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Quantitative Assessment of Soldering-Induced $PM_{2.5}$ Exposure Using a Distributed Sensor Network in Instructional Laboratory Settings

Ian M. Kinsella [1,2], Anna N. Petrbokova [1,2], Rongjie Yang [1,2], Zheng Liu [1,2], Gokul Nathan [1,2], Nicklaus Thompson [1,2], Alexander V. Mamishev [1,2] and Sep Makhsous [1,2,*]

[1] Department of Electrical and Computer Engineering, University of Washington, Seattle, WA 98195, USA; iank6@uw.edu (I.M.K.); apetrbok@uw.edu (A.N.P.); rongjie728@gmail.com (R.Y.); zheng726@uw.edu (Z.L.); gokuln@uw.edu (G.N.); nthomp2@uw.edu (N.T.); mamishev@uw.edu (A.V.M.)
[2] Sensors, Energy, and Automation Laboratory, University of Washington, Seattle, WA 98195, USA
* Correspondence: sosper30@uw.edu

Abstract: Soldering is a common engineering practice that releases airborne particulate matter (PM), contributing to significant long-term respiratory risk. The health impact of this exposure is significant, with up to 22% of soldering workers worldwide being diagnosed with conditions such as occupational asthma, restrictive lung disease, and bronchial obstruction. Studies have reported that soldering can produce $PM_{2.5}$ concentrations up to 10 times higher than the U.S. Environmental Protection Agency's (EPA) 24 h exposure limit of 35.0 $\mu g/m^3$—posing significant respiratory and cognitive health risks under chronic exposure. These hazards remain underappreciated by novice engineers in academic and entry-level industrial environments, where safety practices are often informal or inconsistently applied. Air purification systems offer a mitigation approach; however, performance varies significantly with model and placement, and independent validation is limited. This study uses an indoor air quality monitoring system consisting of six AeroSpec sensors to measure $PM_{2.5–10}$ concentrations during soldering sessions conducted with and without commercial air purifiers. Tests were conducted with and without a selection of commercial air purifiers, and measurements were recorded under consistent spatial and temporal conditions. Datasets were analyzed to evaluate purifier effectiveness and the influence of placement on pollutant distribution. The findings provide independent validation of air purifier capabilities and offer evidence-based suggestions for minimizing particulate exposure and improving safety in laboratory soldering environments.

Keywords: indoor air quality (IAQ); airborne particulate matter (PM); $PM_{2.5}$; soldering emissions; indoor pollution mitigation; air quality monitoring; air purifier assessment; laboratory air quality; occupational health; student health

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1. Introduction

Research indicates that people spend nearly 90% of their time indoors [1], making indoor air quality a critical public health concern. Recent reviews and studies have analyzed indoor air quality and found it has broad-reaching impacts on population health [2,3]. Furthermore, indoor air often is more polluted than outdoor air, even in non-industrial areas [4,5]. $PM_{2.5}$ particles [6], airborne matter with diameters smaller than or equal to 2.5 µm, are of particular concern [7]. Due to their small size, $PM_{2.5}$ particles can bypass the human respiratory defense system and enter the lungs, potentially leading to chronic

conditions such as asthma and heart disease (see review [8]). Poor air quality has also been linked to millions of premature deaths, cognitive decline, and increased stress and anxiety levels worldwide [9]. An area of particular concern for the effects of indoor air quality is educational facilities, where students spend extended periods of time indoors [10]. Air pollutants can impact the health of students and staff, especially when they are in laboratory environments [11]. Students in academic or entry-level industrial settings are particularly susceptible because, despite the well-documented risks of poor air quality, they often overlook the hazards of prolonged fume exposure [12]. Consequently, there is an urgent need to study various sources of indoor air pollution and assess their impact on student health [13]. Without intervention, air pollution will continue to affect students' comfort, productivity, and achievements [13]. Understanding pollution sources and their contributions to poor air quality can lead to more effective mitigation strategies [14].

Although commonly performed in academic and industrial settings, soldering is rarely recognized as a significant contributor to air pollution. The particulate matter released during this process can exceed the EPA's 24 h exposure limit of 35.0 $\mu g/m^3$ for $PM_{2.5}$ levels [15]. Frequent exposure has been associated with measurable increases in respiratory illness among soldering workers; nearly one in five are affected in some studies [16]. Solder wire releases airborne particles of heavy metals like tin, lead [17], copper, silver [18], aluminum, nickel [19], and zinc [20]. Of these metals, lead is especially concerning, with high exposure being linked to reduced intelligence quotient (IQ), poorer working memory, and decreased socioeconomic mobility later in life [21]. Childhood lead exposure has also been associated with Alzheimer's and Parkinson's disease [22]. Other health effects from chronic lead exposure include, but are not limited to, reproductive issues, digestive problems [23], nausea, depression, memory problems, and brain cancer [24,25]. Copper and zinc can cause a metabolic burden on internal organs, such as the lungs, liver, and kidneys [26]. In addition to solder wire, the fluxes used to smooth the solder flow present a health risk. According to the United Kingdom (UK) Health and Safety Executive, the inhalation of fumes from flux containing rosin (a type of resin extracted from pine trees) is a significant cause of occupational asthma in Britain [27]. Frequent and long-term exposure to rosin-based flux has been linked to an increased possibility of exhibiting shortness of breath, wheezing, and chronic coughing [27].

According to the American Society for Engineering Education, as of 2023, there are 54,737 graduate and undergraduate electrical engineering students enrolled in American universities [28]. Many of these universities have made soldering a key part of the required coursework. Students are more likely to neglect proper self-protection procedures during this early learning stage, rendering electrical engineering students a sizeable population with a heightened risk of exposure to soldering fumes [29–31]. This issue is compounded by a shortage of technical skills instructors, making continuous oversight to ensure safe soldering practices challenging to implement [29,30]. Beyond education, the maker movement has gained significant momentum in the past decade due to the increasing availability of 3D printers and electronic tools [32]. This has further increased the number of young people soldering, and oftentimes those involved in the maker movement solder at home without trained supervision or proper safety equipment. Taken together, these populations of young people soldering without proper safety equipment or supervision necessitate an investigation of the effects of soldering on air quality.

To mitigate the harmful effects of soldering and protect students from long-term harm, many instructional laboratories have adopted air purifiers to remove $PM_{2.5}$ [31,33,34]. These air purifiers utilize negative pressure and filtration to capture hazardous fumes and particulates from the air, thereby reducing exposure to potentially harmful substances. Commercially available air purifiers vary widely in price, size, form factor, quality, and

filtration capability. While the health risks associated with soldering activities are well documented, the extent to which air purifiers maintain safe air quality levels in technical laboratories remains underexplored [35].

This study aims to provide an analysis of the ability of multiple commercially available air purifiers to maintain safe air quality levels. To conduct this analysis, AeroSpec sensors were distributed around a soldering iron to monitor $PM_{2.5}$ concentrations throughout the soldering process in laboratory settings and assess the $PM_{2.5}$ filtration effectiveness of various air purifiers. Our findings suggest the following:

- Soldering continues to be a hazardous activity in educational settings, consistently releasing $PM_{2.5}$ particulates into the atmosphere.
- All purifiers tested successfully reduced $PM_{2.5}$ concentrations in the user's breathing zone and helped contain particulates near the soldering station.
- Purifiers have an optimal distance for filtering $PM_{2.5}$, as efficiency is not always linearly dependent on the distance between the inlet and the soldering station.
- The overhead air purifier demonstrated the highest efficiency in removing $PM_{2.5}$ among all models tested.

2. Material and Methods

This study was designed to evaluate the performance of various commercially available air purifiers in removing particulate matter (PM) generated by soldering activities. The AeroSpec system measured ventilation efficiency across four different air purification scenarios, each with various arrangements of the soldering iron and the air purifiers.

2.1. The AeroSpec Sensor System

The AeroSpec sensor is a self-contained, battery-powered air quality monitoring device consisting of a BME280 Temperature and Humidity Sensor, an Adafruit E-Ink display, an Adafruit ESP32, and a Plantower PMSA003 Air Quality Sensor [36–38]. The data are collected and stored locally on a microSD card as a .csv file and then uploaded to ThingSpeak [39], which offers real-time wireless access to data streams. An exploded view of an AeroSpec sensor is shown in Figure 1, where the air quality sensor is labeled as an optical particle counter (OPC) sensor. The key measurement capabilities of the AeroSpec sensor are listed in Table 1.

