confidence Interval. A P-value of less than 0.05 was considered statistically significant. Mean values were compared with hypothesis testing as found applicable. Correlation analysis was attempted between PM 2.5 concentration with and without using air purifiers.

CHAPTER IV

RESULTS AND DISCUSSION

(1) PM 2.5 and air purifiers

To test the efficacy of nanotechnology-based air purifiers; IonicAir and Mini Sanifier in decaying artificially generated PM 2.5 in a fiberglass chamber 3 sets of experiments were done.

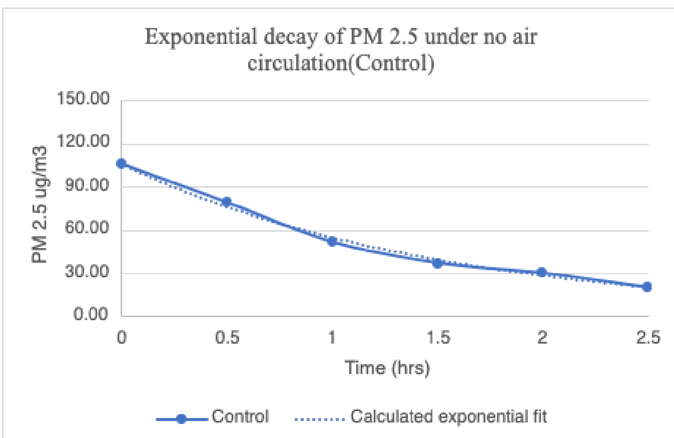


Figure 19. PM 2.5 decay in a fiberglass chamber under controlled conditions with no air circulation and no air purifiers.

Figure 19 shows the exponential decay of PM 2.5 under no air circulation with a calculated exponential line of best fit, this was considered as control. It was found that with no air purifier running, the 30µg/m^3 (acceptable range of PM 2.5) concentration was reached within 120 min and when Mini Sanifier was used, it took 105 mins (Fig. 20).

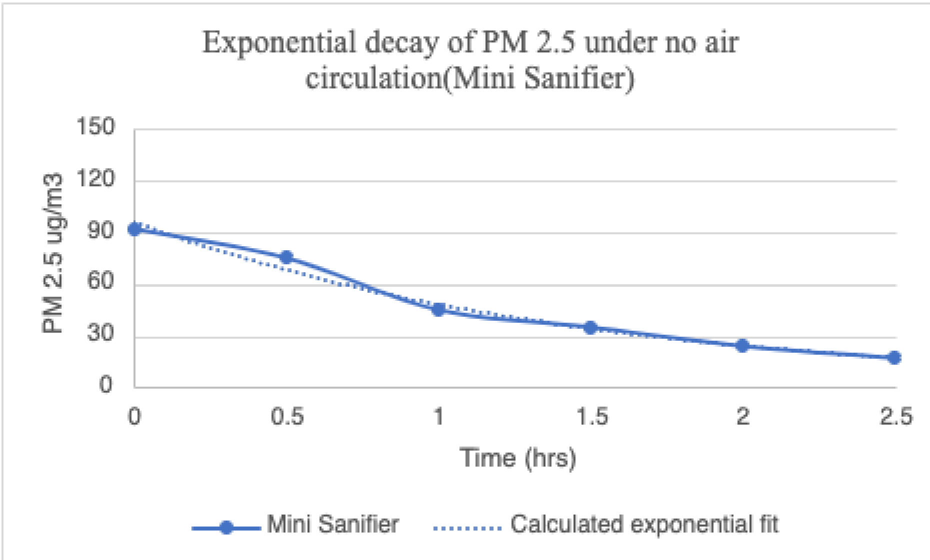


Figure 20. PM 2.5 decay in a fiberglass chamber under controlled conditions with no air circulation and Mini Sanifier air purifier.

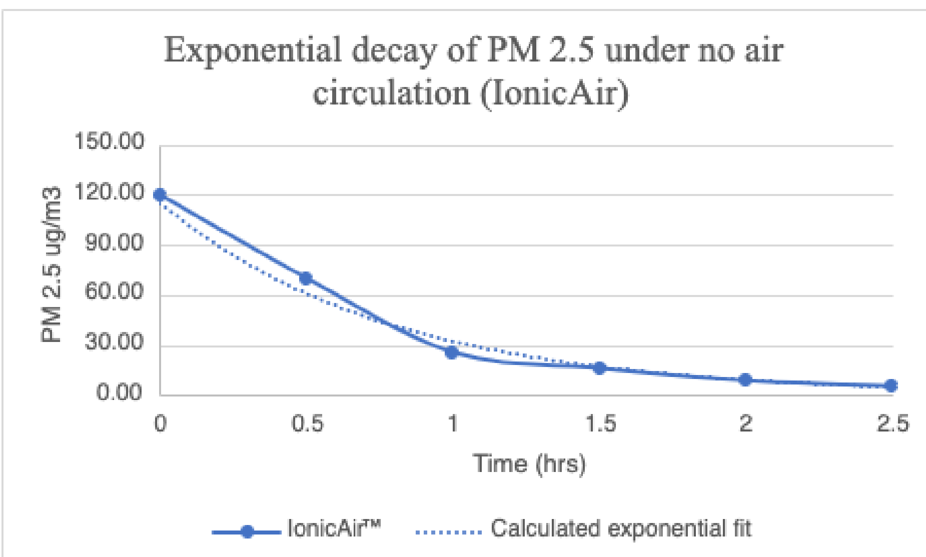


Figure 21. PM 2.5 decay in a fiberglass chamber under controlled conditions with no air circulation and IonicAir air purifier.

