

MEASUREMENTS OF VOLATILE ORGANIC COMPOUNDS AND PARTICLES DURING APPLICATION OF LATEX PAINT WITH AN AIRLESS SPRAYER

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ABSTRACT

Paint may be applied indoors by a variety of methods including brushing, rolling, and spraying. Application of paint by spraying may result in exposure to both volatile organic compounds (VOCs) and aerosols. Experiments were conducted at EPA's Indoor Air Quality Research House to measure airborne concentrations of VOCs and particles during, and following, application of latex wall paint by spraying. Latex paint was applied to all four walls of a closed bedroom (30 m³ volume) by a professional painter using a commercial electric airless sprayer. VOCs were collected on Tenax® and XAD®-7 sorbents and analyzed by gas chromatography. Total suspended particles (TSPs), particles with diameters less than 10 µm (PM₁₀), and particles with diameters less than 2.5 µm (PM_{2.5}) were collected on filters and measured gravimetrically. Particle concentrations and size distributions were measured with an Aerosizer Particle Monitor.

The VOC concentrations in the room were consistent with results from previous tests involving application of a similar paint with a roller. Ethylene glycol concentrations peaked at 5,500 µg/m³ approximately 4 hours after application. Eight hours after application, concentrations of 2,2,4-trimethyl-1,3-pentanediol monoisobutyrate peaked at 13,500 µg/m³. During a 20-minute period of spray application, the average TSPs concentration was 49.7 mg/m³. The PM₁₀ and PM_{2.5} concentrations were 21.9 and 4.62 mg/m³, respectively. During a second test with a 15-minute application period, the TSPs concentration was 38.7 mg/m³, PM₁₀ was 19.9 mg/m³, and PM_{2.5} was 0.8 mg/m³. The particles were predominately in the 4 to 6 µm diameter size fraction during the spray application period. Particle concentrations dropped quickly after the application ended. The measurements showed that painters may be exposed to substantially elevated particle concentrations, at least for part of the work day, particularly if spraying is done in closed rooms.

INTRODUCTION

Interior wall paint may represent a significant source of human exposure to volatile organic compounds (VOCs) because of the large volume of paint applied inside occupied buildings and the frequency of re-application during the life of a building. In recent years, the trend has been to use latex paints for interior walls. Based on survey data, the U.S. Environmental Protection Agency¹ estimated the number of users of latex paint indoors was over 67 million people between ages 18

and 65. EPA estimated that over 44 million of the indoor users had used latex paint in the 12 months prior to the survey. The median duration of use was 3 hours with a median use of 128 oz (3.6 L). It was also of interest that the estimated time in the room after the last use of paint was a median of 5 minutes, but ranged from less than 5 to 240 minutes.

Wall paint is applied in offices and residences by do-it-yourself consumers and professional painters. Wall paint may be applied by brush, roller, or sprayer. In its RM-1 risk assessment for wall paint ¹, the EPA did not determine the percentage of paint applied by spraying.

The VOCs in paints and their emissions have been identified in a number of studies ^{1,2,3,4,5}. Predominant VOCs include ethylene glycol, propylene glycol, dipropylene glycol, butoxyethanol, 2(2-butoxyethoxy)ethanol, and 2,2,4-trimethyl-1,3-pentanediol monoisobutyrate. Formaldehyde, acetaldehyde, and benzaldehyde have also been identified in latex paint ³. The emissions of these compounds from painted gypsum wallboard have been characterized in small chamber tests ^{3,6} and the EPA research house ⁷. Data from these studies can be used to estimate human exposure to VOCs due to inhalation of the compounds in the gas phase.

During application of paint by spraying, painters and building occupants may be exposed to constituents in paint by inhalation of VOCs in the gas phase and inhalation of paint droplets due to overspray from the spray applicator. However, data are lacking on exposure due to inhalation of paint droplets. A study of limited scope was performed to collect initial data on concentrations of VOCs and particles in a bedroom during spray application of latex paint. The objective was to gain a better understanding of the impact of paint spray applications on indoor air quality in a residence. The results of two tests are reported in this paper.