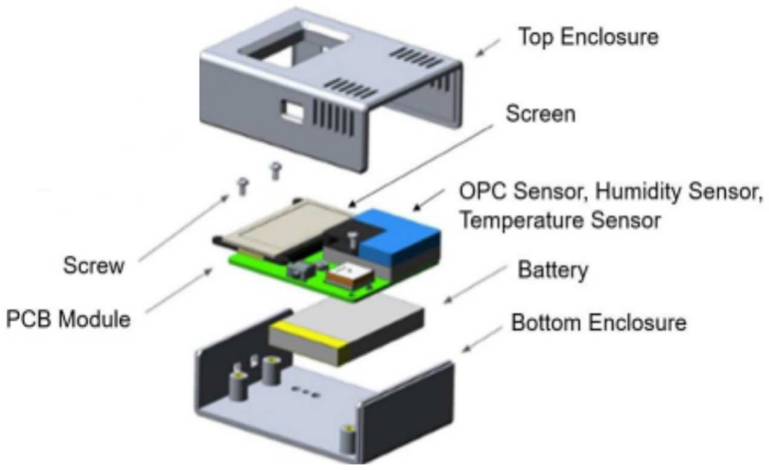


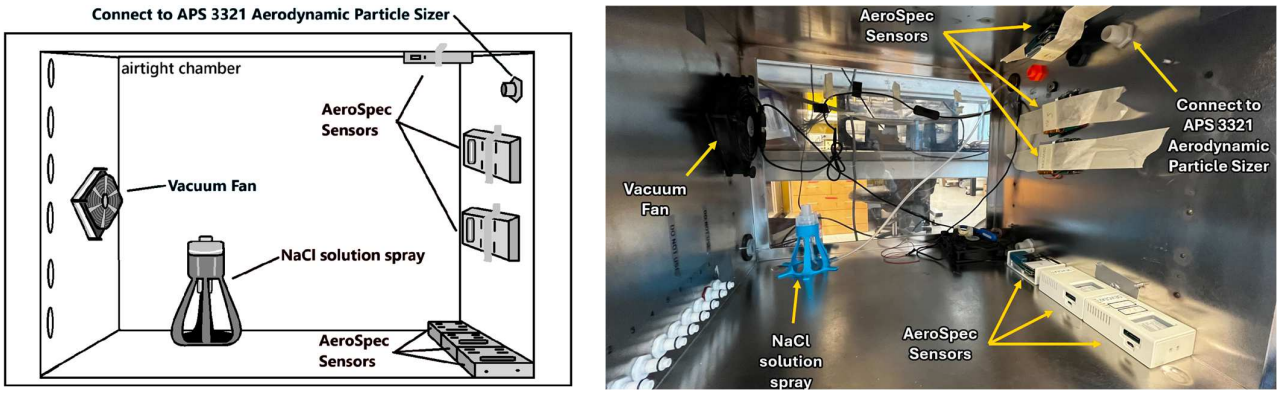
Figure 1. Exploded view of an AeroSpec sensor [37].

Table 1. Measurement range and accuracy of the AeroSpec sensor across various PM sizes [37,40].

Particulate Diameter (μm)	Concentration Range (μg/m^3)	Measurement Error
<1.0 ($PM_{1.0}$)	0–100	±15 μg/m^3
<1.0 ($PM_{1.0}$)	100–500	±15%
<2.5 ($PM_{2.5}$)	0–100	±10 μg/m^3
<2.5 ($PM_{2.5}$)	100–500	±10%
<10 (PM_{10})	0–100	±25 μg/m^3
<10 (PM_{10})	100–500	±25%

2.2. Sensor Performance Validation

The team conducted a sensor performance validation test to confirm that sensor drift of the AeroSpec system was within an acceptable range as supported by relevant literature [41–43]. To achieve this, the AeroSpec sensors were compared to the Aerodynamic Particle Sizer (APS3321), a particulate matter sensor with an observed counting efficiency of 99% for solid airborne particles with a diameter of 3.0 μm [44]. The high measurement accuracy of the APS3321 in measuring airborne particulates with diameters near 2.5 μm allowed it to serve as a reliable source of reference measurements with which to compare $PM_{2.5}$ data from the AeroSpec sensors. During the performance validation test, six AeroSpec sensors and the APS3321 were placed inside an airtight chamber. An atomized 10 mg/L sodium chloride (NaCl) solution was fed through a tube and sprayed into the chamber to simulate airborne particulate matter. NaCl was chosen to simulate $PM_{2.5}$ due to its non-toxicity, low cost, and prior use as a test aerosol in evaluating PM sensors [45]. Researchers used a knob on the outside of the chamber to control the amount of the atomized sodium chloride solution sprayed in. The AeroSpec sensors were placed as close as possible to the APS3321 to ensure that the air being measured by the AeroSpec sensors was as similar as possible in particulate concentration to the air sampled by the APS3321. A diagram and picture displaying the layout of the APS3321 and AeroSpec sensors within the chamber are shown in Figure 2.



(**a**) (**b**)

Figure 2. Validation experiment setup. (**a**) Diagram of the airtight chamber showing sensor and equipment placement. (**b**) Photo of the actual chamber during validation with identical setup.

The AeroSpec sensors and APS3321 captured data every five seconds over a ten-minute validation period. The $PM_{2.5}$ mass concentration data of the AeroSpec sensors and the results from the APS3321 analyzer are displayed in Figure 3. To assess the accuracy of the AeroSpec sensors with respect to the APS3321 analyzer, statistical analysis was performed between the AeroSpec sensors and APS3321, including the Pearson correlation coefficient,

Spearman correlation coefficient, and Jensen–Shannon divergence [46,47]. These metrics are summarized in Table 2.

The statistical metrics in Table 2 indicate that the readings of all six of the AeroSpec sensors maintained strong agreement with the APS3321 during the validation test. The Pearson correlation coefficients range from 0.94 to 0.98, and the Spearman correlation coefficients range from 0.91 to 0.97. Both metrics indicate a strong linear agreement and monotonic trends [48–51]. Additionally, the Jensen–Shannon divergences for all sensors were below 0.1, suggesting only minor variation between the distributions of the AeroSpec sensors and the APS3321 [48,51]. The findings demonstrate that all AeroSpec sensors used in this study were well calibrated, and that sensor drift was within an acceptable range for precise environmental measurements during the validation period.

However, it is important to note that the validation test was conducted over a limited, 10 min period, which may not fully capture longer-term sensor behavior or potential drift under extended usage. While the results support the reliability of the sensor data during the main experiment, they do not entirely eliminate the possibility of time-dependent calibration drift. This limitation is discussed further in Section 6.

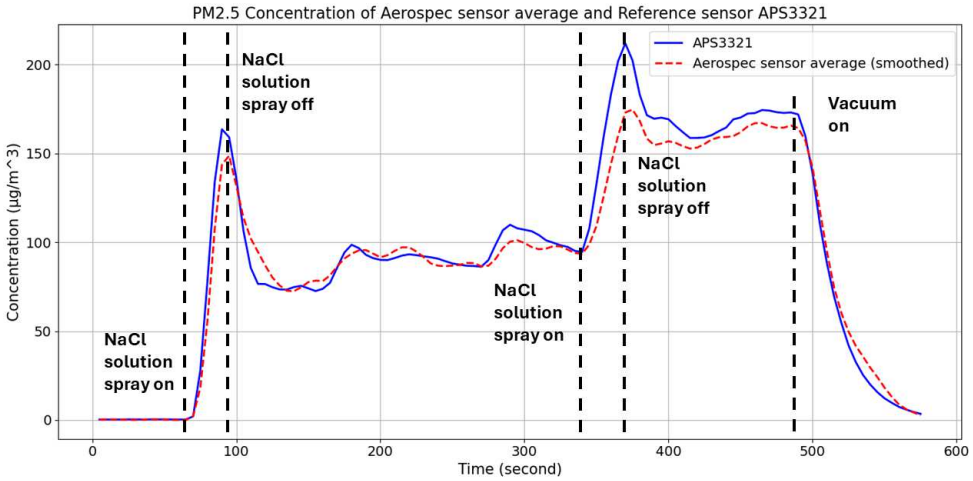


Figure 3. $PM_{2.5}$ concentration was measured by the AeroSpec sensors (red dashed line) and the APS3321 reference analyzer (blue solid line) during the validation test. Signal data in the graph were smoothed using a rolling average to reduce short-term noise.

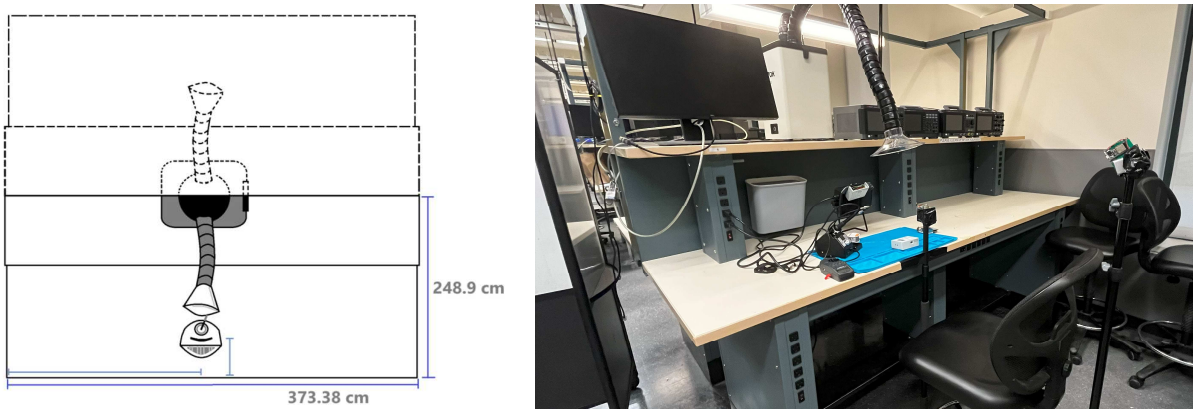
Table 2. Statistical comparison between each AeroSpec sensor and the APS3321 reference sensor, including Pearson and Spearman correlation coefficients and Jensen–Shannon divergence values.