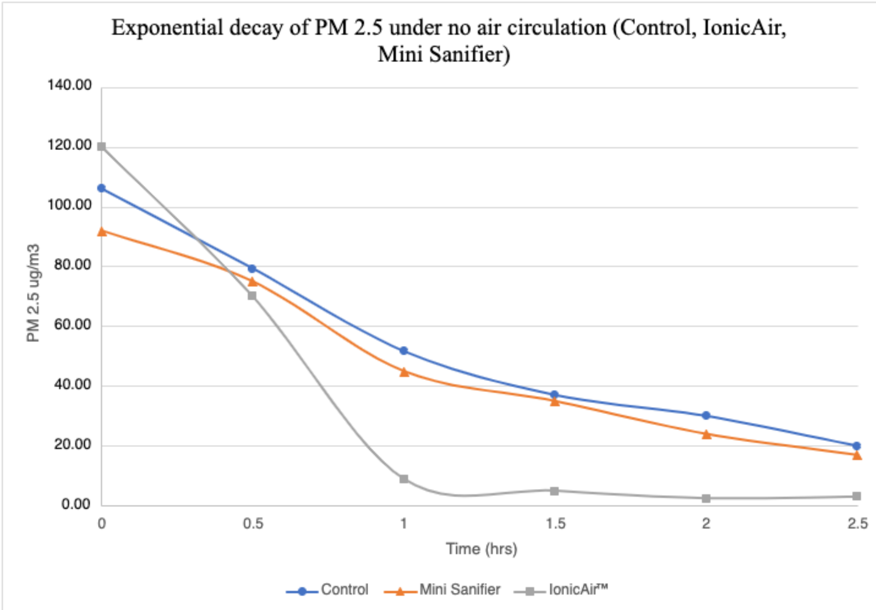


Figure 22. Comparison of PM 2.5 decay for control and when using IonicAir and Mini Sanifier units as a function of time

With IonicAir, air purifier it only took less than 45 min to reach the acceptable range of PM 2.5 (Fig. 21). A representative graph of the PM 2.5 concentration experiments including control, Mini sanifier and IonicAir has been shown in Figure 22. Figure 22 shows the series of IonicAir constantly decreasing with time. The steeper the slope, the faster the decay of PM 2.5. The IonicAir showed the steepest slope in comparison to Mini Sanifier and control. Thus, the IonicAir significantly decreased the PM 2.5 concentration as a function of time compared to the control.

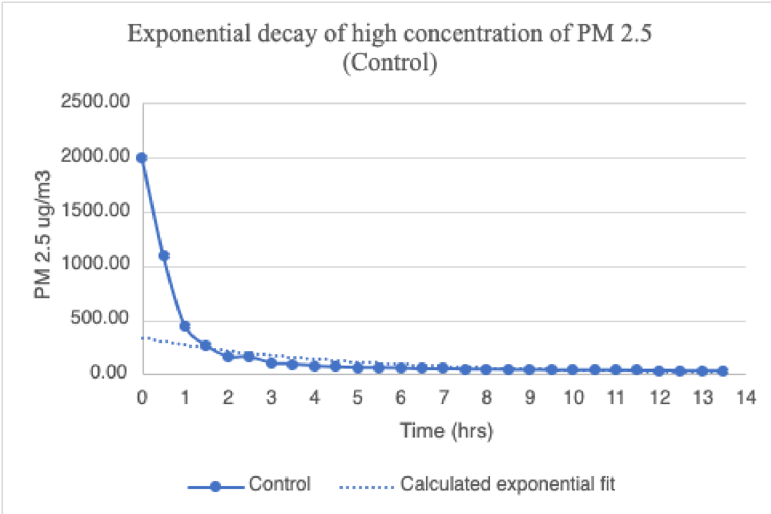


Figure 23. PM 2.5 decay in a fiberglass chamber with continuous air circulation and no air purifier.

Second set of experiments were done to check the efficacy of air purifiers under high PM 2.5 concentrations. Figure 23, 24, 25. shows the exponential decay for high concentration of PM 2.5 with calculated line of best fit of control, and when using Mini Sanifier and IonicAir units. It was found that with no air purifier running, the 30µg/m^3 (acceptable

the range of PM 2.5) concentration was reached within 13.5 hrs and when Mini Sanifier was used, it took 8.5 hrs (Fig. 24) and with IonicAir it only took 5.5 hrs to reach the acceptable range of PM 2.5 (Fig. 25).

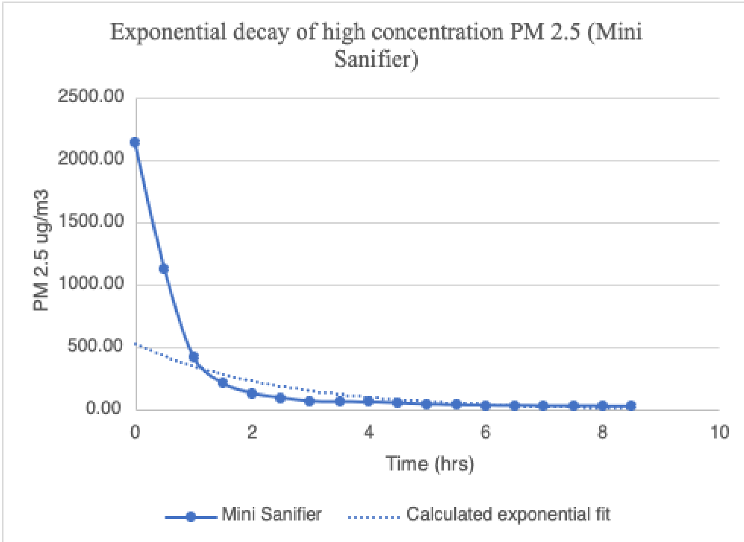


Figure 24. PM 2.5 decay in a fiberglass chamber with continuous air circulation and Mini Sanifier.