EXPERIMENTAL METHODS

Experiments to measure gas-phase and particle concentrations during spray application of latex paint were performed at the U.S. Environmental Protection Agency (EPA) Indoor Environment Management Branch (IEMB) Indoor Air Quality Research House in Cary, NC. Two tests were performed at the house. The tests involved application of wall paint by a professional painter in a closed bedroom. Air samples were collected during the paint application and for approximately 30 hours following application. The experimental methods are described below.

Research House and Test Room

The IEMB Research House is an unoccupied single-family residential dwelling of standard wood frame construction. It is a single-story ranch-style house with a floor area of approximately 121 m² (1300 ft²) with a volume of 300 m³. The house layout consists of a kitchen, dining room, living room, and den at one end of the house. Three bedrooms and two bathrooms are located at the other end of the house. The house is fully instrumented for measurements of environmental parameters, air exchange rates, gaseous pollutants, and particulate matter. The attached garage serves as the laboratory for the research facility.

The spray paint tests were performed in the front corner bedroom, a room with a volume of approximately 30 m³. For tests with paint, the approach has been to apply new gypsum wallboard

onto furring strips placed on the existing walls. With this approach, the same types (and lot) of substrate can be used in different tests, and the source of VOC emissions can be removed from the house after the test is completed. The edges of the sheets of gypsum wallboard were placed close together, but were not taped. All walls in the room were covered with new gypsum board, including the closet, to obtain a total application area of 29.5 m². Samples were collected at approximately breathing height (1.55 m above the floor) near the center of the room, near the front window, and near the painter. To prevent interference with the painter's movements, the painter did not wear a personal sampler. As an alternative, a technician collected samples at locations near the painter during the application period.

The spray application was performed under "worst case" conditions, with the bedroom door closed during application. The heating and air-conditioning system was not operated during the tests. No windows were open.

Measurement Parameters and Methods

Measurements were performed during application of the paint and for approximately 30 hours after application to measure VOCs emitted from the paint and aerosols generated by the spray application. The measurement parameters included:

- Total Suspended Particles (TSPs) - Collected on a 37-mm filter in a standard industrial hygiene plastic sampling cassette at a nominal flow rate of 5 L/min.
- PM_{2.5} - Collected on tared Teflon® filters (2-µm pore size) with size-selective impactors operated at 20 L/min.
- PM₁₀ - Collected on tared Teflon® filters (2-µm pore size) with size-selective impactors operated at 20 L/min.
- Particle concentrations and size distribution - Measured with a real-time laser particle measuring system, described below.
- VOCs - VOCs in the gas phase were collected on tubes containing Tenax® TA sorbent using a low-volume sampling pump. Samples during the application period were collected using a glass wool prefilter to prevent paint droplets from depositing in the Tenax® tube.
- VOCs - Air samples for analysis of VOCs were also collected on XAD®-7 sampling cartridges (SKC 226-57) during the initial 1.5 hours of the experiment. The samplers consisted of a glass fiber filter and sorbent bed. The cartridges collected the total mass of VOC that might be inhaled, including the gas-phase VOCs on the XAD® and the VOCs in the droplets on the filter.
- Paint Mass Sprayed- The amount of paint applied was determined gravimetrically by weighing the paint and can before and after application.
- Mass of Paint on the Wall - The mass of dry paint applied to the walls was estimated by weighing 12 coupon foils that were attached to the 4 walls.

Particle mass collected on filters was determined gravimetrically. Filters were weighed in the controlled-environment weighing facility following standard practice.

Real-time measurements of particle concentrations were performed with an Aerosizer Particle Measuring System (Amherst Process Instruments, Hadley, MA). The Aerosizer is a “time-of-flight” measurement device capable of measuring individual particles with an aerodynamic diameter in the size range of 0.5 to 700 μm .

VOCs were sampled on both Tenax® and XAD®-7 cartridges. The Tenax® method is based on EPA Compendium Method TO-17 for sampling on sorbent tubes⁸. The XAD®-7 sampling and analyses were performed based on procedures described in the NIOSH Method 5523 for Glycols⁹. During these tests, the filter and backup sorbent section were combined and extracted together to obtain the total mass of glycols on the sampler. Analyses were performed by gas chromatography/flame ionization detection (GC/FID). Tenax® sorbent tube samples were analyzed by thermal desorption/GC/FID using a Hewlett Packard HP 5890 GC system interfaced with an Entech 5100 thermal tube desorber/concentrator system. Chromatography was performed with a 30-m capillary column with a polyethylene glycol stationary phase.

