AIR POLLUTION Inside Kingspan

Initial Results from a 3-Day Monitoring Study

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This report was made possible by the numerous Kingspan employees and community volunteers who participated in data collection as well as the Madison Park Neighborhood Association (MPNA) and International Association of Sheet Metal, Air, Rail and Transportation Workers (SMART). All data analyzed and presented in this report was collected voluntarily by community members and Kingspan employees, while all data analysis was conducted by Shahir Masri, Sc.D., of Masri Research and Consulting.

MASRI RESEARCH AND CONSULTING

Masri Research & Consulting was founded by Shahir Masri, Sc.D. Dr. Masri has over 10 years of experience in environmental research, monitoring and data analysis, and is the first author of numerous peer-reviewed scientific studies. He has dedicated his career to research in the areas of environmental exposure assessment and modeling, including the characterization of air and soil pollution and the potential impacts to disadvantaged communities. Dr. Masri is an assistant specialist in air pollution exposure assessment and epidemiology at the University of California, Irvine, where he works on air and soil pollution exposure and modeling as well as climate change communication research. He also holds an academic appointment at the Schmid College of Science and Technology at Chapman University where he teaches courses on environmental health and pollution.

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EXECUTIVE SUMMARY

PM2.5 is an air pollutant widely associated with a range of adverse health conditions including respiratory and cardiovascular problems, as well as increased mortality and hospital admissions. Following concerns raised by workers at the Kingspan facility in Santa Ana, California, workers and community leaders organized and engaged experts in the construction of an air monitoring assessment to measure the levels of PM2.5 to which Kingspan workers and local residents are exposed during the workday. To measure PM2.5, participants were outfitted with government-validated personal air monitoring devices called AtmoTube® Pros over three separate workdays (5AM-1:30PM) in the summer, 2021. Results showed an average PM2.5 concentration inside the Kingspan facility of 112.3 µg/m3, nearly 7-times higher than the outdoors (17.3 µg/m3). Of eight employees who carried personal indoor air monitors, five recorded measurements above 100 µg/m3, with three recording maximum concentrations above 500 µg/m3. If these averages were measured outdoors, their ranking would fall between “unhealthy” and “very unhealthy” according to EPA’s Air Quality Index. For one employee, personal PM2.5 exposure was 210.9 µg/m3 when averaged over three workdays, with some measurements reaching the maximum limit of the monitor’s detection ability (1,000 µg/m3). For context, the annual government-reported outdoor PM2.5 concentration for Orange County ranged from 8.8 to 11.3 µg/m3 in 2020. Welding-related activities within the Kingspan buildings tended to result in the highest PM2.5 concentrations, compared to other activities.

RECOMMENDATIONS: Given elevated concentrations of PM2.5 inside the Kingspan facility, it is recommended that management implement basic measures of indoor air pollution control, including the installation of appropriate ventilation systems to exhaust and filter indoor air contaminants, and that welders be outfitted with adequate personal protective equipment that includes face masks equipped with supplied-air respirators. Further, these findings suggest the need for ongoing air monitoring both inside and outside of the Kingspan facility so as to better characterize the long-term air pollution concentrations to which workers and community members may be exposed and to allow for adequate follow-up evaluation following the implementation of mitigation measures.

1. INTRODUCTION

Extensive epidemiological research has identified exposure to airborne particulate matter (PM) to be associated with increased hospital admissions and all-cause mortality [1–3] as well as multiple adverse respiratory, cardiovascular, and neurological conditions.[4–6] In such studies, exposure is usually characterized based on the measured mass concentration of particles within specific size ranges. Those of particular importance to health are the particles less than 2.5 micrometers (μm) in aerodynamic diameter (PM2.5). For reference, the approximate diameter of a human hair is 70 μm, making a PM2.5 particle about 30-times smaller.[7] In contrast to larger particles, which can be filtered out by the respiratory tract when inhaled, smaller PM2.5 particles have the ability to penetrate to the deepest area of the lung—the alveolar region—where gas exchange takes place.[7] This region is not coated with a protective mucus layer, and also takes longer to clear deposited particles, thus allowing for potentially greater health effects.[7] In contrast to larger particles that can originate from various natural sources including pollen and resuspended dust, smaller particles tend to originate from combustion sources including the burning of fossils fuels as well as industry operations.

Southern California tends to experience some of the worst PM2.5 and other air pollution given its abundance of vehicle traffic, industrial facilities, and presence of the nation's largest port complex. Importantly, however, exposure to such pollutants is not realized equally across ethnic groups and income levels. Instead, a long history and extensive body of literature has shown that low-income communities and communities of color are often disproportionately exposed to the highest levels of contamination both in California and across the United States, including to air and soil pollution among other environmental hazards.[8–14] Recently, a study in Santa Ana, California, showed that census tracts with a median household income below $50,000 had roughly a five-times higher soil concentration of lead—a harmful heavy metal—than did higher-income census tracts.[15] Similarly, soil samples collected in areas with higher proportions of Hispanic residents had over two-times higher soil lead concentrations compared to the least Hispanic areas.[15] What is more, a follow up risk assessment of Santa Ana found that nearly all census tracts met the U.S. Environmental Protection Agency's (EPA) definition of unacceptable cancer risk due to elevated soil concentrations of eight heavy metals.[16] As a city consisting predominantly of Hispanic residents (77.3%), such findings underscore not only a public health concern, but an issue of environmental injustice that is consistent with modern history.[17]