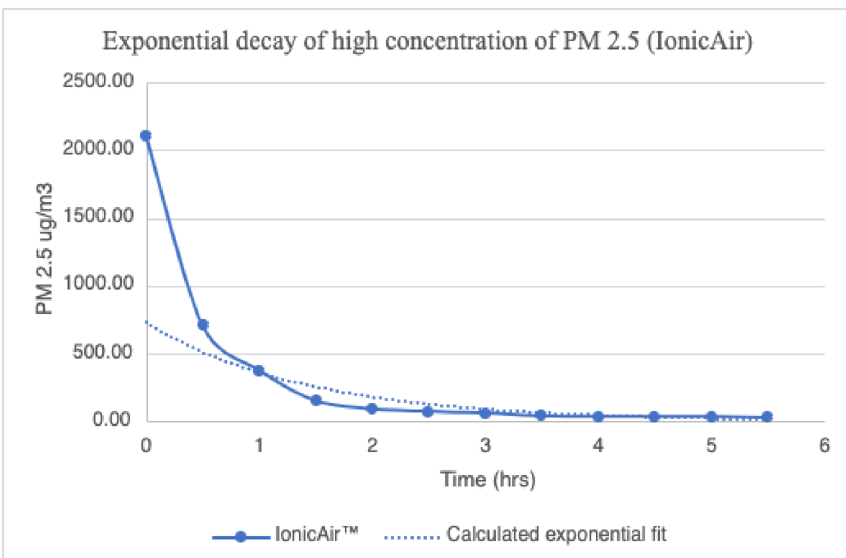


Figure 25. PM 2.5 decay in a fiberglass chamber with continuous air circulation and IonicAir

A representative graph of the PM 2.5 high concentration experiments including control, Mini sanifier and IonicAir has been shown in Figure 26. Figure 26 shows the slope for the high concentration PM 2.5 decay as a function of time. While using the IonicAir unit it took less than half the time of control to reach the acceptable concentration of PM 2.5.

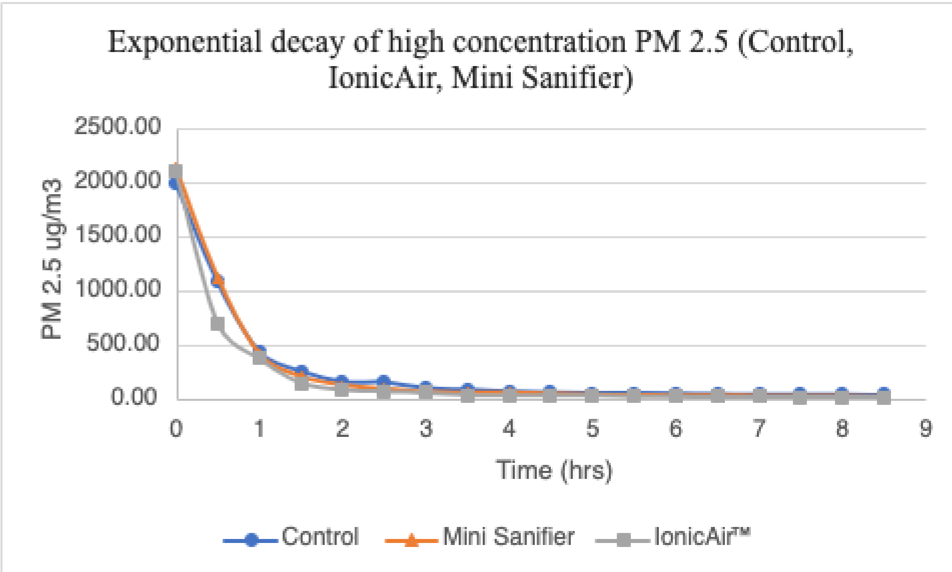


Figure 26. Comparison of PM 2.5 decay for control and when using IonicAir and Mini Sanifier units as a function of time.

Third set of experiments were done to check the efficacy of air purifiers under low PM 2.5 concentrations. Figure 27, 28, 29 shows the exponential decay for low concentration of PM 2.5 with calculated line of best fit of control, and when using Mini Sanifier and IonicAir units. It was found that with no air purifier running, the 30µg/m^3 (acceptable range of PM 2.5) concentration was reached within 10.5 hrs followed by Mini Sanifier which took 6 hrs (Fig. 28) and with IonicAir air purifier it only took 3.5 hrs to reach the acceptable range of PM 2.5 (Fig. 29). A representative graph of the PM 2.5 low concentration experiments including control, Mini sanifier and IonicAir has been shown in Figure 30.

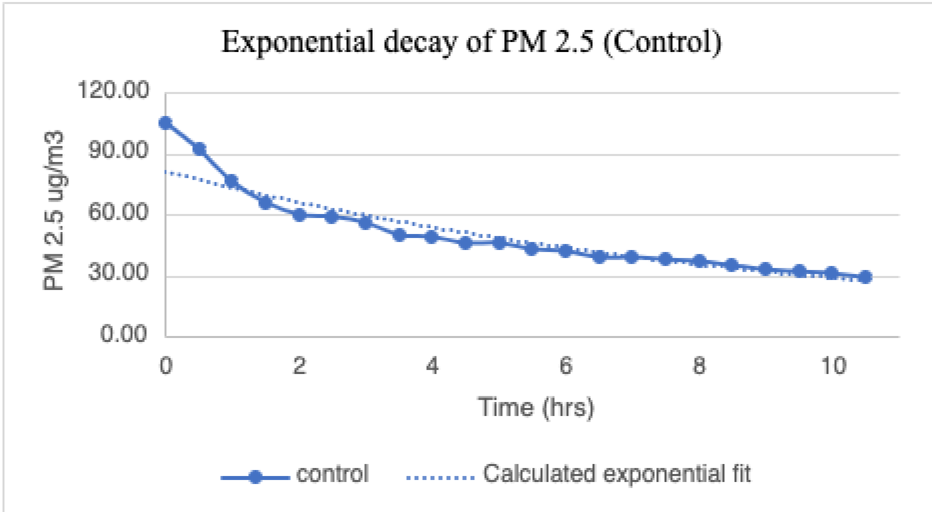


Figure 27. PM 2.5 decay in a fiberglass chamber with continuous air circulation and no air purifier