Description of the Paint and Application Method

The paint used in the experiments was a commercially available interior latex flat wall paint purchased from a local retail outlet. Prior to use in the study, the bulk paint was analyzed by gas chromatography/mass spectrometry following EPA Method 311 to identify and quantify the major constituents in the paint¹⁰. The predominant constituents included: ethylene glycol (41.3 mg/g), propylene glycol (0.34 mg/g), dipropylene glycol (0.58 mg/g), 2-(2-butoxyethoxy)ethanol (4.30 mg/g), and 2,2,4-trimethyl-1,3-pentanediol monoisobutyrate (11.2 mg/g). The results showed that it was a conventional paint, not a “low-VOC” paint. The total solids in the paint were determined gravimetrically to be 55% by weight.

The paint was applied with a commercially available electric airless sprayer that is commonly used by professional painters. A professional painter set up the sprayer and performed the application during the tests. The painter and technicians wore respirators while in the room. The paint application rate was based on the painter’s judgement that the paint coverage was adequate on the wallboard surface. A single coat of paint was applied in each test. Therefore, the amount of paint applied in each test was not controlled and varied between the tests. During the first test, 4.95 kg of paint was sprayed on the new gypsum wallboard. The estimated dry weight sprayed was 2.72 kg. The total estimated mass of dry paint on the 29.5 m² of wall surface was 2.66 \pm 0.53 kg based on measurements of the dry paint mass on 12 foil coupons randomly placed on the 4 walls. During the second test, the latex paint was applied to the same wallboard that had been painted in the first test. The application rate was somewhat lower, with a total of 3.74 kg of paint sprayed. The estimated dry paint mass on the walls, determined by weighing the foil coupons, was 2.07 \pm 0.74 kg. The high variability of the mass determined on the coupons suggests a non-uniform coating on the wall, although visually the paint coverage appeared to be adequate in all areas. The estimated dry weight of paint on the walls was not substantially different from the estimated mass of paint sprayed, suggesting that there was little overspray. However, observation during paint application indicated visual overspray in the air during application and paint on the drop cloth on the floor following application.

RESULTS AND DISCUSSION

Tests were performed to measure concentrations of VOCs and particles under worst-case conditions in a closed room during the paint spray application period and during the day following application to gain a better understanding of the impact of paint spraying on indoor air quality.

VOC Measurement Results

VOC concentrations measured during the second experiment, in which latex paint was applied by spray application, are summarized in Figures 1 and 2. The concentrations of the predominant VOCs in the paint were consistent with previous results of latex paint tests conducted at the Research House⁷. The ethylene glycol concentrations peaked at 5,540 $\mu\text{g}/\text{m}^3$ approximately 4 hours after the application, and 2,2,4-trimethyl-1,3-pentanediol monoisobutyrate peaked at approximately 13,500 $\mu\text{g}/\text{m}^3$ at 8 hours after the application. In a previous test at the Research House, a similar paint was applied with a roller to the walls in the same bedroom. During that test, ethylene glycol peaked at 2,520 $\mu\text{g}/\text{m}^3$ 5 hours after application, and the 2,2,4-trimethyl-1,3-pentanediol monoisobutyrate peaked at 7,610 $\mu\text{g}/\text{m}^3$ 7 hours after application, but the door of the front corner bedroom was open and the air handler fan was operated continuously in the test, which resulted in lower VOC concentrations in the bedroom and dilution of the VOCs in the 300 m^3 volume of the house.