Sensor Number	Pearson Correlation Coefficient with the APS3321	Spearman Correlation Coefficient with the APS3321	Jensen–Shannon Divergence with the APS3321
1	0.96	0.94	0.0671
2	0.94	0.91	0.0743
3	0.97	0.91	0.0568
4	0.98	0.96	0.0522
5	0.98	0.97	0.0469
6	0.95	0.93	0.0885

2.3. Experimental Procedure

2.3.1. Description of Study Area

The study presented in this paper was performed in a large laboratory room at the University of Washington in Seattle. Within the lab, there were several designated soldering workstations. Workstations were 248.9 cm long and 373.38 cm wide, with a ceiling height of 365.7 cm. Every workstation was split into two parts by a low wall, with each side of the workstation having its own soldering iron and purifier. For this study, the X-Tronic 3060 Pro soldering iron [52] was selected, as it closely resembles models commonly used in instructional labs, where students typically learn through hand soldering [53]. Since our study targets environments where novice users are developing basic soldering skills, it was appropriate to focus on handheld soldering irons like the one selected [54]. Being constrained by having six AeroSpec sensors only a single user soldered during all sub-trials. This decision was based on the need to maintain sufficient spatial resolution around the soldering workstation. Introducing a second user would have required splitting the sensors between two setups, which would have halved the number of sensors monitoring each user and potentially compromised the ability to detect localized variations in $PM_{2.5}$ exposure. A top-down view of a soldering workstation is shown in Figure 4a and a two-point perspective view of a soldering workstation given in Figure 4b.



(**a**) (**b**)

Figure 4. Experimental workstation setup. (**a**) Top-down view of the lab workstation used for study experiments, including the Vevor Solder Fume Extractor (Purifier 2). (**b**) Perspective view of workstation setup.

2.3.2. Purifier Considerations and Sensor Arrangements

AeroSpec sensors were used to evaluate the ability of various commercially available air purifiers to remove $PM_{2.5}$ caused by soldering in a laboratory environment. Table 3 includes the specifications of the purifiers used in this study. Among the purifiers tested in the experiment, Purifiers 1, 3, and 4 were relatively inexpensive (under USD 100) and used activated carbon filters [55]. Purifier 2 was the most expensive unit, retailing at USD 293, but came with the highest airflow, as shown in Table 3, and used High Efficiency Particulate Air (HEPA) filters [56]. HEPA filters have been found to be more effective than activated carbon filters at removing $PM_{2.5}$ from the air, with one study revealing that activated carbon filters achieved, at best, 36.6% filtration efficiency for $PM_{2.5}$, compared to the $\geq$99.7% filtration efficiency required of HEPA filters [57,58]. Despite this significant performance gap, our market survey revealed that activated carbon remains a common filter type in relatively inexpensive commercial air purifiers. This presents an important question, given the known limitations of activated carbon for $PM_{2.5}$ filtration—why do manufacturers continue to implement this technology in budget-friendly units that may be

used in laboratory settings? We chose to include both activated carbon filters and HEPA filters in our study to determine if there might be previously undocumented performance benefits that explain the continued use of activated carbon in commercial purifiers. By testing both filter types, we can assess whether the less expensive activated carbon units (Purifiers 1, 3, and 4) can provide $PM_{2.5}$ removal equal to that provided by HEPA-equipped filters, thus justifying the continued use of activated carbon filters in purifiers.

Table 3. Key specifications of the air purifiers used in the study [59–64].

Purifier Number	Name	Maximum Airflow	Filter Type	Cost (USD)	Purifier Type	Dimensions (cm)
Purifier 1	AOYUE 486 Fume Extractor	115 ft^3/min	Activated carbon	$36	Desktop	19.05 × 16.51 × 8.89
Purifier 2	Vevor Solder Fume Extractor XF250	147.1 ft^3/min	HEPA	$293	Overhead	28 × 28 × 162.92
Purifier 3	Fonsoning FSY12038HA1	100 ft^3/min	Activated carbon	$23.85	Desktop	12 × 12 × 3.8
Purifier 4	Valtcan VALT921	Not specified	Activated carbon	$65	Desktop	27.94 × 24.13 × 16.51

As shown in Figure 5, the first sensor was hung around the neck of the person soldering and was approximately 20 cm below the operator's nose. The second sensor was placed in front of the soldering station, as close as possible to the tip of the soldering iron, where fumes are generated. The third sensor was placed at the mouth of whichever fume extractor was being used. A fourth sensor was placed halfway along an imaginary line connecting the nose of the person soldering to the tip of the soldering iron. The fifth sensor was placed directly above the head of the person soldering, at a height of 127.75 cm from the ground, which is the halfway point between the average sitting and standing height of the 50th percentile of British adults aged 19–25 [65,66]. The sixth sensor was positioned near the soldering station, placed 30.48 cm to the right of the soldering iron. Figure 5 shows the sensor network setup for evaluating the ventilation units. Table 4 summarizes the locations of all sensors used in the study.

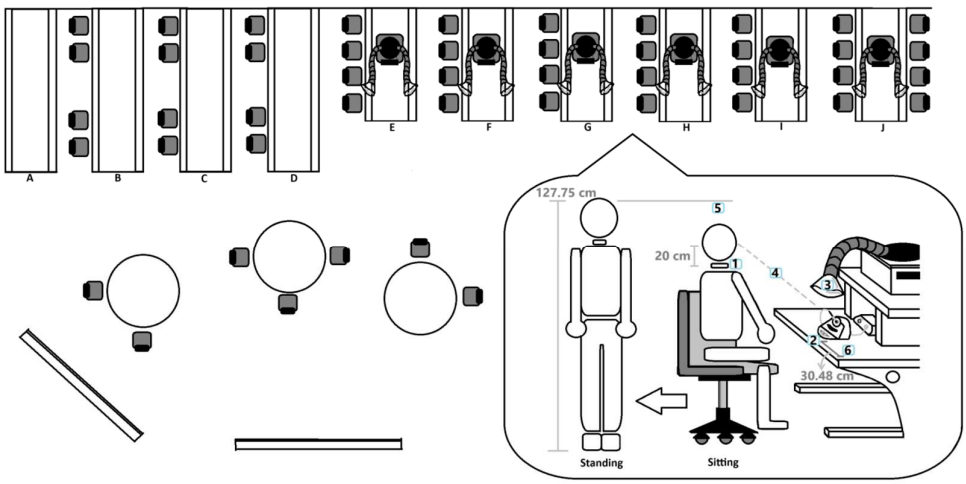


Figure 5. Top and side views of the laboratory station showing the positions of six AeroSpec sensors used during testing. The side view illustrates sensor placements relative to the user and the largest fume extractor used in the study.

Table 4. Descriptions of the six AeroSpec sensor placements relative to the user and soldering iron during experimental trials.

Sensor Number	Location
1	Hung around the neck of the person soldering (~20 cm below the nose)
2	Placed as close as possible to the tip of the soldering iron where fumes emanate from
3	Placed at the mouth of whatever fume extractor is being used; note that the example picture and drawing happen to show the large fume extractor
4	Placed halfway along an imaginary line connecting the nose of the person to the tip of the soldering iron when it is in use
5	Placed directly above the head of the person soldering, at a height of 127.75 cm
6	Placed 30.48 cm to the right of the soldering iron

2.3.3. Particulate Matter Data Collection

Particulate matter data were collected over fifteen sub-trials, which were divided into five groups of three sub-trials each. Each group represents a different air purifier being used, and the sub-trials within a group differed in how far the soldering iron was placed from the air purifier. During the three sub-trials for each group, the purifier would be placed 10 cm, 20 cm, and 30 cm away from the soldering iron. Table 5 summarizes the procedure for each sub-trial.

Table 5. Experiment group and sub-trial setup.