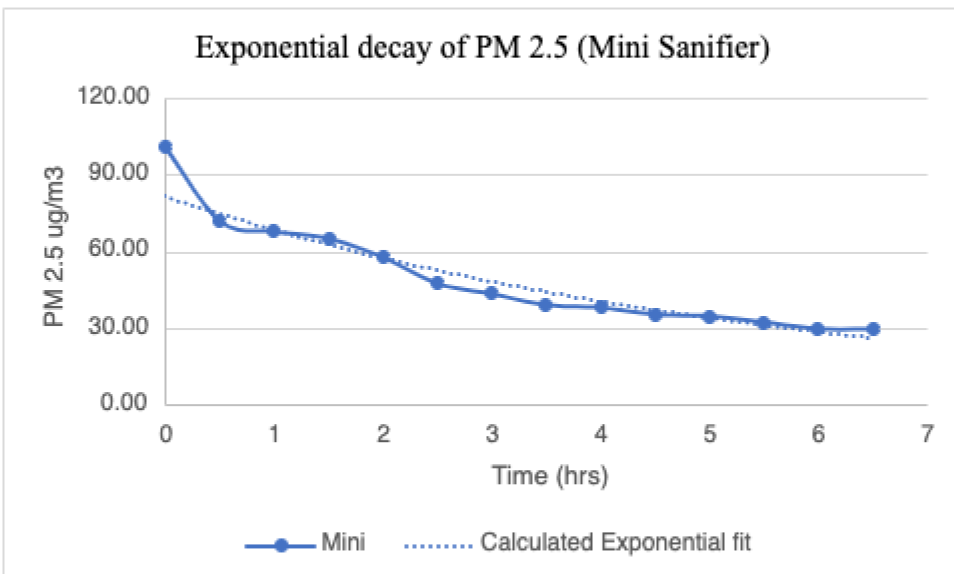


Figure 28. PM 2.5 decay in a fiberglass chamber with continuous air circulation and Mini Sanifier

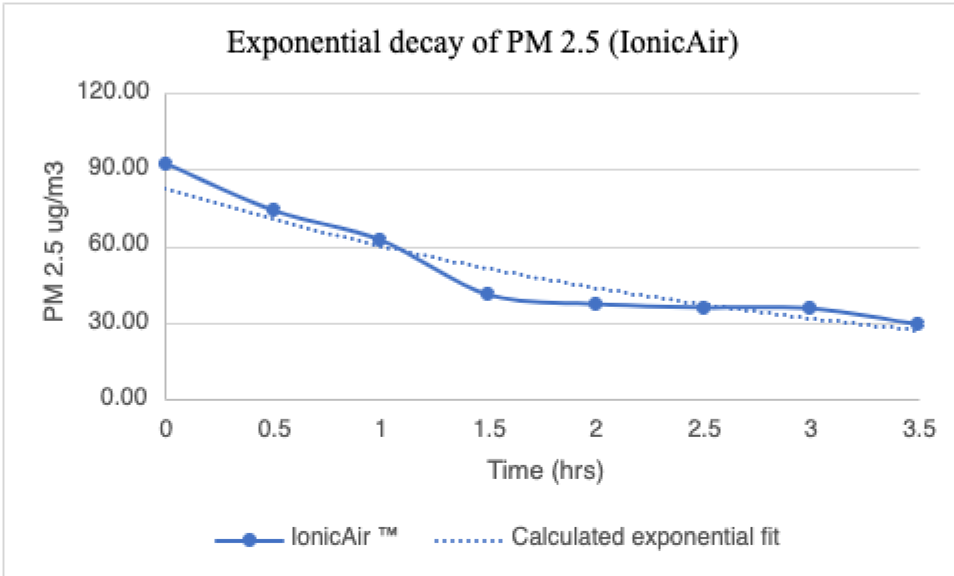


Figure 29. PM 2.5 decay in a fiberglass chamber with continuous air circulation and IonicAir

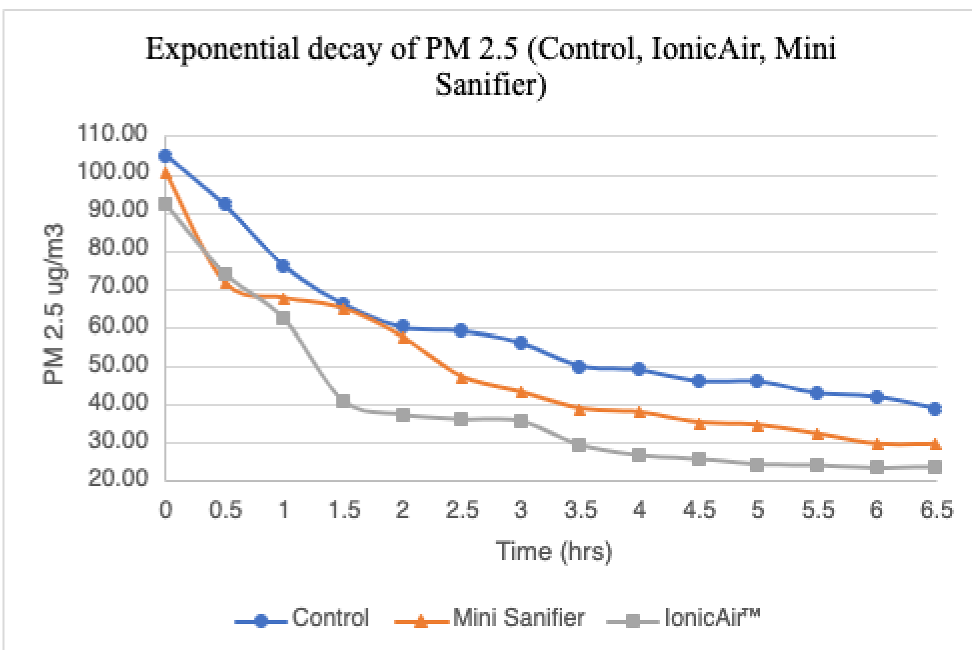


Figure 30. Comparison of PM 2.5 decay for control and when using IonicAir and Mini Sanifier units as a function of time.