One industrial facility in Santa Ana that has recently come under focus among employees of the company as well as neighboring residents due to air pollution concerns is a facility that consists of two buildings operated by Kingspan Group, PLC. Kingspan is a global manufacturing company that is headquartered in Ireland, and which specializes in the production and sales of building materials such as insulation, skylights, ventilation systems, flooring, roofing and other products designed to make "green" energy efficient buildings. With approximately 166 factories around the world and 15,500 employees, Kingspan experienced sales of $5.5 billion and a trading profit of roughly $600 million in 2020, despite the COVID-19 pandemic.[18] The types of industrial operations that Kingspan is engaged in varies widely, and includes many processes known to release soil, water and air pollution. Since Kingspan first received its Industrial General Permit in 2018, the company has violated its allowable level of zinc discharge to storm water runoff each of the three years. At their Santa Ana location, pollution-emitting operations include painting, welding, sanding, and grinding.

In the summer of 2021, workers at the Kingspan factory in Santa Ana raised concerns about poor indoor air quality related to such activities and began to organize with the International Association of Sheet Metal, Air, Rail and Transportation Workers (SMART). One of the consistent concerns that employees raised was about poor air quality inside the buildings. This concern was shared by local residents in the area, many of whom recently participated in a government-funded pilot project that found an increase in air pollution around the general Kingspan industrial area. The study was led by Santa Ana's Madison Park Neighborhood Association (MPNA) and was designed to characterize outdoor air pollution around the city's so-called "industrial corridor," of which Kingspan is a part.

Subsequently, collaborations between Kingspan employees, community organizers and volunteers, along with experts in the field of air pollution, were established. As with the MPNA study, in which trained "citizen scientists" utilized hand-held instruments to carry out their own air monitoring and data collection, workers at Kingspan similarly drew upon expert advice in order to construct an air monitoring campaign that would enable workers to collect personal exposure data for analysis. This report describes the details of that sampling campaign along with key findings from an initial analysis of the air monitoring data that was collected by employees and community volunteers. Both the data analysis and writing of this report were carried out by Dr. Shahir Masri, who is an air pollution scientist at the University of California, Irvine, and also the founder of Masri Research and Consulting.

2. METHODS

2.1 INDOOR AIR MONITORING

Between 5AM-1:30PM on three separate workdays in August, 2021, Kingspan workers inside the Kingspan Light and Air building located at 302 Goetz Avenue in Santa Ana, CA (henceforth, the “302 Building”) along with the neighboring Kingspan building located at 401 Goetz Avenue (henceforth, the “401 Building”) were outfitted with personal air pollution monitoring devices called AtmoTube® Pros (AtmoTech, Inc., San Francisco, CA) as well as Global Positioning System (GPS) devices called Qstarz® Travel Recorders (QStar Technologies, Inc., Denver, CO) in order to measure indoor concentrations of PM2.5 to which workers are exposed during the workday, and to identify the locations where the greatest exposures occurred.

The AtmoTube® Pro recently underwent field evaluation by the South Coast Air Quality Management District (SCAQMD) and demonstrated a high measurement accuracy for the detection of ambient PM2.5 concentrations when compared to Federal Equivalent Method (FEM) instruments (R2 = 0.79-94).[19] Measurements of PM2.5 are therefore the focus of this report. Figures 1 and 2 depict the Kingspan facility in relation to the neighboring residential community and to the city of Santa Ana (and state) as a whole.

Figure 1. Aerial image depicting Kingspan facility in relation to neighboring homes.

FIGURE 2. MAP DEPICTING KINGSPAN FACILITY AND CITY OF SANTA ANA WITHIN CALIFORNIA.

The workers who participated in the three-days of air monitoring consisted predominantly of employees who live in Santa Ana, some of whom live within just a few blocks of the Kingspan facility. The age of participants ranged from early 20s to late 40s. Most workers were Latino, with Spanish being their first language. All participants reported working at Kingspan for at least three years, with some working at the company for as long as 10 years.

Based on descriptions by employees who work within the 401 and 302 buildings, air pollution within these buildings (and therefore potentially outside of the buildings) was assumed to consist of a mixture of both fine (PM2.5) and course (PM10) particulate matter as well as volatile organic compounds (VOCs). As shown in Table 1, the number of air pollution sources within the 401 and 302 buildings as described by employees totaled to 17 and 12 unique sources, respectively, including welding, oven-related heating of plastics, cutting/grinding of plastics and metals, and chemical mixing/spraying (including painting). Despite the various sources likely contributing to contamination of the indoor air, this analysis (as noted earlier) focuses exclusively on PM2.5 concentrations.

Table 1. Summary of air pollution sources and activities based on employee descriptions.

Air Pollution Source Activity	# of Activities (401 Building)	# of Activities (302 Building)	Type of Air Pollution
Welding	2	7	$PM_{2.5}$
Oven (plastic softening)	4	0	VOCs
Cutting/Grinding	5	3	PM_{10}
Chemical Mixing/Spraying	6	2	VOCs
Total	17	12	

In order to understand PM2.5 variability on the interior of the Kingspan buildings, and to help characterize potential hotspots of air pollution from workstation to workstation, both mobile and stationary air monitoring devices were deployed on the interior of each building. Stationary devices consisted of devices that remained in fixed locations throughout the duration of the workday. Sites where stationary devices were placed were those which, based on verbal accounts by workers, were considered to be potential air pollution hotspots (e.g., multiple emission-activities taking place adjacent to one other).