The VOC measurement results depicted in Figures 1 and 2 are concentrations measured with Tenax® sorbent tubes that had been fitted with a glass wool prefilter on the inlet to prevent droplets of paint from being collected on the Tenax®. This approach was taken to avoid significant contamination of the thermal desorber and concentrator system. The results most likely represent the concentrations of VOCs to which a painter would be exposed if the painter were wearing a dust mask that prevented inhalation of particles. After the spray application was completed, a limited number of samples were collected simultaneously with Tenax® sorbent tubes with and without the glass wool prefilter. The concentrations measured with Tenax® tubes fitted with the glass wool prefilter were 20 to 35% lower than samples collected without the prefilter. Samples were also collected with tubes containing XAD®-7 sorbent media. With this method, both paint droplets and gas-phase VOCs were collected on the media and recovered in the methanol extract. Three samples were collected that had concurrent XAD® and Tenax® samples. During the period of paint application, the concentrations of VOCs measured at the center of the room with the XAD® ranged from 2 to 7 times higher than the measurement results for samples collected with Tenax® using the prefilter. These results were consistent with the expectation that paint droplets would be collected on the XAD® and that the VOCs would be recovered from the droplets in the methanol extract. As discussed below, the concentrations of VOCs in the paint aerosol during the application period could be substantially higher than the VOC concentrations in the gas phase.

Figure 1. Concentrations of ethylene glycol and propylene glycol during a spray paint test

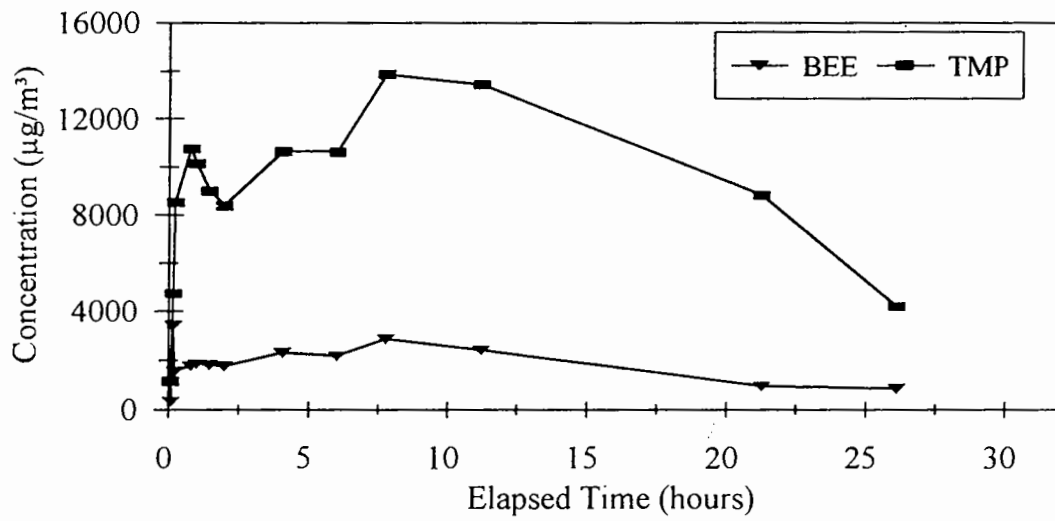
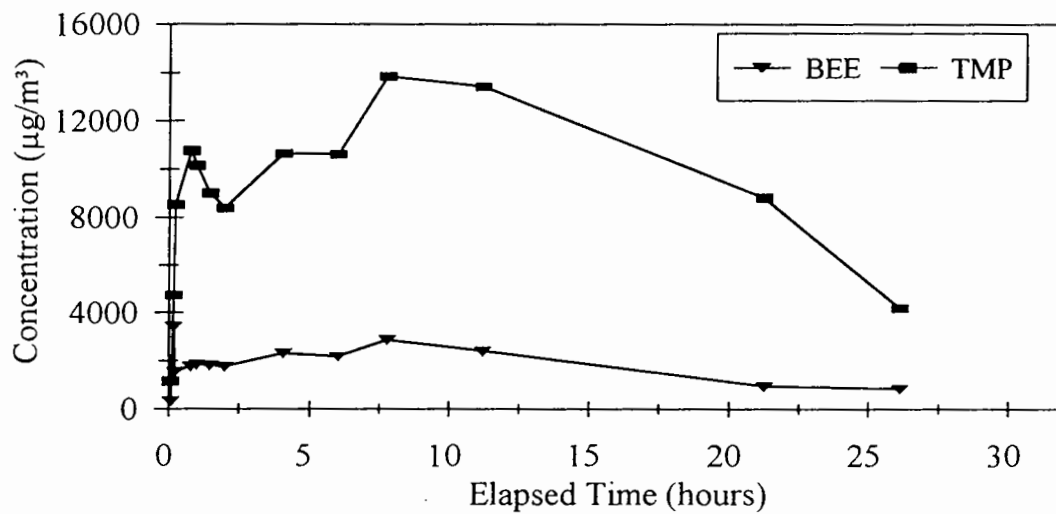