Group Number	Sub-Trial Number	Purifier Used	Distance from Purifier
1	1	Purifier 1	10 cm
1	2	Purifier 1	20 cm
1	3	Purifier 1	30 cm
2	4	Purifier 2	10 cm
2	5	Purifier 2	20 cm
2	6	Purifier 2	30 cm
3	7	Purifier 3	10 cm
3	8	Purifier 3	20 cm
3	9	Purifier 3	30 cm
4	10	Purifier 4	10 cm
4	11	Purifier 4	20 cm
4	12	Purifier 4	30 cm
5	13	No Purifier	10 cm
5	14	No Purifier	20 cm
5	15	No Purifier	30 cm

The purifier-free sub-trials in Group 5 served as control trials to determine the level of air pollutants generated by soldering activities without any intervention. This setup helps students understand the risks of soldering without proper air purification and is intended to aid them in following safety protocols to minimize exposure to harmful soldering fumes. For each sub-trial that required a purifier, the purifier was placed on

the desk, at the designated distance from the soldering iron, and the temperature of the soldering iron was set to 450 °F (232 °C). Once it was confirmed that the soldering iron had reached the correct temperature and the purifier's flow rate was stable, all sensors were turned on simultaneously, and a one-minute recording of the room's natural state was taken for reference.

After one minute, the purifier (if present) was turned to its maximum intensity, and a four-minute timer was enabled. During the first two minutes, a user melted solder wire, following the hand soldering process [67]. Soldering was conducted for two minutes during which 20 cm of solder wire was melted to ensure a similar amount of $PM_{2.5}$ particles were released by the soldering process during each of the sub-trials. After two minutes, the purifier was turned off, and the sensors remained active for an additional two minutes. During these two minutes, all participants in the experiment moved as little as possible to ensure that the surrounding air would not be disturbed. At the end of the two minutes, all the sensors were turned off simultaneously, and the data collected by each sensor for that sub-trial were extracted and saved to a computer before proceeding to the following sub-trial. Any visible smoke was exhausted between sub-trials to ensure similar starting conditions in all sub-trials. If the sensors detected abnormal particulate levels even after the cleaning process, the room was left to air out until $PM_{2.5}$ levels had returned to the threshold defined by the Environmental Protection Agency's (EPA) National Ambient Air Quality Standards [15]. This process is illustrated in Figure 6.

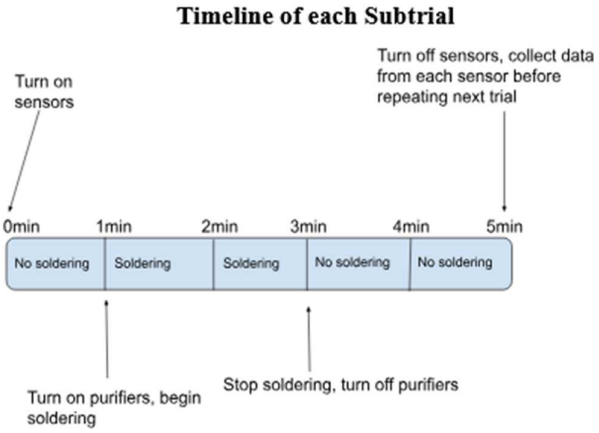


Figure 6. Timeline and the sequence of actions of each sub-trial.

2.4. Data Processing and Statistical Analysis Methodology

Within the collected .csv data file, readings of the number of particles with a diameter >0.3 µm, >0.5 µm, >1.0 µm, >2.5 µm, >5.0 µm, and >10 µm in 0.1 L of air and mass concentrations of $PM_{1.0}$, $PM_{2.5}$, and PM_{10} ($\mu g/m^3$) were saved, with these metrics having been recorded every second for the duration of each sub-trial. The data processing procedure mainly adopted the arithmetic mean calculation, which measures the central tendency of data points, to provide a single, straightforward, and intuitive metric to represent the air quality situation.

The average mass concentration of $PM_{2.5}$ ($\mu g/m^3$) was calculated for each sensor across the 12 sub-trials where purifiers were used, as well as across the 3 sub-trials where no purifier was used. This average was calculated using Equation (1)

$$Avg_S = \frac{1}{n_S}\sum_{i=1}^{n_S} x_S \quad (1)$$

where Avg_s is the average $PM_{2.5}$ mass concentration of a given sensor S across a range of sub-trials, n_s is the number of measurements of a given sensor S across the sub-trials, and x_S is the $PM_{2.5}$ mass concentrations of a given sensor S across the sub-trials. This average effectively quantified which locations around the soldering iron were experiencing the highest $PM_{2.5}$ concentrations. Using this average, recommendations can be made for the safest places for bystanders and those soldering to be when a soldering iron is actively in use.

For each purifier P, the average $PM_{2.5}$ mass concentration was calculated across all six sensors during the sub-trials where a purifier was used. This average was calculated by Equation (2)

$$Avg_P = \frac{1}{n_P}\sum_{i=1}^{n_P} x_P \tag{2}$$

where Avg_P is the average $PM_{2.5}$ mass concentration of all six sensors across the sub-trials where purifier P was used. Here, n_P is the number of measurements taken by the sensors while a given purifier P was being used, and x_P is the $PM_{2.5}$ mass concentrations of all sensors across those sub-trials. This average was used as a high-level way to rank the purifiers tested.

Further granularity was achieved by calculating the average $PM_{2.5}$ mass concentration of all the sensors while purifier P was used at a distance D (excluding sub-trials without a purifier). This average was calculated using Equation (3)

$$Avg_{PD} = \frac{1}{n_{PD}}\sum_{i=1}^{n_{PD}} x_{PD} \tag{3}$$

where Avg_{PD} is the average $PM_{2.5}$ mass concentration of all six sensors across the sub-trials where purifier P was used at a distance D. Here, n_{PD} is the number of measurements taken by the sensors while a given purifier P was being used at a distance D, and x_{PD} is the $PM_{2.5}$ mass concentration of all sensors across that sub-trial. This average was used to more closely investigate how the performance of each purifier was affected by its distance from the soldering iron.

3. Experiment Results

The analysis of air quality data collected from our custom sensor array revealed significant variations in pollutant concentrations during soldering operations. Peak $PM_{2.5}$ concentrations reached 1400 $\mu g/m^3$ for approximately one second, a value about 93 times higher than the WHO's 24 h $PM_{2.5}$ exposure limit of 15 $\mu g/m^3$ [68]. These measurements demonstrate that despite the use of air purifiers, $PM_{2.5}$ concentrations can still momentarily reach extremely high levels during intensive soldering work.

3.1. PM Concentrations with No Purifier

To evaluate baseline PM levels, three sub-trials were conducted without the use of a purifier. Figure 7 displays the average $PM_{2.5}$ concentrations recorded by each sensor during these trials. Sensor 3, which was intended for placement at the purifier intake, was intentionally omitted during the no-purifier trials. In the absence of the purifier, Sensor 3's intended function—to assess $PM_{2.5}$ levels entering the purifier—was no longer relevant. Rather than relocating Sensor 3, it was omitted in order to preserve consistency in sensor roles.

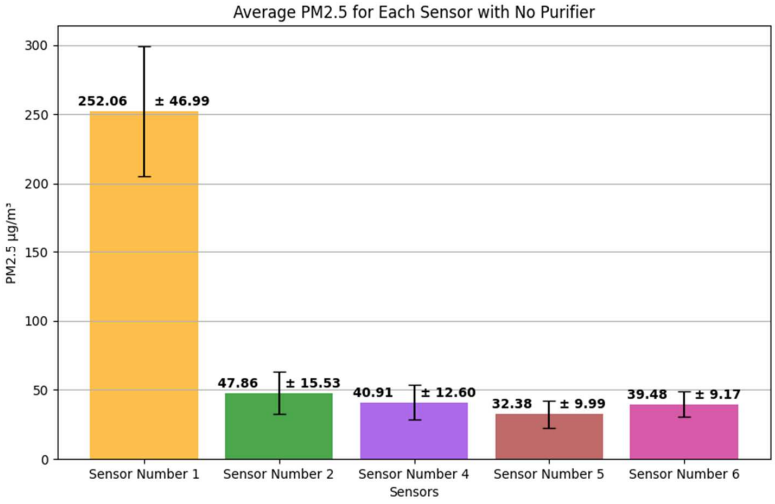


Figure 7. Average $PM_{2.5}$ readings from each sensor during the sub-trials without an air purifier. Error bars represent the standard deviation across repeated measurements.

The results for these purifier-free trials demonstrate that Sensor 1 recorded the highest average $PM_{2.5}$ concentration. Sensor 2's average readings were about 19% of those at Sensor 1, while Sensors 4, 5, and 6 ranged between 13% and 16% of Sensor 1's levels.

3.2. Analysis of Purifier Performance

To quantify purifier effectiveness, the Avg_P was calculated for all purifiers tested. Note that calculating Avg_P data from Sensor 3 was not included in the analysis. The readings of Sensor 3 were not considered because its placement directly in front of the purifier's filter meant that they represented $PM_{2.5}$ removed from the environment, while the other five sensors measured $PM_{2.5}$ that remained in the surrounding air. High readings at Sensor 3 indicated that the purifier was effectively capturing $PM_{2.5}$ because a large amount of $PM_{2.5}$ was being pulled into the purifier's filter. High readings at all the other sensors, however, indicated the purifier's inability to remove $PM_{2.5}$ from the air surrounding the soldering iron. The average $PM_{2.5}$ readings showed that Purifier 2 outperformed the others by a large margin, with $PM_{2.5}$ levels 21.2 times lower than Purifier 1, 13.8 times lower than Purifier 3, and 17 times lower than Purifier 4. The Avg_P values of each purifier are shown in Figure 8.