Figure 30 shows the concentration of PM 2.5 constantly decreasing with IonicAir as a function of time. The steeper the slope, the faster the decay of PM 2.5. The IonicAir showed the steepest slope followed by the Mini Sanifier unit. The control slope was not as steep compared to the slopes of the two units.

Table 1 Calculated rate of decay, the area under each curve and the area between each curve.

PM 2.5 decay with no air circulation				
	Rate of decay (%)	Area under the curve ($\mu g/m^3$)*hr	Area between Control and Mini Sanifier ($\mu g/m^3$)*hr	Area between Control and IonicAir™ ($\mu g/m^3$)*hr
Control	63	130.50	13.75	39
Mini Sanifier	76	116.75		
IonicAir™	345	91.50		
PM 2.5 decay under air circulation and high concentration				
	Rate of decay (%)	Area under the curve ($\mu g/m^3$)*hr	Area between Control and Mini Sanifier ($\mu g/m^3$)*hr	Area between Control and IonicAir™ ($\mu g/m^3$)*hr
Control	31	2101.17	285.34	759
Mini Sanifier	50	1815.83		
IonicAir™	77	1342.17		
PM 2.5 decay under air circulation and low concentration				
	Rate of decay (%)	Area under the curve ($\mu g/m^3$)*hr	Area between Control and Mini Sanifier ($\mu g/m^3$)*hr	Area between Control and IonicAir™ ($\mu g/m^3$)*hr
Control	12	518.00	204.58	344.42
Mini Sanifier	20	313.42		
IonicAir™	32	173.58		

Table 1 Shows comparison between the calculated rate of decay, the area under the curve, and the area between each curve of all the three sets of experiments done. The results of table 1 suggests that the area between the control and IonicAir was maximum in all the three sets of experiments. By looking at the graph and the table, it was recorded that when using IonicAir PM 2.5 rate of decay was also maximum followed by while using Mini Sanifier.

(2.) Secondhand smoke (SHS) generated PM, as an indoor pollutant and air purifiers

In the first set of experiments related to SHS comparison of PM 1 maximum concentrations reached with the smoke of one cigarette, with and without (control) using air purifiers inside a fiberglass chamber was done (Figure 31). It was observed that there was no significant change in PM 1 concentration inside the chamber even while using the air purifier units. Figure 32 shows the comparison of PM 1 maximum concentrations reached by the smoke of one cigarette, with and without (control) using air purifiers inside a 225 sq.ft. room. In this study the air purifiers were effective in controlling the PM 1 concentration in comparison to control.

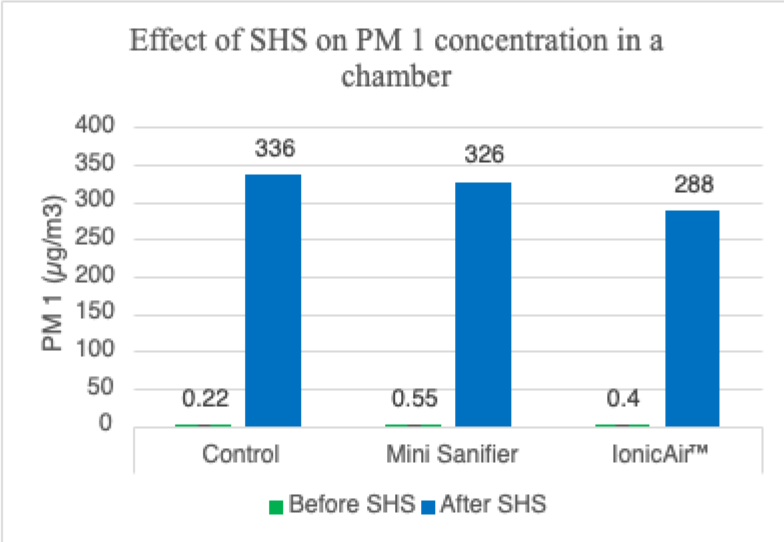


Figure 31. Comparison of PM 1 maximum concentrations reached with the smoke of one cigarette, with and without (control) using air purifiers inside a fiber glass chamber.