Figure 2. Concentrations of 2-(2-butoxyethoxy)ethanol (BEE) and 2,2,4-trimethyl-1,3-pentanediol monoisobutyrate (TMP) during a spray paint test



Gravimetric Particle Measurements

Two tests were performed to measure particle concentrations in the room due to application of latex paint by spraying. Integrated air samples were collected throughout each test to measure TSPs, PM₁₀, and PM_{2.5}. Results for the first test are presented in Table 1. The TSPs concentration during the 20-minute application period was 40.9 mg/m³ at the center of the room and 39.6 mg/m³ near the front wall of the room, suggesting good mixing in the small room. The TSPs concentration in the air sample collected near the painter's breathing zone was somewhat higher at 49.7 mg/m³. Concentrations of TSPs dropped quickly after the spray application ended. The average concentration of TSPs for the period from 2 to 8 hours after the start of the test was only 0.06 mg/m³. The concentrations of PM₁₀ and PM_{2.5} were 21.9 and 4.62 mg/m³, respectively, during the application period. Like TSPs, the concentrations decreased rapidly after the application ended.

Table 1. Concentrations of TSPs, PM₁₀, and PM_{2.5} in the closed bedroom during the first spray paint test.

Sampling Location	Time Period	TSPs (mg/m ³)	PM ₁₀ (mg/m ³)	PM _{2.5} (mg/m ³)
Room Center	Pre-test	0.03	0.04	0.02
Room Center	0-20 min	40.9	21.9	4.62
Near Window	0-20 min	39.6	-- ^a	-- ^a
Near Painter	0-20 min	49.7	-- ^a	-- ^a
Room Center	0.75-1.75 hr	2.89	2.99	0.06
Near Window	0.75-1.75 hr	3.00	-- ^a	-- ^a
Room Center	2-8 hr	0.06	0.05	0.04
Room Center	8-24 hr	-- ^b	0.02	0.01
Room Center	24-30 hr	BDL ^c	0.01	0.01
Near Window	24-30 hr	0.03	-- ^a	-- ^a

^a PM₁₀ and PM_{2.5} not collected at these locations

^b Sample lost during collection period

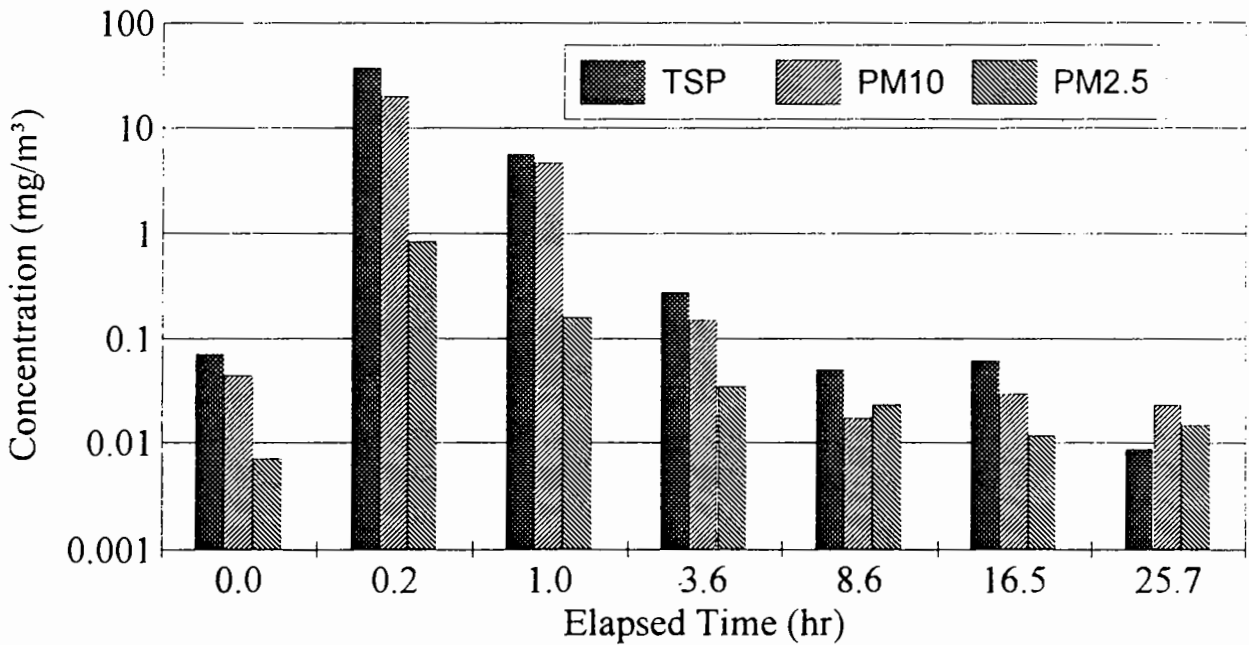
^c Mass on filter below detection limit of 0.003 mg/m³