In Figures 3 and 4, the approximate locations of stationary devices and their corresponding Site ID designations are indicated using numbered red stars. As shown, six sites were selected for stationary air sampling in the 401 Building and three sites in the 302 Building.

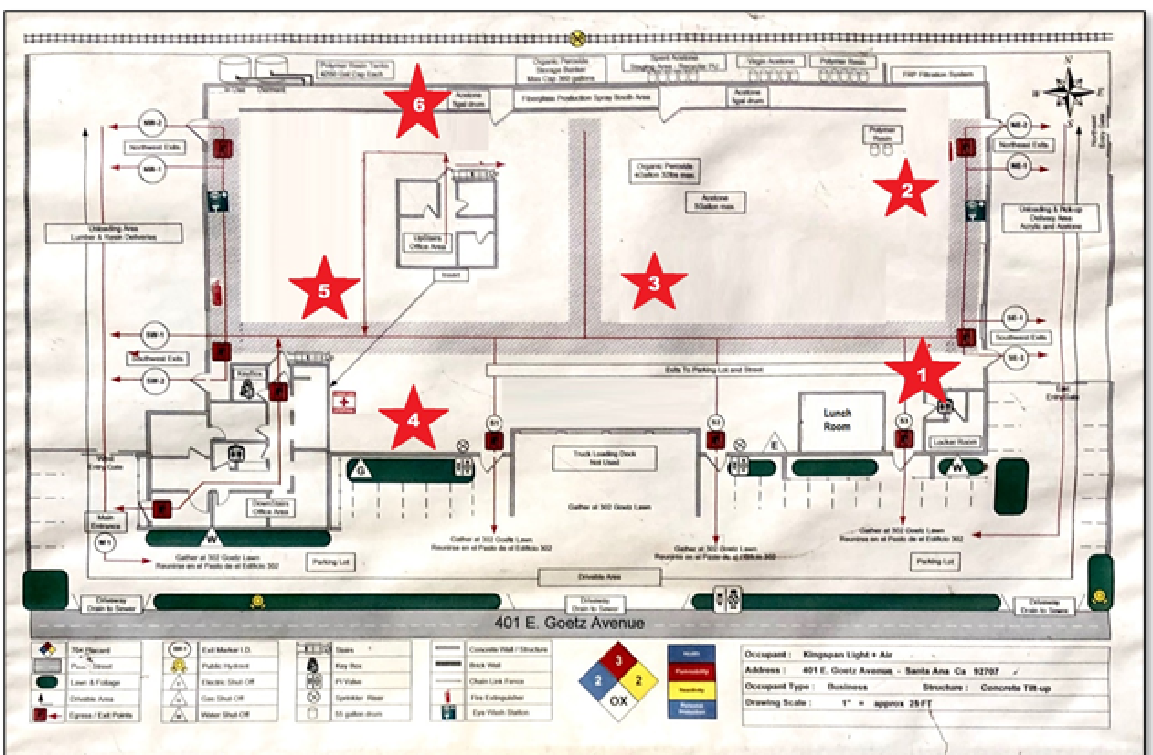


Figure 3. Locations of six potential hotspots identified for stationary sampling inside the 401 Building based on air pollution sources reported by employees.