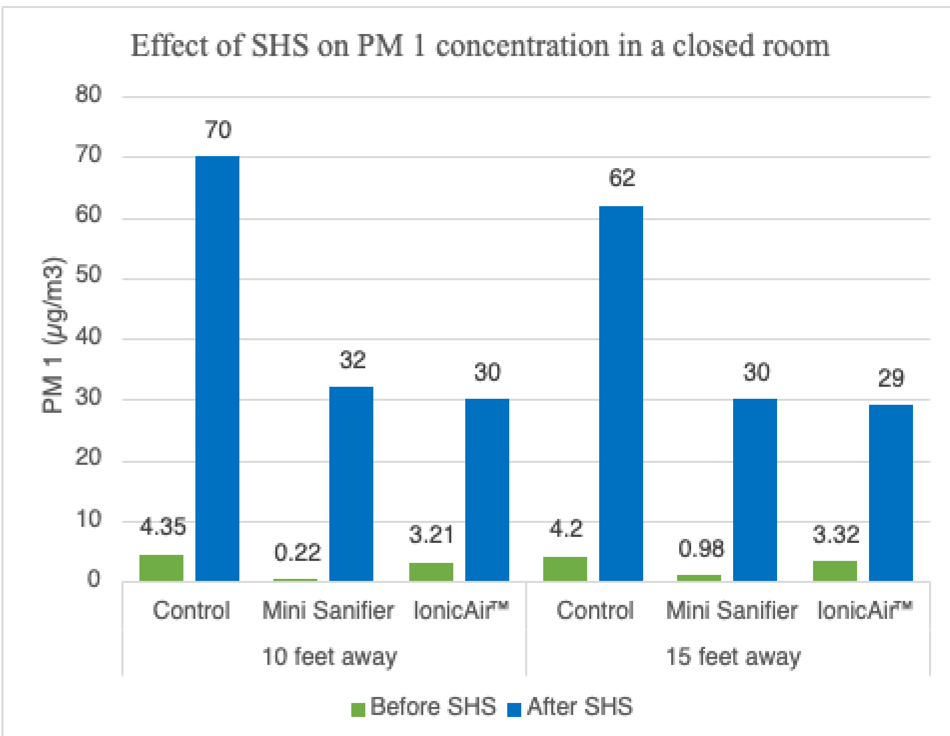


Figure 32 Comparison of PM 1 maximum concentrations reached by the smoke of one cigarette, with and without (control) using air purifiers inside 225 sq.ft room.

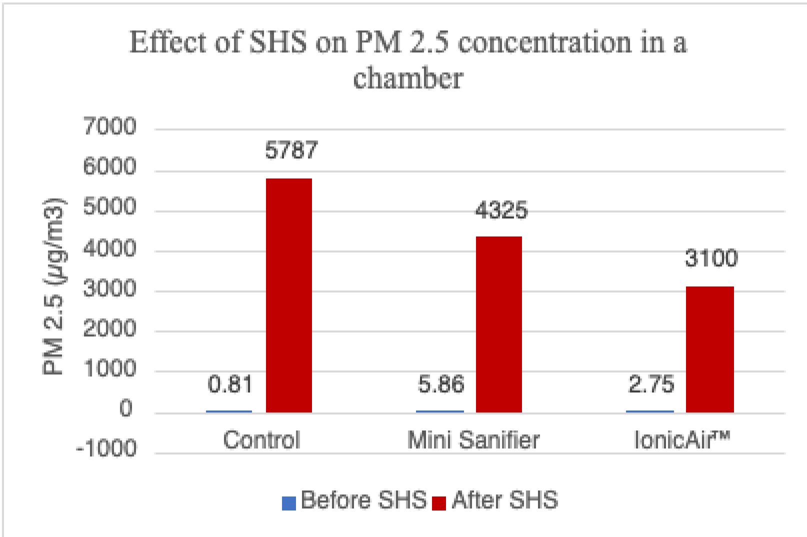


Figure 33. Comparison of PM 2.5 maximum concentrations reached with the smoke of one cigarette, with and without (control) using air purifiers inside a fiber glass chamber.

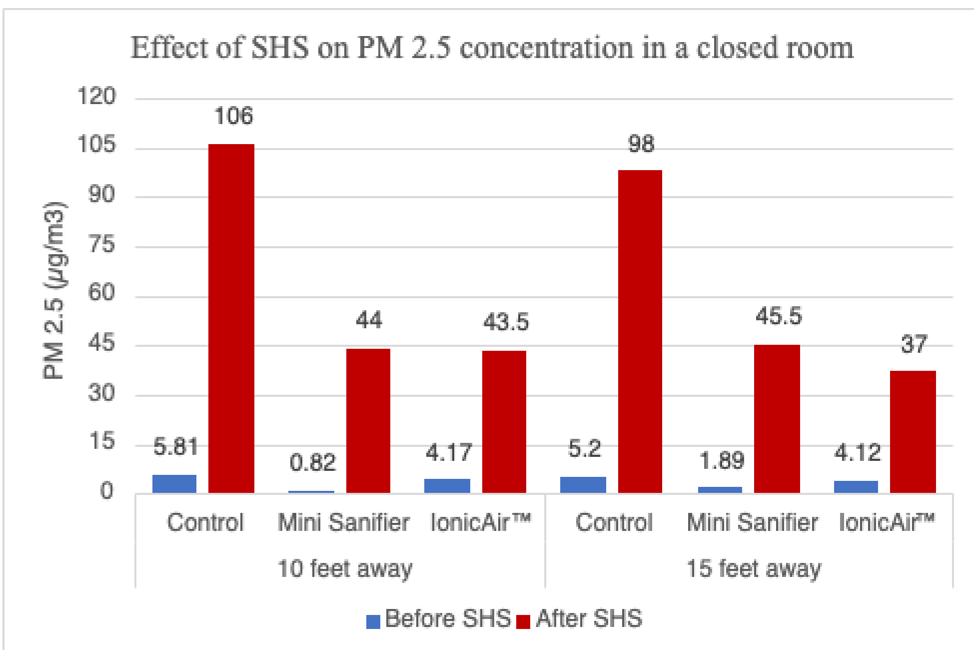


Figure 34. Comparison of PM 2.5 maximum concentrations reached by the smoke of one cigarette, with and without (control) using air purifiers inside 225 sq.ft room.