The TSPs concentration of 49.7 mg/m³ measured near the painter during the spray application of the paint was substantially higher than the Occupational Safety and Health Administration (OSHA) Time Weighted Average (TWA) Permissible Exposure Limit (PEL) of 15 mg/m³ for nuisance dust (defined as total dust)¹¹. The PM₁₀ concentration was also higher than the American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Value (TLV) of 10 mg/m³ for inhalable nuisance particulates¹¹. The PM_{2.5} concentration was higher than the 3 mg/m³ TLV for respirable nuisance particulates¹¹. However, the reader is cautioned that the PELs and TLVs apply to the average concentration during an 8-hr workday exposure period, not the short 20-min application period used in this test. There are no Short-Term Exposure Limits

(STEL) or Ceiling concentrations defined for nuisance particulates by OSHA or the ACGIH. The PELs and TLVs are presented here only to provide reference values.

Results of measurements of particulate matter during the second test are depicted in Figure 3. The time “0.0” measurements were for air samples collected in the room immediately prior to the test. There had been some activity in the room due to sampler setup and room preparation. Concentrations of TSPs were less than 0.1 mg/m³ in the background samples. During the second test, the application period was 15 minutes. The TSPs concentration of 37.2 mg/m³ measured in the second test was similar to the 40.9 mg/m³ measured in the first test, but the concentration of 38.7 mg/m³ near the painter was lower than in the first test. The PM₁₀ concentration of 19.9 mg/m³ was also similar to the concentration of 21.9 mg/m³ measured in the first test. But, the PM_{2.5} concentration of 0.83 mg/m³ was substantially lower. The reason for the difference in PM_{2.5} mass levels between the two tests could not be determined. As shown in the figure, the particle concentrations quickly dropped after the spray application was completed. Particle concentrations were near background levels in the samples collected during the time period from 5.6 to 11.6 hours after the start of the test, labeled as elapsed time of 8.6 hours in Figure 3.

Figure 3. Concentrations of TSPs, PM₁₀, and PM_{2.5} measured during a spray paint test



When interpreting the particle mass data, note that, although the samples collected with the size-selective impactors are reported as PM₁₀ and PM_{2.5}, the impactors have not been tested to determine their collection efficiency for paint droplets. Their performance and cut-point may differ substantially from those when used to collect particles in ambient air.

Also note that the particle mass concentrations reported for these tests represent particle dry weight. The particulate matter on the filters was dried at 110 °C for 16 hours. Then the filters were conditioned in a controlled-environment weigh room for 24 hours prior to weighing. The latex paint was determined to be approximately 55% solids by weight. Therefore, the wet weight of particle mass on the filters at the time of collection may have been approximately 1.8 times higher than that reported.