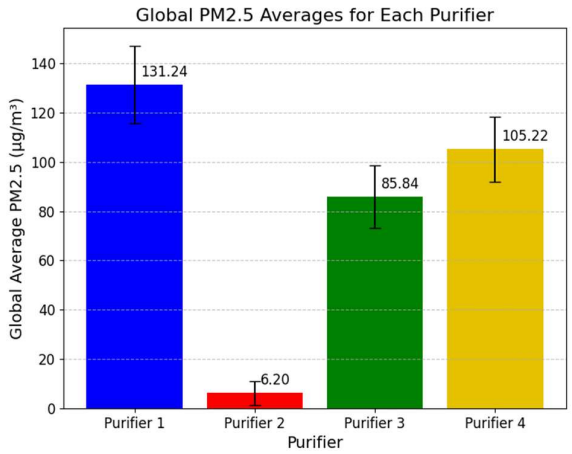
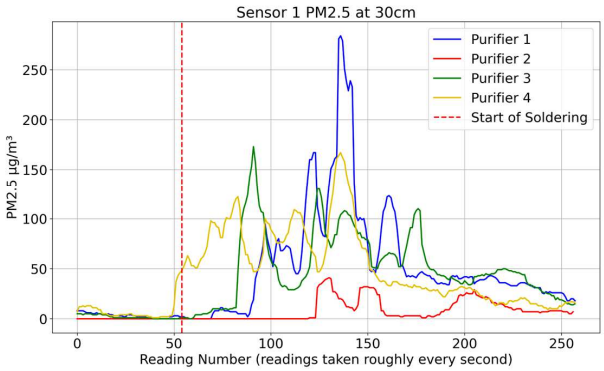


Figure 8. Global average $PM_{2.5}$ concentration associated with each air purifier across all sub-trials. Error bars indicate the variability of measurements across different sensor placements.

Purifier 2 exhibited the lowest average $PM_{2.5}$ concentration, which was 95.3% lower than Purifier 1, 92.8% lower than Purifier 3, and 94.1% lower than Purifier 4. The results

displayed in Figure 8 indicate that Purifier 1 performed the worst in terms of $PM_{2.5}$ removal, exhibiting the highest average $PM_{2.5}$ concentration across all the purifiers. Purifiers 3 and 4 showed better performance, with average $PM_{2.5}$ levels of 34.5% and 19.8%, respectively, lower than Purifier 1. To further validate these performance differences, pairwise Welch's *t*-tests were conducted between purifier datasets and are presented in Section 4.2.

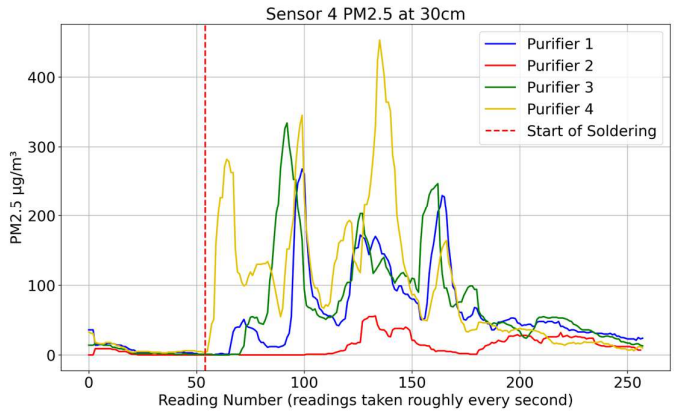
Evaluating purifier performance solely based on overall averages, however, does not provide a complete picture. The global averages shown in Figure 8 do not account for variations in purifier performance based on sensor location or the distance of the soldering iron from the purifier. A more granular analysis of the data reveals that the effectiveness of the purifier is not consistent across all locations near the purifier. Rather, each purifier's effectiveness varies based on the location of the air being measured relative to the purifier. Figure 9 plots the $PM_{2.5}$ concentration readings of Sensor 1 during the four sub-trials where the soldering iron was placed 30 cm away from the purifier.



Purifier	Avg PM2.5	Peak PM2.5
Purifier 1	45.71	284.00
Purifier 2	7.19	41.00
Purifier 3	41.63	173.00
Purifier 4	44.11	167.00

Figure 9. Time series of $PM_{2.5}$ concentrations was recorded by Sensor 1 while the air purifiers were positioned 30 cm from the soldering source. The table on the right summarizes the average and peak $PM_{2.5}$ values for each purifier.

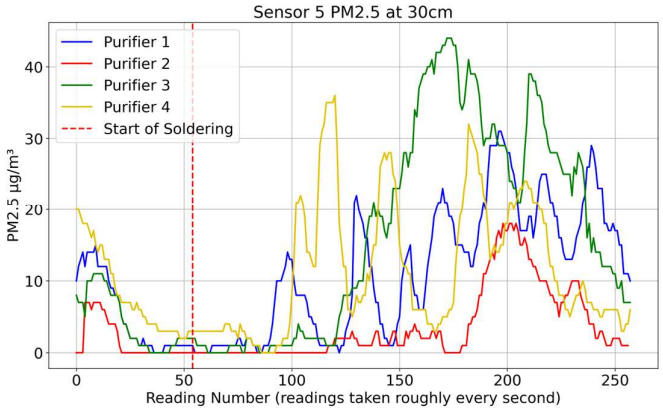
From 30 cm away, Purifier 1 recorded the highest average $PM_{2.5}$ readings, followed closely by Purifier 4 and Purifier 3. The averages given in Figure 8 show that Purifier 1's average $PM_{2.5}$ was 52.9% higher than that of Purifier 3 and 32.9% higher than Purifier 4. However, in Figure 9, the average $PM_{2.5}$ of Sensor 1 is only 4.8% higher than the average $PM_{2.5}$ of Sensor 3, and only 1.6% higher than that of Purifier 4. Similar to the results from Sensor 1, a more granular analysis of Sensor 4 data reveals disagreements with the average $PM_{2.5}$ values given in Figure 8. Figure 10 plots $PM_{2.5}$ readings of Sensor 4 during the four sub-trials where the soldering iron was placed 30 cm away from the purifier.



Purifier	Avg PM2.5	Peak PM2.5
Purifier 1	54.83	268.00
Purifier 2	11.55	56.00
Purifier 3	65.19	334.00
Purifier 4	82.72	453.00

Figure 10. A time series of $PM_{2.5}$ concentrations was recorded by Sensor 4 while the air purifiers were positioned 30 cm from the soldering source. The table on the right summarizes the average and peak $PM_{2.5}$ values for each purifier.

When examining only Sensor 4, Purifier 4 had the highest average and peak of $PM_{2.5}$ readings, with values 9.5% and 20.5% higher than those of Purifier 3. Following Purifiers 4 and 3, Purifier 1 had the next highest average and the peak of $PM_{2.5}$ values. These findings contrast sharply with Figure 9, which indicates that Purifier 1 had the highest overall $PM_{2.5}$ concentration. Figure 11 shows $PM_{2.5}$ values recorded by Sensor 5 during the sub-trials in which the soldering iron was placed 30 cm away from the purifier.



Purifier	Avg PM2.5	Peak PM2.5
Purifier 1	10.51	31.00
Purifier 2	3.32	18.00
Purifier 3	14.62	44.00
Purifier 4	10.99	36.00

Figure 11. Time series of $PM_{2.5}$ concentrations was recorded by Sensor 5 while the air purifiers were positioned 30 cm from the soldering source. The table on the right summarizes the average and peak $PM_{2.5}$ values for each purifier.

The data from Sensor 5, shown in Figure 11, indicates that Purifier 3 allowed the highest average and highest peak $PM_{2.5}$ concentrations. Purifier 1 recorded a notably lower average and lower peak $PM_{2.5}$ values than Purifier 3, and a nearly equal average $PM_{2.5}$ value as Purifier 4. This is again notably different from what the data from Sensor 1 given in Figure 9 and the averages given in Figure 8 show.

Additional variations in purifier performance beyond those described above were observed when the performance of individual purifiers at varying distances from the soldering iron was investigated. The results showed that for desktop purifiers (Purifiers 1, 3, and 4), moving the purifier closer to the soldering iron did not necessarily reduce $PM_{2.5}$ concentrations. Figure 12 shows the average $PM_{2.5}$ concentrations across Sensors 1–6 during the 12 sub-trials where each purifier was used at 10 cm, 20 cm, and 30 cm from the soldering iron.

Both Purifiers 1 and 4 recorded their highest average $PM_{2.5}$ concentration when placed 20 cm from the soldering iron, suggesting an intermediate distance where efficiency declines. Conversely, Purifier 3 recorded its lowest $PM_{2.5}$ concentration at 20 cm, with higher $PM_{2.5}$ levels at both 10 cm and 30 cm.