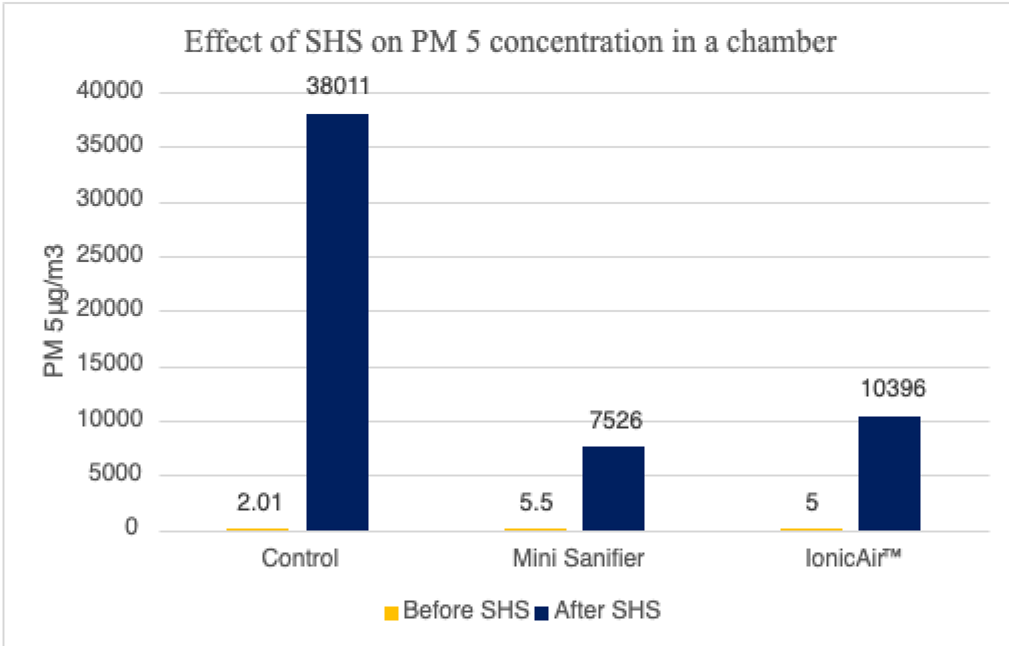


Figure 35. Comparison of PM 5 maximum concentrations reached with the smoke of one cigarette, with and without (control) using air purifiers inside a fiber glass chamber.

In the second set of experiments, comparison of maximum PM 2.5 concentrations reached as a result of SHS, with and without (control) using air purifiers inside a fiberglass chamber was done (Figure 33). It was observed that IonicAir was effective against PM 2.5 accumulation inside the chamber as well as in the closed room setup followed by the Mini Sanifier (Figure 34).

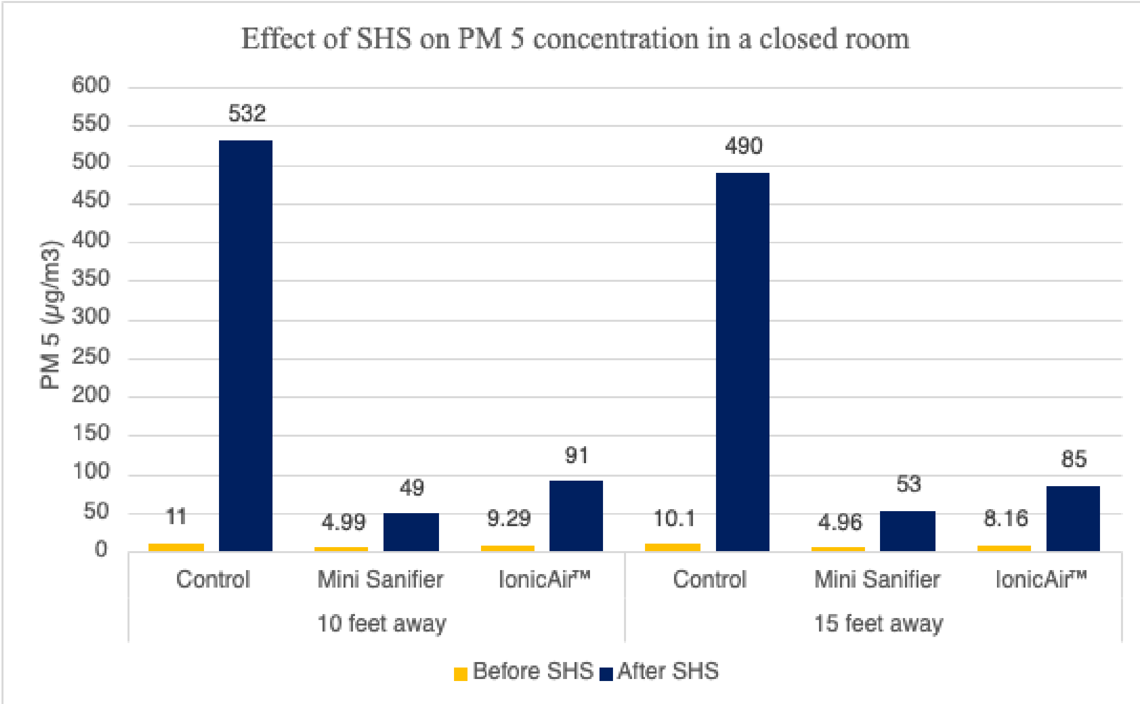


Figure 36. Comparison of PM 5 maximum concentrations reached by the smoke of one cigarette, with and without (control) using air purifiers inside 225 sq.ft room.

In the third set of experiments, comparison of maximum PM 5 concentrations reached as a result of SHS, with and without (control) using air purifiers inside a fiberglass chamber and a closed room was done (Figure 35, 36). It was found that with IonicAir, maximum PM 5 concentration reached was about 4 times less than control and about 5 times less with Mini Sanifier in the chamber. Similarly, in a closed room IonicAir reduced the PM 5 concentration by 5 times and Mini Sanifier reduced the PM 5 concentration by 10 times.

Table 2. Calculated rate of decay For PM 1, PM 2.5 and PM 5

Effect of air purifiers on decay rate of cigarette generated PM 1, PM 2.5, and PM 5 in a 225 sqft closed room.			
	PM 1 (Rate of decay) (%)	PM 2.5 (Rate of decay) (%)	PM 5 (Rate of decay) (%)
Control	3.25	2.77	0.22
Mini sanifier	3.52	3.53	**6.40**
IonicAir™	**4.31**	**4.81**	3.21
Effect of air purifiers on decay rate of cigarette generated PM 1, PM 2.5, and PM 5 in a closed fiber glass chamber.			
	PM 1 (Rate of decay) (%)	PM 2.5 (Rate of decay) (%)	PM 5 (Rate of decay) (%)
Control	7.22	21.78	20.22
Mini sanifier	**60.60**	**98.69**	**57.16**
IonicAir™	17.79	41.01	37.01

Table 2 shows the comparison of the rate of decay of SHS generated PM 1, PM 2.5, PM 5 inside a fiberglass chamber and a closed room. It was observed that both the units showed a significant rate of decay over the control. However, Mini Sanifier was more effective against PM 5 and IonicAir was more effective against PM 1 and PM 2.5.