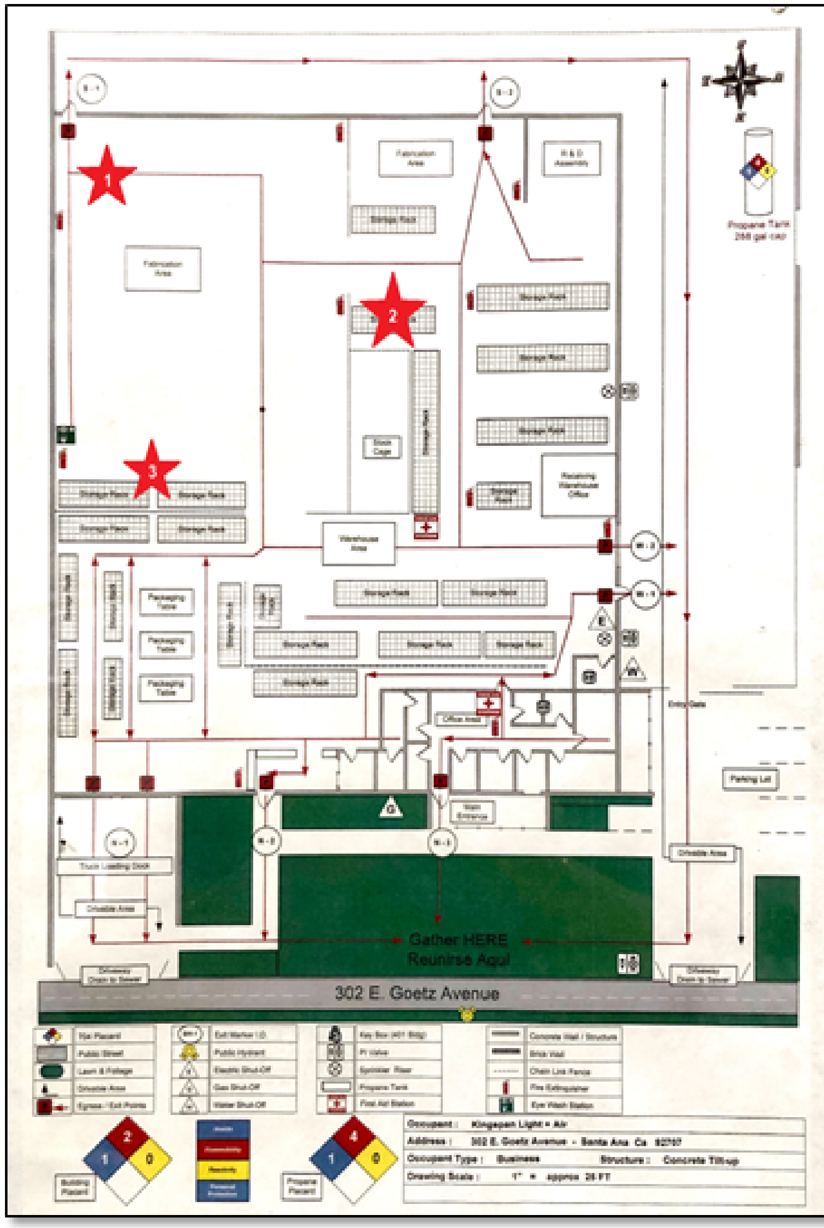


FIGURE 4. LOCATIONS OF THREE POTENTIAL HOTSPOTS IDENTIFIED FOR STATIONARY SAMPLING INSIDE THE 302 BUILDING BASED ON AIR POLLUTION SOURCES REPORTED BY EMPLOYEES. NOTE, THIS IS A MODIFIED FIRE SAFETY MAP. THUS, THE DESCRIPTIVE CONTENT AT THE BOTTOM CAN BE IGNORED FOR THE PURPOSES OF THIS REPORT.

Personal (or mobile) air monitoring devices were those that were worn by employees throughout the workday (e.g., hung around the neck), therefore enabling a characterization of personal workplace exposure. Those who participated in personal air monitoring included workers from a diverse range of specialties, thus enabling a broad understanding of work-related air pollution exposure within the buildings. Although beyond the scope of the present report, employees who participated in personal air sampling were also outfitted with GPS devices, which enable the pinpointing of specific locations in and around the Kingspan buildings where air pollution levels were highest.

So as to not attribute elevated air pollution to activities that were not work-related, workers involved in air monitoring were instructed to avoid smoking cigarettes while conducting air monitoring and to record such activities if/when they occurred. However, no workers reported such activity while air monitoring.

2.2 OUTDOOR AIR MONITORING

To understand emission sources contributing to polluted indoor air, it is important to measure the outdoor environment. This ensures that what is being detected indoors is not merely an artifact of polluted outdoor air (e.g., outdoor smoke penetrating indoors). Measuring the outdoor air also enables an understanding of the extent to which neighboring residential communities may be incurring harmful air pollution exposures drifting over from nearby sources. What is more, pairing such measurements with continuous measurements of wind speed and wind direction can aid in the identification of such sources (e.g., industrial emitters).

In the present case, outdoor air monitoring was carried out by community volunteers during both the morning (~10AM-12PM) and afternoon (1-3PM) on the same three days during which workers on the interior of the Kingspan buildings measured indoor air. Specifically, outdoor air was measured along five prescribed walking routes that encircled the two Kingspan buildings. These routes were named routes A, B, C, D, and E and are shown in Figure 5. Routes A and B were the routes that most closely encircled the two Kingspan buildings, while routes C and E encircled larger areas around the industrial area. Route D was a route that encircled the neighboring residential community.