Considered as a whole, the data presented in the above section reveal that each purifier has its own range of most effective distances to be placed from the soldering iron, and that purifier performance in removing $PM_{2.5}$ varies significantly based on the user's position relative to the purifier. While the averages presented in Figure 8 are useful for a high-level overview of purifier performance, a more granular examination of the experimental data was required to effectively characterize the performance of each purifier.

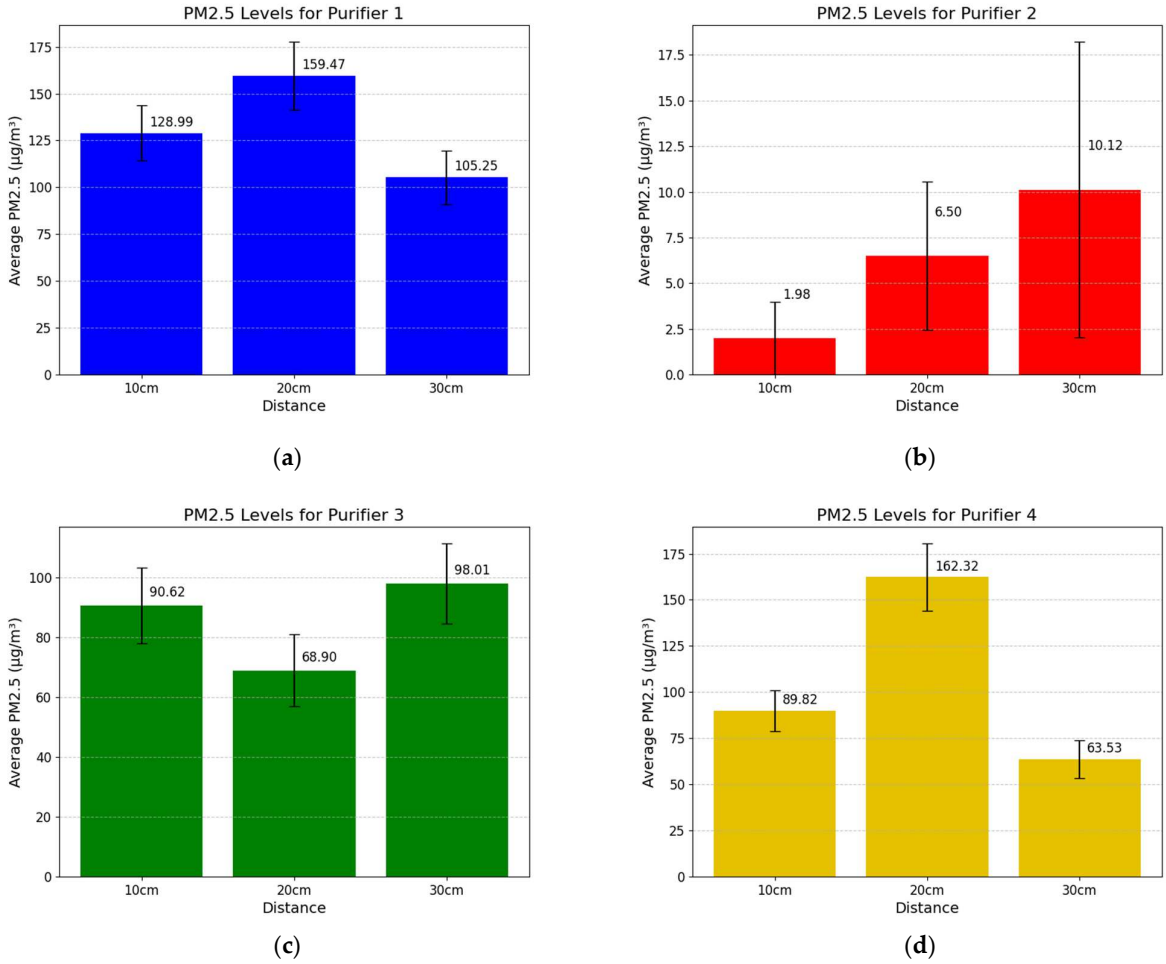


Figure 12. Average $PM_{2.5}$ concentrations for each purifier at distances of 10 cm, 20 cm, and 30 cm from the soldering source: (**a**) Purifier 1, (**b**) Purifier 2, (**c**) Purifier 3, (**d**) Purifier 4. Error bars represent measurement variability.

3.3. Variations in PM Concentrations by Sensor

An analysis of the Avg_s values of each sensor revealed that all the purifiers tested were able to keep $PM_{2.5}$ in the area near the desk upon which the soldering iron was placed, protecting the user from $PM_{2.5}$ accumulation in their breathing zone. Sensor 3, the sensor placed at the intake of the air purifier, recorded the highest $PM_{2.5}$ concentration at 190.93 µg/m^3, which indicates that purifiers were effectively extracting PM from the surrounding environment. Figure 13 shows the Avg_s values calculated for each sensor.

Sensor 3's readings were 21.6% higher than Sensor 2 and 69.3% higher than Sensor 6. Sensors 2 and 6, positioned on the same desk as the soldering iron, recorded the second- and third-highest concentrations. Sensors 1, 4, and 5, which were closest to the user's breathing zone, recorded the lowest $PM_{2.5}$ concentrations. When the results presented in Figure 7, which show the Avg_s values of each sensor during the sub-trials where no purifier was used, are compared to the values shown in Figure 13, a large decrease in $PM_{2.5}$ levels at Sensors 1 and 5 can be observed. Sensor 1 exhibited an 83.4% decrease in average $PM_{2.5}$ concentrations when a purifier was in use, and Sensor 5 showed a 61.5% decrease. Taken together, these trends of low $PM_{2.5}$ concentrations at Sensors 1, 4, and 5, and higher concentrations at Sensors 2, 3, and 6 when a purifier is used indicate that all the purifiers tested were able to shuttle $PM_{2.5}$ away from the breathing zone of the user and towards the desk upon which the soldering iron was placed. These findings are further supported by the current literature, which suggests that indoor $PM_{2.5}$ particulates are a very localized

phenomenon and $PM_{2.5}$ concentrations can vary greatly over short distances [69]. It can be concluded then that even if a purifier's filter is not entirely effective in capturing and removing $PM_{2.5}$ from the air, its ability to draw particles away significantly reduces user exposure. As detailed further in 4.1, this conclusion provides an important insight into protection against $PM_{2.5}$ exposure provided by air purifiers.

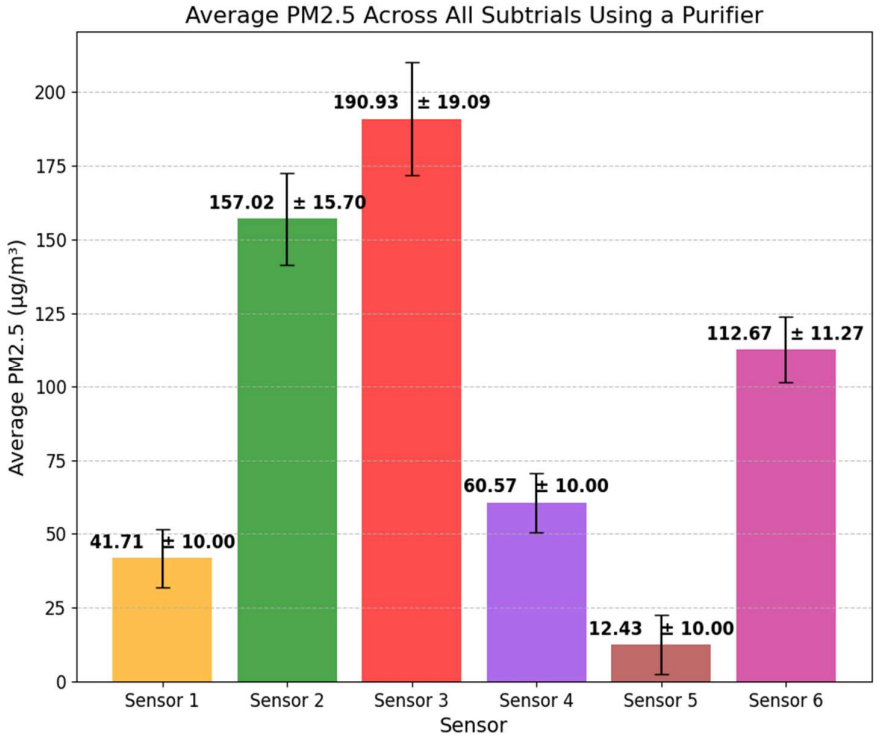


Figure 13. Global average $PM_{2.5}$ concentrations recorded by each sensor across all trials. Error bars represent the instrumental uncertainty of the AeroSpec sensors.