Particle Concentrations and Size Distributions

During the second test, an Aerosizer Particle Monitor was used to measure the particle concentrations and size distributions during and following the spray application of the paint. In order to prevent the instrument from becoming overloaded with paint droplets, a limited number of measurements were performed during the spray application period. Measurements were performed after an initial test spray, after spraying one wall, after spraying a second wall, and after the paint application was completed. After the spray application was completed, particle concentrations were measured continuously for the next 30 hours.

Figure 4 depicts the total particle concentration during the first 7 hours of the test. The concentration was nearly 1,000,000 particles/m³ in the room prior to the start of paint spraying. The first peak in Figure 4 was the result of a short test application on one wall. The particle concentrations increased rapidly once the spray paint application started, to a peak of 195,000,000 particles/m³ near the end of the 15-min application period. Particle concentrations decreased rapidly after the application ended. Approximately 3.5 hours after the end of the application, the particle concentrations in the closed room had decreased to the background concentrations measured prior to the test.

The size distribution of the particles prior to, during, and following the spray application is depicted in Figure 5. Prior to the start of the application, the mean aerodynamic diameter of the particles was nearly 2 µm. Immediately after the first test spray, which consisted of less than 30 seconds of spraying, the particle size measured with the Aerosizer increased to approximately 5.5 µm. Following this initial measurement, air was sampled from outside the room to ensure that the instrument was not overloaded with paint droplets. The air outside the room had a mean particle diameter of less than 2 µm. Measurements were resumed with the Aerosizer approximately 8 minutes after the start of the application. These measurements are indicated by the increase to the peak mean aerodynamic diameter of 5.5 µm. Following the end of the application, the mean diameter decreased in a profile similar to the decrease in particle concentrations. Within 4 hours, the mean particle diameter was again nearly 2 µm.

CONCLUSIONS

The particle measurement results show that high concentrations of particles were present in the closed room during the application of latex paint with an airless sprayer. Painters may be exposed to elevated concentrations of particles during the application period if proper respiratory protection is not worn. The results of these tests represent potentially worst-case conditions, in a closed room. Although the intent of the tests was not to measure a painter's workday exposure, the data show that a worker could potentially be exposed to concentrations of particles that exceed the

Figure 4. Total airborne particle concentrations during the second spray paint test

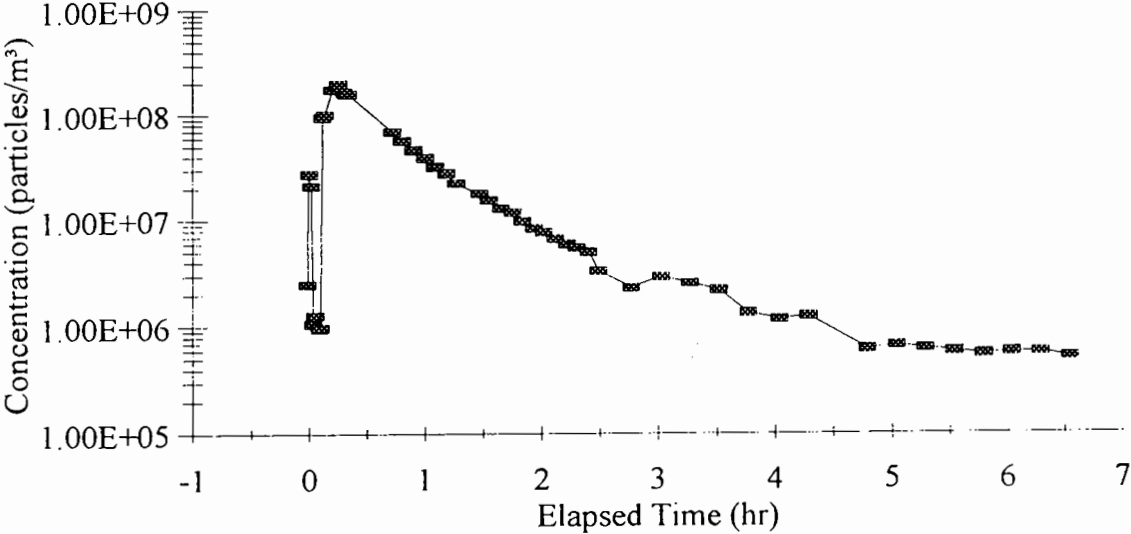
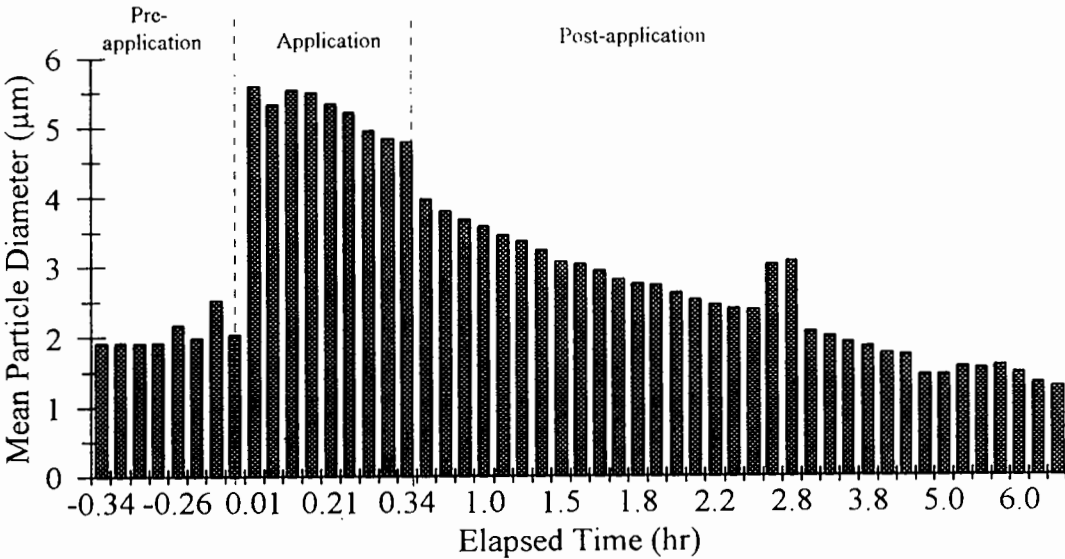