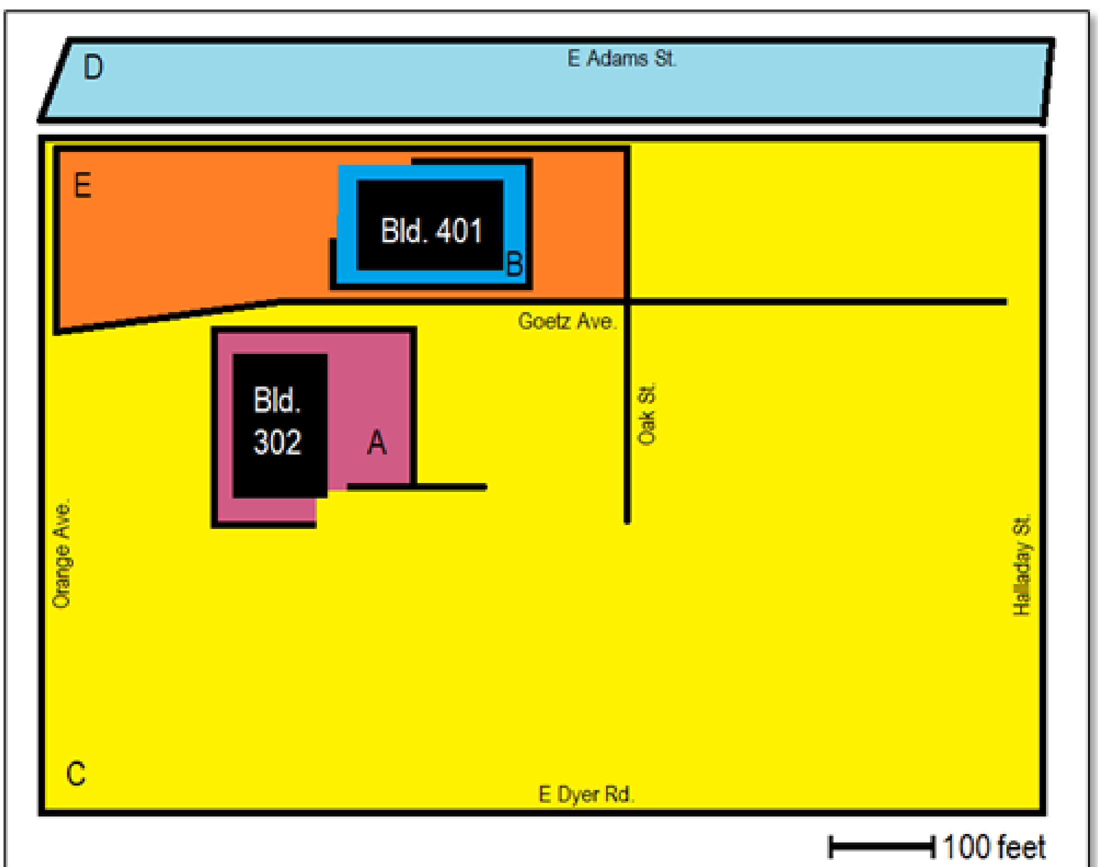


Figure 5. Walking routes (black lines) of outdoor air monitoring. Each color signifies the general area that each route encompassed.

3. RESULTS

3.1 INDOOR AIR MONITORING

A total of 20,794 minutes (~347 hours) of indoor air monitoring data were collected across eight mobile and eight stationary air monitoring devices over the three separate workdays inside the Kingspan 302 Building and 401 Building. On average, the PM2.5 concentration measured in the indoor environment of the Kingspan 302 Building and 401 Building was 102.2 µg/m3 and 120.3 µg/m3, respectively, with a combined indoor average of 112.3 µg/m3. This corresponds to an approximately 6- to 7-times greater PM2.5 concentration measured inside of the buildings relative to outside of the buildings. Of note, maximum PM2.5 concentrations measured inside of both Kingspan buildings reached 1,000 µg/m3, which is a value that corresponds to the upper detection limit of the AtmoTube® Pro air monitoring device. This upper detection limit was reached 212 times (on a one-minute basis) throughout the three-day measurement period. Detailed summary statistics of indoor and outdoor PM2.5 measurements categorized by monitoring type and building are presented in Tables 2 and 3.

Table 2. Summary statistics of $PM_{2.5}$ by type.

Type	Minutes of Data	Mean	St. Dev.	Min	Max
Indoors (personal)	10,154	91.4	118.2	1.0	1000.0
Indoors (stationary)	10,595	132.3	188.4	1.0	1000.0
Outdoors	867	17.3	5.3	1.0	39.0

Table 3. Summary statistics of $PM_{2.5}$ by building.

Building #	Minutes of Data	Mean	St. Dev.	Min	Max
302	9,187	102.2	112.8	1.0	1000.0
401	11,562	120.3	187.9	1.0	1000.0

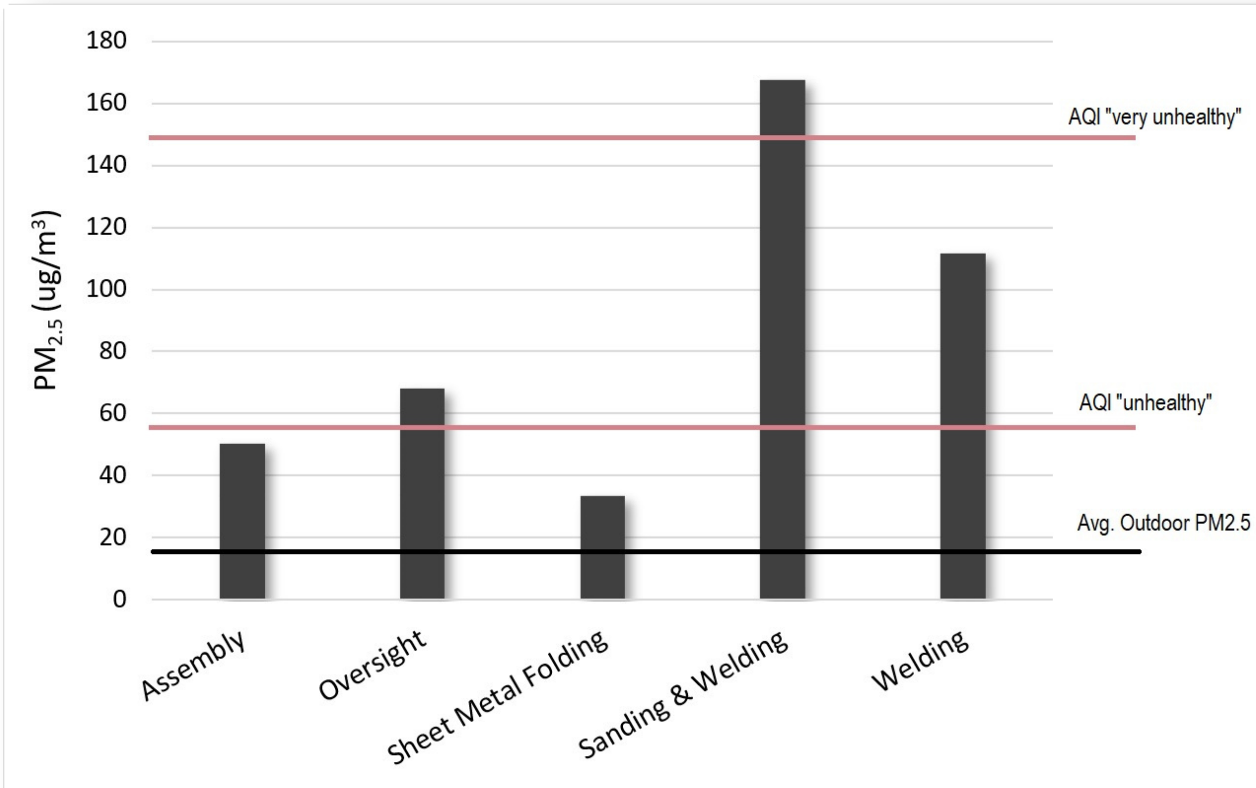


Figure 6. Indoor PM2.5 concentrations averaged by occupational category relative to outdoor average and relative to EPA's outdoor air quality index (AQI).