4. Discussion

The results of the study indicate significant variations in the abilities of purifiers to remove $PM_{2.5}$ generated by soldering activities. A previously unreported finding is that even purifiers with lower filtration efficiency can reduce $PM_{2.5}$ exposure by generating airflow patterns that divert particles away from the breathing zone towards surface and desk-level regions, creating a localized zone of reduced pollutant concentration and enhancing user safety. Although all purifiers provide some level of protection, their efficiency varies substantially depending on the model and its placement relative to the soldering iron. As shown above in Figure 12, only Purifier 2 was able to keep average $PM_{2.5}$ concentrations below the EPA's 24 h $PM_{2.5}$ exposure limit of 35 $\mu g/m^3$, while all other purifiers tested failed to keep average $PM_{2.5}$ concentrations below this limit. It is important to note that none of the purifiers evaluated in this study explicitly claim to meet or guarantee compliance with any specific air quality standards, such as those set by the EPA.

4.1. Protection Provided by All Purifiers

The analysis of the average $PM_{2.5}$ readings from Sensors 1-6, taken during sub-trials with and without purifiers, supports the idea that purifier fan airflow—regardless of the model or quality—provides a protective effect by preventing $PM_{2.5}$ from accumulating in the user's breathing zone. As shown in Table 6, Sensor 1 recorded an average $PM_{2.5}$ concentration of 252.06 $\mu g/m^3$ without a purifier, a 504% increase from its average with a purifier and substantially higher than the average $PM_{2.5}$ concentrations recorded by

sensors 2–6. This is a concerning trend, as Sensor 1 was positioned directly below the researcher's chin, and $PM_{2.5}$ in that region could easily be inhaled.

Table 6. Comparison of average $PM_{2.5}$ readings from Sensors 1–6 during sub-trials conducted with and without air purifiers.

Sensor Number	Average $PM_{2.5}$ Reading with Purifier ($\mu g/m^3$)	Average $PM_{2.5}$ Reading without Purifier ($\mu g/m^3$)
1	41.71	252.06
2 *	157.02	47.86
3 *	190.93	--- *
4	60.57	40.961
5	12.43	32.36
6 *	112.67	39.48

* Sensor 3 was not used in the "No Purifier" condition because it was positioned at the purifier's inlet. * Sensors 2, 3, and 6 were located near the soldering spot and generally recorded higher $PM_{2.5}$ concentrations when a purifier was in use.

Sensors 2 and 6 both demonstrated notably higher $PM_{2.5}$ values when purifiers were used than when they were not. With purifiers running, Sensor 2 measured an average $PM_{2.5}$ concentration of 157.02 $\mu g/m^3$, while Sensor 6 measured 112.67 $\mu g/m^3$. By contrast, when no purifier was used, Sensors 2 and 6 recorded average concentrations of 47.86 $\mu g/m^3$ and 39.48 $\mu g/m^3$, respectively. The pattern, high $PM_{2.5}$ concentrations at Sensor 1 without a purifier, and lower concentrations at Sensor 1 but higher levels at Sensors 2 and 6 when purifiers were used, suggests that purifiers redirected $PM_{2.5}$ particles away from the breathing zone toward the surrounding areas.

The data given in Table 7 support this conclusion. Sensor 1 shows a higher concentration of readings at lower (<100 $\mu g/m^3$) values when a purifier is used versus when no purifier is used. Sensors 2, 4, and 6 on the other hand demonstrate a greater proportion of readings at higher (>100 $\mu g/m^3$) concentrations when a purifier is used. This provides evidence that the use of a purifier removes very localized high concentrations of $PM_{2.5}$ from the user's breathing zone and redistributes them around the desk and soldering iron. This reduction of user exposure to high $PM_{2.5}$ spikes can provide notable population health benefits, including reduced daily mortality and reduced risk of asthma and heart disease [70,71].

Table 7. Percentages of readings from Sensors 1 through 6 that were <100 $\mu g/m^3$ and $\leq$100 $\mu g/m^3$ in the sub-trials that were conducted with and without purifiers.

Sensor Number	Without Purifier >100 $\mu g/m^3$	Without Purifier $\leq$100 $\mu g/m^3$	With Purifier >100 $\mu g/m^3$	With Purifier $\leq$100 $\mu g/m^3$
1	38.45%	61.55%	12.19%	87.81%
2	30.35%	69.65%	35.71%	64.29%
3	--- *	--- *	38.00%	62.00%
4	15.49%	84.51%	18.28%	81.72%
5	0.62%	99.38%	0.44%	99.56%
6	25.61%	74.39%	30.97%	69.03%

* Sensor 3 was not used in the "No Purifier" condition because it was positioned at the purifier's inlet.

The redistribution of $PM_{2.5}$ represents a critical protective measure offered by all of the purifiers tested. Regardless of the purifier's ability to filter $PM_{2.5}$ out of the air, the act

of moving $PM_{2.5}$ from the user's breathing zone toward the desk area provided a degree of protection since $PM_{2.5}$ near the desk is less likely to be inhaled than $PM_{2.5}$ accumulating in the user's breathing zone.

4.2. Statistical Differences Between Purifiers

Welch's *t*-tests were conducted between the data from each of the purifiers to investigate whether differences between the purifiers in reduction of $PM_{2.5}$ were significant. Table 8 summarizes the results of Welch's *t*-tests between the four purifiers.

Table 8. Results of Welch's *t*-tests on the average $PM_{2.5}$ readings of the four purifiers. To find average $PM_{2.5}$ values for each purifier average $PM_{2.5}$ was calculated across the 10 cm, 20 cm, and 30 cm sub-trials for that purifier.

Comparison	t-Statistic	*p*-Value	Adjusted *p*-Value	Significant
Purifier 1 vs. Purifier 2	41.5	0 *	0 *	True
Purifier 1 vs. Purifier 3	12.3	2.93×10^{-34}	1.76×10^{-33}	True
Purifier 1 vs. Purifier 4	10.1	9.25×10^{-24}	5.55×10^{-23}	True
Purifier 2 vs. Purifier 3	−39.5	0 *	0 *	True
Purifier 2 vs. Purifier 4	−41.0	0 *	0 *	True
Purifier 3 vs. Purifier 4	−2.49	1.29×10^{-2}	7.71×10^{-2}	False

* It is not possible to have a *p*-value or adjusted p-value of true 0; the output of 0 is a result of a rounding error in the Python 3.9 software used to conduct the Welch's *t*-tests. In Python, the smallest reasonable floating-point value that can be displayed is 2.2×10^{-38}; when trying to display numbers smaller than this Python will round down to 0. The reported *p*-values of 0 should be interpreted as incredibly small *p*-values, smaller than the floating-point limit.

Pairwise Welch's *t*-tests with Bonferroni correction revealed that large statistical differences exist between almost all of the purifiers tested. All comparisons except the comparison of Purifier 3 vs. Purifier 4 had extremely small *p*-values (<<0.05) even after Bonferroni correction, and magnitudes of t-statistics > 10 for all but one comparison. Purifier 2 stands out with extremely large magnitudes of t-values (>38) and incredibly small *p*-values, the t-statistics of Purifier 2 highlight its significantly superior abilities in removing $PM_{2.5}$ from the air as compared to the other purifiers tested. These findings demonstrate that purifier performance does vary meaningfully, and careful selection of air purifiers is important to achieve desired air quality metrics.

4.3. Purifier Optimal Ranges

The results indicate that for all purifiers, performance does not increase as the distance from the soldering iron decreases. Instead, each purifier has a unique range of distances at which it is most effective. This could be attributed to several factors, including the purifier's fan strength, the aerodynamics of the purifier's air intake, and the effect of the purifier's fan in dispersing $PM_{2.5}$.

Purifiers 1 and 4 both recorded their highest average $PM_{2.5}$ concentrations when placed 20 cm away from the soldering iron. These two purifiers were similar in that they were both desk-mounted purifiers, and each featured plastic fairings around the mouth of the purifier. High average readings at 20 cm could suggest that, at this distance, the combination of the suction of the purifiers' fans and the aerodynamics of the plastic fairings

mixes and distributes $PM_{2.5}$ in the surrounding air instead of directing it into the mouth of the purifier. This effect appears to be strongest at 20 cm. At 10 cm and 30 cm, Purifiers 1 and 4 recorded lower $PM_{2.5}$ averages, indicating that at these distances, the purifiers were not impeded by turbulence caused by their fans or the aerodynamics of the plastic fairings, and were better able to remove $PM_{2.5}$ from the air.