(3) Insects and air purifiers

A preliminary study was done to assess the effect of air purifiers on the insects' behavior. Table 3 shows the repellency effect of Mini Sanifier on the fruit flies. It was found that Mini Sanifier was effective in keeping the *Drosophila* away within its 25 cm radius. Another observation was that all the flies stuck to the upper side of the wall and stopped moving.

Table 3: Effect of Mini sanifier on fruitflies inside the fiberglass chamber

Distance between bait and air purifier	**No. of flies on bait**	**No. of flies near air purifier (10 cm)**
25 cm	10	1
50 cm	15	0
100 cm	15	0

(5) Sampling Indoor Air for aeroallergens

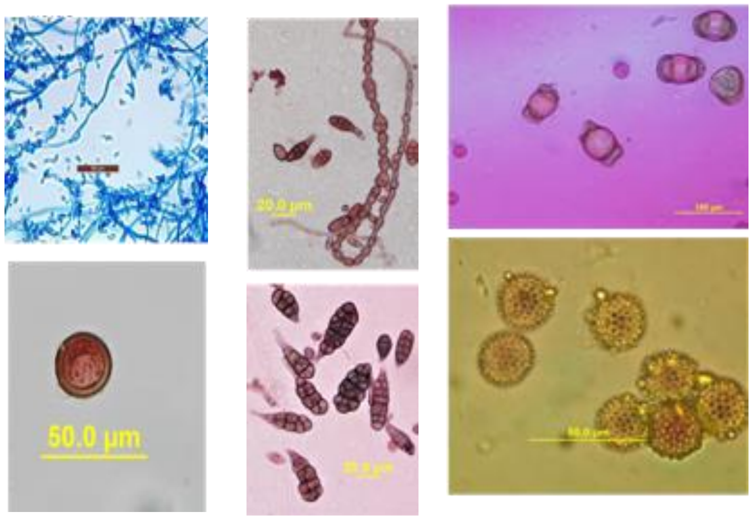


Figure 37: Some of the common indoor aeroallergens collected.

Air sample was taken using a two-stage bioaerosol cyclone sampler by the National Institute for Occupational Safety and Health (NIOSH). The samples collected into a 15 mL centrifuge tube were analyzed for their content. In the samples collected traces of fungal hyphae, dust and pollen were observed. Further identification of the samples will be carried out in the future.

As in the developed countries people spend most of the time indoors, thus there is increasing concern for better air quality indoors. To keep the air clean inside proper ventilation is important. But if the residential or occupational area is near the busy highways or a polluted area, then opening windows and doors can make the indoor quality worse. Another way is, to cut down the use of sources generating the indoor PM. Some studies indicated that cooking and cigarette smoking are the largest sources of indoor PM (Ferro et al., 2004) and smoking is estimated to increase PM 2.5 ranging from 25 to 45 µg /m^3 (Wallace 1996) in residential areas. Sometimes, cutting down the source of the PM is not possible. In such scenarios demand for better air purifiers is increasing. Most of the current studies show air purifiers to be effective against lower concentration of the PM 2.5 (5–50 µg/m^3), although more recently some studies are done at higher concentrations of PM 2.5 (Li et al 2017). In most of these studies, the use of air purifiers has been shown to reduce indoor PM 2.5 (Dong et al., 2019). In the present work, air purifiers tested against high concentration of PM 2.5 showed equally good potential as with low concentration of PM 2.5. With the IonicAir unit working, the high concentration PM 2.5 was decayed within less than half of the time taken by control. Similarly, with the low concentration PM 2.5 (90-120 µg/m^3) IonicAir lowered the PM 2.5 concentration to the acceptable range within less than 3 times of the control. Thus, IonicAir can reduce the time of exposure to the PM 2.5 indoors. A study by Morishita et al., (2018) showed that an effective air purifier can reduce the average exposure over 24 hours by >40% inside a house.

Another important finding of the current study was that SHS smoke generates PM of varying sizes. Among all the sizes of PM generated, PM 5 concentration can increase to 50 times after burning of only one cigarette and it was followed by PM 2.5, whose concentration can increase by 20 times. The air purifiers under the study were able to decrease the SHS generated PM 2.5 by 50% and PM 5 by 80%. The IonicAir unit was more effective in decreasing the concentration of PM 1 and PM 2.5 and Mini Sanifier was more effective in decreasing the concentration of PM 5 in the closed room. Besides this the rate of decay of PM was also found to be increased with the air purifier units on. The rate of decay for dust generated PM 2.5 was different then SHS generated PM. This difference can be attributed to the chemical nature of the PM.

Our research also showed that, in the room SHS was distributed equally and there was no significant difference between the PM 1, PM 2.5 and PM 5 concentration when the cigarette and the PM monitor were placed 10 and 15 feet away from each other. Thus, we can say that if somebody is smoking in a room distance doesn't decrease the amount of PM inhaled by the nonsmoker, sitting in the same room. However, the type of ventilation can influence it. Secondhand smoke exposure causes disease and death. Because not all populations are equitably protected by comprehensive smoke free laws intended to address exposure to secondhand smoke, it is not always possible for people to avoid exposure to SHS. Thus, air purifiers can be considered as a potential intervention. Due to increasing air purifiers demand, multiple companies with different innovative techniques are featuring their products. In such a scenario it is hard for the common people to make the right choice of air purifier. Thus, such a type of study can help the common people to decide which product can be best for them, as the statements backed up by scientific experiments makes things reliable.

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