When examining indoor personal PM2.5 concentrations across five general occupational groups, the highest average PM2.5 concentration (167.6 µg/m3) was measured by those whose work involved "sanding and welding," followed closely by those whose work involved only welding (111.7 µg/m3). These averages were approximately 2- to 5-times higher than the other three occupational categories examined (33.5-68.1 µg/m3), which included work relating to sheet metal folding, assembly, etc. Average PM2.5 concentrations calculated for each occupational group were based on a minimum of 1,400 minutes of measurement data. PM2.5 concentrations measured across these five occupational groups were approximately 2- to 10-times higher than the average PM2.5 concentration measured outside of the two Kingspan buildings. A histogram depicting the indoor PM2.5 concentration averaged across each occupational category relative to the average outdoor concentration and relative to the U.S. EPA's air quality index (AQI) is presented in Figure 6.

Figure 7 depicts average indoor PM2.5 concentrations as measured by eight employees who wore personal air monitors over the three workdays inside the Kingspan buildings. The highest three-day average PM2.5 concentration was 210.9 µg/m3. Of the eight personal air monitors, five showed average PM2.5 concentrations above 100 µg/m3 and three showed maximum concentrations in excess of 500 µg/m3. Although not shown in the figure, an average PM2.5 concentrations as high as 406.1 µg/m3 was reported for one of the stationary monitoring devices. This data is presented in tabulated form in the appendix (Table A1).

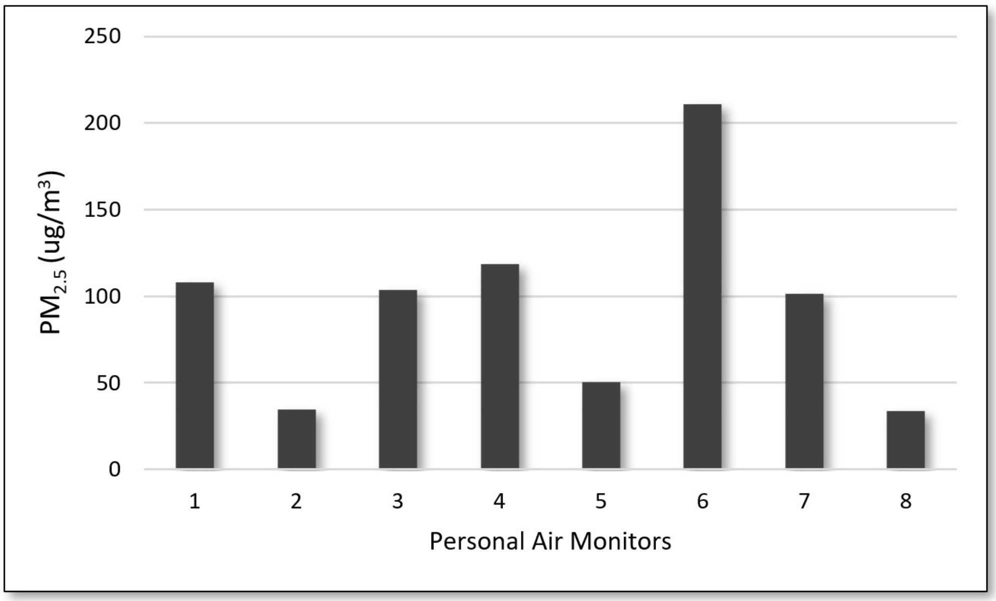
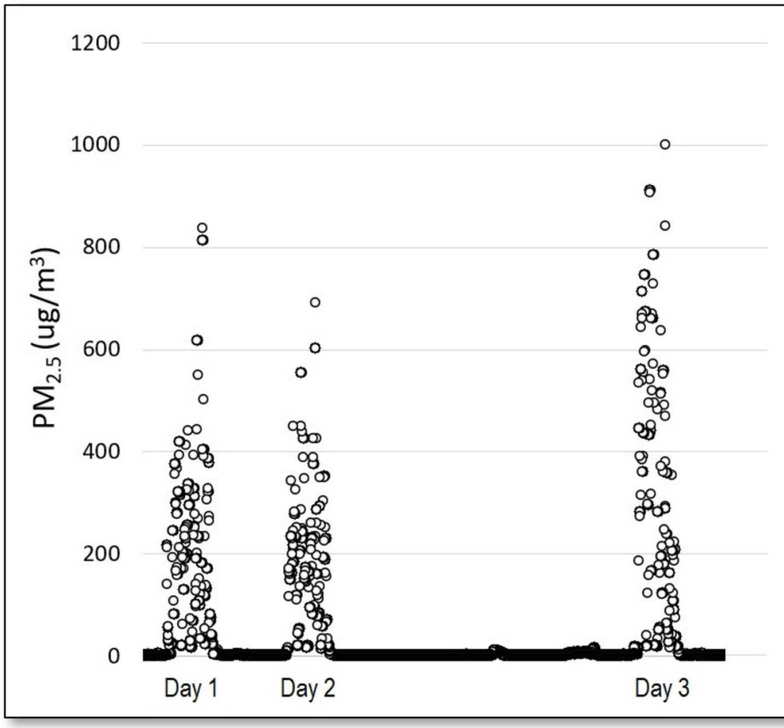


Figure 7. Indoor PM2.5 concentrations averaged across each employee who participated in personal air monitoring.