Purifier 3 demonstrated a different range of ideal distances than Purifiers 1 and 4. Purifier 3 was a desktop-mounted purifier, but it had no plastic fairings and had a much smaller footprint than the other purifiers tested. Purifier 3 had its lowest average $PM_{2.5}$ concentration of 96.98 $\mu g/m^3$ when placed 20 cm away from the soldering iron, as compared to 107.04 $\mu g/m^3$ and 129.25 $\mu g/m^3$ at 10 cm and 30 cm, respectively. This notable increase in average $PM_{2.5}$ concentrations when placed 30 cm from the soldering iron is likely because Purifier 3 contained the weakest fan of all the purifiers tested. Its fan is rated at 20 W and can move 88–100 cubic feet of air per minute. In comparison, the fans in Purifiers 4 and 2 can move up to 115 and 147 cubic feet of air per minute, respectively. It is likely that, as Purifier 3 was moved further from the soldering iron, its weaker fan lost the ability to pull the $PM_{2.5}$ being generated by the soldering iron toward itself, resulting in higher average $PM_{2.5}$ readings. Purifier 3's high readings at 10 cm can be explained by its small footprint. The mouth of Purifier 3 was approximately four times smaller than the mouth of the other desktop purifiers, and when placed close to the soldering iron, it was likely hindered by its small size and unable to capture a sufficient volume of air, allowing a significant portion of the $PM_{2.5}$ to disperse into the surrounding environment.

Purifier 2 was the only purifier that demonstrated a linear relationship between the distance from the soldering iron and average $PM_{2.5}$ concentrations. This is an encouraging result, as Purifier 2 was the only overhead purifier and was by far the most expensive model tested, retailing at USD 293 as of March 2025. Users who invest in the more expensive overhead purifiers can be sure that they will not have to account for the variable effective ranges of desktop purifiers and will instead be certain that simply moving the fume extractor closer to the soldering iron will reduce $PM_{2.5}$ concentrations.

5. Conclusions and Recommendations

The findings of this study indicate that the concentrations of $PM_{2.5}$ during soldering activities that lack any air purification significantly exceed the EPA's recommended exposure limits. Even brief soldering without proper purification can expose the user to extremely high momentary $PM_{2.5}$ concentrations, potentially increasing the risk of serious and long-term health effects. All purifiers tested in the experiment, regardless of filtration efficiency, significantly reduced $PM_{2.5}$ concentrations within the immediate breathing zone by redistributing pollutants toward desk-level areas through air movement induced by the purifiers' fans. For all laboratories that are involved in soldering activities, to minimize exposure to harmful $PM_{2.5}$ concentrations during these activities, it is strongly recommended that they adopt soldering air purifiers. Even purifiers with lower filtration efficiency can offer meaningful reductions in user $PM_{2.5}$ exposure.

Design differences across air purifier models create significant differences in purification efficiency. The purifier's performance is affected by specifications that include mechanical intake design, fan power, type of filter used, and overall dimensions. Large desktop purifiers equipped with more powerful fans typically provide superior protection compared to smaller or less powerful units. If possible, it is best to use a purifier like Purifier 2, one that comes equipped with an overhead fume extractor. Purifier 2 showed the best performance in removing $PM_{2.5}$ from the surrounding air, and research supports that the HEPA filter used in Purifier 2 can effectively remove $PM_{2.5}$ from educational environments [72].

Despite the study's finding that PM concentrations were consistently highest near the soldering source and significantly lower at elevated positions near the user's breathing zone when purifiers were operational, it also revealed that air purification performance is significantly affected by the purifier's placement relative to the soldering iron. Laboratories should explicitly guide experimenters, especially students or beginners, on how to properly place soldering air purifiers at optimal distances and maintain the correct position during soldering. Not only does such training ensure the user's safety, but it also helps beginners develop correct laboratory habits. Furthermore, the results show that the optimal distances vary significantly for each purifier, with some performing better at shorter distances, while others are optimal at intermediate ranges. Laboratories should provide clear guidance on the placement of their soldering air purifier based on the specific air purifier model they have adopted; this will ensure that their air purifiers are operating at maximum effectiveness.

6. Limitations of the Study

A limitation of the study reported in this paper was the limited number of sensors deployed. Considering that the lab bench area measured approximately 3.73 m by 2.49 m, the use of six sensors constrained the spatial resolution of the data captured. Although a formal analysis of minimum sensor density was not conducted, typical indoor air quality mapping suggests grid spaces of 1 to 1.5 m would be appropriate for capturing $PM_{2.5}$ gradients in a space of this size [73]. This would require 12 sensors to generate a high-resolution spatial mapping. This was calculated by using the 1 m spacing recommendation which resulted in four sensors along the long axis and three sensors along the short axis. The current study uses six sensors, aligning with the lower-density estimate (1.5 m spacing). While this setup provided a coarse mapping of $PM_{2.5}$ dispersion, increasing the number of sensors in future studies would result in higher spatial resolution and more detailed exposure modeling.

Another important limitation was the testing of only a single overhead purifier. This restricts the generalizability of the findings, as performance characteristics may vary across different overhead purifier models and designs. Additionally, testing only one overhead purifier prevents comparative analysis, which could have identified design features or placements of overhead purifiers that improve effectiveness at reducing $PM_{2.5}$ exposure.

An additional key limitation was the narrow scope of soldering activities. This research specifically studied hand soldering that involved the melting of solder wire. However, actual soldering is a complex activity that can involve not only melting solder wire, but also de-soldering, the use of a hot plate or hot air gun, prolonged soldering sessions, or the use of different soldering materials. As a result of this specific focus, the findings may not fully represent the level of air pollution and airflow disruptions associated with real-world electronics work. In particular, the study lacks an examination of situations in which several soldering stations work simultaneously, which is a typical scenario in beginner soldering courses at universities. Such scenarios may introduce compounding thermal effects, pollutant buildup, or complex airflow interactions that significantly influence purifier performance and pollutant exposure levels. A more comprehensive study of diverse soldering activities would provide a deeper understanding of the air quality risks faced by those soldering and explore more targeted mitigation strategies.

Another limitation stems from the brief duration of the validation test, which lasted for 10 min. While this method allows for controlled, short-term accuracy checks, it may not capture long-term trends in sensor accuracy or reflect performance under prolonged exposure conditions. An extended validation period would provide more robust evidence of sensor

consistency. Future studies with extended monitoring periods should incorporate periodic recalibration checks to account for potential time-dependent drift in the AeroSpec sensors.

Lastly, single metrics of particle count are insufficient to assess the complex physiological effects of air pollution; some factors, such as humidity and chemical compound interactions, also need to be considered when evaluating the impact of poor indoor air quality [74]. Therefore, the health impact analysis in this paper is limited; such cautious interpretation needs support from more comprehensive spatiotemporal pollutant data.

7. Future Work

7.1. Sensor Network Expansion

To overcome the limits of the spatial resolution mentioned in the previous section, one of our future objectives will be to focus on expanding the number and distribution of the AeroSpec sensors in each trial. This involves integrating intelligent air quality management systems that utilize Internet of Things (IoT) smart sensor platforms to enable easier and more flexible access to sensor monitoring and management, which enables a denser network of sensors that cover a larger lab area [75]. Future sensor networks could also consider the use of RFID-enabled air quality sensors [59]. There exists an open-source RFID platform that could greatly accelerate the development of such a sensor network [76].

7.2. Experimental Scope Expansion and Diversification of Soldering Scenarios

To address the limitation on the range of soldering activities in this study, future studies could include the incorporation of a broader set of soldering processes, including desoldering, prolonged soldering operations, using different soldering tools, and concurrent soldering on multiple devices. These changes aim to make the data collected from the AeroSpec sensors more representative of operational scenarios in academic, industrial, and residential environments. The introduction of more soldering operations would provide a more comprehensive understanding of how various soldering processes emit PM and how air purifiers perform in combatting these emissions. Future experiments could also increase the duration of soldering sessions to explore pollutant buildup and more accurately evaluate potential long-term exposure risks. These changes would improve the practical applicability of the results and provide recommendations and guidelines for diverse use cases.

7.3. Involvement of Computational Fluid Dynamics (CFD)

Although experimental approaches were used in this study, computational fluid dynamics (CFD) software such as Ansys CFD version 2025 R1 could help cross-validate results and enhance the robustness and reliability of findings. CFD simulations can provide detailed insights into the dynamics of airflow and particulate matter concentration, allowing researchers to explore the functional relationship between the specifications of an air purifier and its purification effectiveness. Additionally, CFD simulations can be a supplementary tool for studying hypothetical yet realistic scenarios, such as variations in room layouts, the presence of air conditioners, and other objects that could potentially affect airflow.

7.4. Forming a Comprehensive Set of Mitigation Strategies

Possible mitigation measures concerning the exposure to air pollutants, aside from air purifiers and fume hoods, include the use of properly selected and fitted face masks, as well as a switch to low-smoke flux and lead-free solder. To overcome the limitations of spatial resolution mentioned in the previous section, one of our future objectives will be to focus on expanding the number and distribution of AeroSpec sensors in each experimental setting.

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Data Availability Statement: The sensor validation, experiment data, data processing scripts, and the result plot and figures presented in this paper are available upon request from the corresponding author.

Use of Artificial Intelligence: The authors utilized Grammarly, an AI-assisted tool for spelling and grammar checking, to enhance readability and clarity. Additionally, ChatGPT was utilized to review the paper's content, but it was not used to create written material or perform calculations.

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