Figure 5. Geometric mean diameter of particles in the second spray paint test



current TLV-TWA, depending on the amount of time spent spraying, the ventilation conditions, and the extent of use of respiratory protection. Inhalation of paint droplets may result in increased exposure to higher molecular weight, less volatile, water-soluble compounds in the paint. Although professional painters may wear appropriate respiratory protection, inexperienced painters, for example homeowners that rent airless sprayers, may not be aware of the potential exposure to high levels of aerosols during spray application. The tests, however, show that particle concentrations decreased rapidly after spraying ended. If building occupants remain out of the sprayed area for a few hours, it is likely that they will not experience any incremental exposure to particles due to spray application.

During these tests, the painter wore a respirator that had cartridges for protection from both particle and VOC contaminants. This is not likely to be the type of respiratory protection worn routinely by painters. Painters may wear cloth or paper dust masks to prevent inhalation of particles, but the masks are not likely to provide much protection from ethylene glycol and other volatile constituents emitted from paint. The EPA has reported that hazard risk quotients indicate concern for chronic risks from 2-(2-butoxyethoxy)ethanol for professional painters¹. Results from these tests showed elevated concentrations of the volatile constituents during, and following, paint application. The results, which were consistent with previous tests at the Research House⁷, show that the concentrations remain elevated for an extended period following paint application, which will result in extended periods of exposure for building occupants.

The measurements during these tests showed that exposure to the VOCs in the paint could occur both due to inhalation of the compounds in the gas phase and inhalation of paint droplets. Substantial VOCs in the airborne paint droplets could contribute to a painter's exposure. For example, during the application period in the second test, the room-air TSPs concentration was 37.2 mg/m³ dry weight or approximately 67 mg/m³ wet weight of paint aerosol. The concentration of ethylene glycol in the liquid paint was 41.3 mg/g of paint. Therefore, the concentration of ethylene glycol in the aerosol during this measurement period would have been approximately 2.8 mg/m³, which was nearly twice the concentration of 1.5 mg/m³ measured in the air samples collected on Tenax®. The results show the need for appropriate respiratory protection for both particulate and gas-phase contaminants during spray application of paint.

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