Figure 8 presents an example of the three-day sampling period as measured by a personal air monitor carried by one of the welders inside of the Kingspan facility. The graph clearly depicts the dramatic air pollution spikes which tended to peak in the middle of each workday. Also visible in the graph is the high frequency of PM2.5 measurements above 100 µg/m3. Over the course of the workday, some employees experienced uninterrupted spikes in PM2.5 concentrations that were sustained for two hours or more.

FIGURE 8. EXAMPLE OF THE THREE-DAY SAMPLING PERIOD AS MEASURED BY A PERSONAL AIR MONITOR CARRIED BY ONE OF THE WELDERS INSIDE OF THE KINGSPAN FACILITY.



3.2 OUTDOOR AIR MONITORING

There were 867 minutes (~14 hours) of outdoor air monitoring data that was collected within an approximately one-block radius around Kingspan, an area which encompassed both Kingspan buildings as well as other industrial facilities and residential homes. On average, the PM2.5 concentration measured outside of the Kingspan buildings on the same days that indoor monitoring took place was 17.3 μg/m3, with a maximum concentration of 39.0 μg/m3. When examining outdoor PM2.5 concentrations by route, the highest average PM2.5 levels were measured along the A (22.2 μg/m3) and B (23.6 μg/m3) routes, which are the two routes that most closely encircled the two Kingspan buildings. These averages, however, were based on limited available data (35 mins combined). The third-highest average PM2.5 concentration (20.1 μg/m3), based on much more data (153 minutes), was measured along the D route. This was the route that encircled the neighboring residential community.

4. DISCUSSION

4.1 INDOOR AIR MONITORING

In this analysis, indoor and outdoor PM2.5 concentrations were examined over three workdays inside and outside of the Kingspan facility located in Santa Ana, CA, in order to characterize the air pollution to which concerned Kingspan employees were exposed while on the job. Compared to the outdoor environment, indoor PM2.5 concentrations were 6- to 7-times higher on average, with an overall average indoor concentration of 112.3 μg/m3. Of eight employee participants who measured the indoor air, five recorded average PM2.5 measurements above 100 μg/m3, with three recording maximum concentrations above 500 μg/m3. For one employee, the concentration exceeded 200 μg/m3 when averaged over approximately 26 working hours (~3 work shifts). Welding-related activities within the buildings tended to result in the highest average PM2.5 concentrations, compared to other activities (e.g., sheet metal folding).

Converting the average PM2.5 concentrations measured inside the Kingspan buildings into the EPA's air quality index, albeit traditionally used to rank outdoor air quality, results in an air quality ranking that ranges between "unhealthy" to "very unhealthy."[20] For added context, the average PM2.5 concentrations measured inside the Kingspan buildings was approximately 25% higher than the maximum outdoor PM2.5 concentrations measured near Santa Ana approximately one year prior when major wildfires in northern California brought visible smoke to the southern part of the state for multiple days. In general, during wildfire episodes, smoke often results in a 2- to 4-fold increase in PM2.5 concentrations. In some studies, wildfire events in southern California resulted in PM2.5 concentrations that were 10-times (>230 μg/m3) above background levels.[21,22] While high, this level is only slightly higher than that measured by one of the personal air monitoring devices carried by a welder working inside the Kingspan facility, and is approximately half of the concentration detected by one of the stationary monitors placed inside the building. This comparison is all the more noteworthy when considering that the wildfire statistics relate to maximum levels, whereas the aforementioned indoor measurements at Kingspan refer to multi-hour averages. For additional reference, the annual outdoor PM2.5 concentration for the county (Orange Country, CA) as reported by SCAQMD ranged from 8.8 to 11.3 μg/m3 in 2020.[23]

The results presented in this analysis are similar to peer-reviewed studies in the literature that have shown welding-related activities to generate PM2.5 concentrations that are well above the levels typically measured outdoors. In several studies, PM2.5 concentrations of 1,000 μg/m3 (as measured in this study) and even higher have been reported.[24–26] Welding operations typically lead to elevated PM2.5 concentrations as hot vaporized metal from the welding activity cools and condenses, forming small solid metal particles.[27] These vaporized metal particles become oxidized upon contact with oxygen in air, rendering metal oxides as the primary components of welding fumes.[27]

While welding is known to subject workers to elevated PM2.5 exposure, evidence suggests that such exposure is not without adverse health effects. For instance, a Harvard School of Public Health study by Wong et al. (2014) examined a cohort of boilermaker workers over eight years and found evidence of genetic trauma, as measured by leukocyte telomere length, among workers with recent occupational exposure to elevated welding fumes.[28] Similarly, a nine-year study of welding workers by Haluza et al. (2014) documented a statistically significant decrease in pulmonary function associated with duration of occupational exposure to welding fumes.[29] In general, numerous epidemiology studies have shown welders to experience some form of respiratory illness, including bronchitis, airway irritation, altered lung function, and a possible increase in lung cancer risk.[27]

While occupational groups are often regarded as healthy populations, and therefore less prone to suffer from adverse exposures, such studies showcasing fume-related health effects among welding workers serve as importance evidence of the potential adverse impacts that such individuals may nonetheless incur, in turn underscoring the importance of mitigatory steps to minimize welding fumes in the workplace. Importantly, while health effects from welding fume exposure are known to depend, in part, on the chemical content of the PM2.5, a speciation analysis identifying the metal content of individual metals in the Kingspan facility was beyond the scope of the present analysis.

4.2 OUTDOOR AIR MONITORING

While the average outdoor PM2.5 concentration measured through this assessment was substantially lower than the average concentrations measured inside the Kingspan buildings, the outdoor average was nonetheless higher than the annual average (range: 8.8 to 11.3 μg/m3) reported for Orange Country by SCAQMD in 2020.[23] Additionally, this concentration is higher than the EPA annual PM2.5 standard of 12.0 μg/m3. However, given that the air monitoring reported in this analysis was restricted to three sampling days, as opposed to the three years required to demonstrate federal standard exceedance, the average outdoor PM2.5 concentration reported in this document (17.3 μg/m3) cannot alone confirm compliance or lack of compliance with the annual standard. Neither does this report confirm compliance or lack of compliance with the EPA's 24-hour PM2.5 standard (35 μg/m3) since this too requires three years of measurement data to confirm. Instead, the outdoor levels reported in this study serve as evidence of a potential public health concern that warrants continued 24-hour outdoor air motoring.

An analysis of outdoor average PM2.5 concentrations categorized by route showed the highest levels measured along the A and B routes, which are the two routes that most closely encircled the two Kingspan buildings. These averages, however, were based on limited data and do not take into account wind direction or precise monitoring locations. Thus, the present analysis cannot discern as to whether the Kingspan facility is the likely reason for elevated outdoor air pollution along these routes. Having said that, combining these findings with the fact that the third-highest average PM2.5 concentration was measured along the residential D route underscores the importance of analyzing the GPS and meteorological data (e.g., wind direction) collected during this sampling campaign in order to better characterize air pollution hotspots and potential emissions sources.

5. CONCLUSIONS & RECOMMENDATIONS

Results from this analysis suggest the need for ongoing air pollution monitoring both inside and outside of the Kingspan facility. An effective and convenient way to accomplish this is to permanently install two low-cost PM2.5 measurement devices (e.g. PurpleAir sensors[30]) inside both Kingspan buildings, along with a separate device installed in the backyard of a local resident who lives in the neighboring community. Given the activities conducted within the facility, air monitoring should not be restricted to PM2.5, but should also include VOC measurements. Air, location, and meteorological data that was collected during the course of the three-day monitoring period, yet which was not presented in this report, should also be analyzed and presented. This includes an analysis of indoor air temperature, PM2.5 concentrations paired with high-resolution GPS data, as well as outdoor air pollution concentrations in relation to wind speed and wind direction. Dust samples collected during this period should similarly be analyzed so as to quantify the metal content of the particles that are contaminating the indoor environment. The above steps will contribute to a better characterization of the long-term air pollution concentrations to which workers and community members are exposed and will aid in ultimately determining whether outdoor air pollution concentrations are in violation of national standards.

Additionally, this analysis underscores the importance of implementing basic measures of indoor air pollution control within the Kingspan buildings, including the installation of appropriate ventilation systems to direct air contaminants away from the breathing zones of employees. Such ventilation systems should be equipped with high efficiency particulate air (HEPA) filtration in order to filter fine particles from the indoor environment and to prevent their being exhausted outdoors to the neighboring community. What is more, it is recommended that workers engaging in welding activities be outfitted with adequate personal protective equipment, including face masks equipped with supplied-air respirators.

As a basic immediate step to reducing indoor air pollution exposure (until the prior recommendations are adopted), and where it constitutes no violation of safety protocol, it is recommended that company management ensure that doors and windows remain open (and allow workers to do the same) during the workday so as to allow for the infiltration of cleaner outdoor air and a healthier indoor working environment for employees.

APPENDIX

Table A1. Summary statistics for PM2.5 (μg/m3) concentrations across all sampling devices averaged over three workdays.

Type	N	Mean	St. Dev.	Min	Max
Indoors (personal)	912	107.8	74.3	1	274
Indoors (personal)	1,533	34.8	19.6	8	147
Indoors (personal)	1,036	103.5	165.5	3	1,000
Indoors (personal)	511	118.6	110.3	1	728
Indoors (personal)	1,548	50.3	34.6	9	209
Indoors (personal)	1,533	210.9	193.7	3	1,000
Indoors (personal)	1,533	101.4	64.1	1	304
Indoors (personal)	1,548	33.5	18.5	1	112
Indoors (stationary)	1,353	106.2	60.5	1	275
Indoors (stationary)	1,533	30.5	25.7	1	88
Indoors (stationary)	1,037	92.1	119.6	1	1,000
Indoors (stationary)	511	184.2	140.8	1	988
Indoors (stationary)	1,548	127.5	116.0	1	786
Indoors (stationary)	1,532	406.1	315.1	14	1,000
Indoors (stationary)	1,548	99.2	113.6	1	1,000
Indoors (stationary)	1,533	31.6	13.8	2	75

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