

Reducing Workers' Exposures to Chemicals and Dust in Nail Salons
Using Local Exhaust Ventilation Systems

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Abstract

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Nail salon technicians are potentially exposed to a wide variety of hazardous chemicals including acrylates and solvents in the form of dusts or vapors. Nail salon exposures have been evaluated by a small number of studies and the potential adverse health outcomes have been identified. According to the conducted studies, the possible health outcomes may include respiratory, neurological, and musculoskeletal disorders. The main routes of exposure are considered as inhalation and skin contact while the proximity of the technicians' breathing zone to the chemicals and dust during nail treatments is a reason for concern. Local exhaust ventilation systems can minimize inhalation exposures in nail salons, though few studies have investigated the efficiency of these systems in reducing the exposures.

The goals of this study were one; to evaluate four local exhaust ventilation (LEV) systems to determine their effectiveness at eliminating vapors and dust from the breathing zone

of nail salon technicians and their clients and two; to assess the overall efficiency of the systems in an isolated static exposure chamber.

Four commercially available LEV systems were evaluated for their capture efficiency. For this purpose, acetone vapor and acrylic nail dust were generated at finger level using realistic work activities in a lab setting and exposures measured in the technician's breathing zone using real-time air monitoring. The dust was generated by grinding acrylic nails using a standard salon tool and typical position and duration for the work. The technician's breathing zone dust exposures were measured in real-time using a Thermo PDR-1500. To assess the solvent capture efficiency, a bowl containing acetone was placed on the table for 10 minutes to simulate the exposure during the acrylic nail removal process. Also, the nails were wiped with an acetone-saturated cotton ball. A MiniRAE 2000 photoionization detector was used to measure the acetone exposure during this process. Each scenario was measured with and without the LEV systems to compare the exposures. To assess the overall efficiency of the systems, acetone decay was measured over time using each system and the "no control" scenario. The Clean Air Delivery Rate (CADR) was calculated for each system.

Without controls, the average acetone exposure was between 50 and 330 ppm. The different LEV systems were able to decrease the average exposure by at least 77% and these reductions were statistically significant (p -value <0.001). Without controls, the average dust exposures ranged between 10 and 13 $\mu\text{g}/\text{m}^3$. The different LEV systems were also able to reduce the dust exposures by 67-90% (p -value <0.001).

The LEV systems can significantly minimize the workers' and most likely their clients' exposures to particles and organic vapors in nail salons. The ability of the systems to reduce technician's exposures during real use will depend on the systems' usability and filter capacity.

Dedication

This thesis is dedicated to my beloved parents, Nader Shakibaei and Parvin Karimi, my husband, Anis Rezvanian, and my sister, Niloofar Shakibaei. You have always believed in me, pushed me to succeed, and supported me in all my scholastic accomplishments. I truly acknowledge and thank you for your endless support.

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Introduction

According to industry estimates in 2010, there are approximately 200,000 nail salons with 375,000 employees in the United States (Marlow, Looney, & Reutman, 2012). Ninety six percent of these employees are females and 63% are minority workers. The majority of these workers are Vietnamese immigrants and refugees. According to the US Environmental Protection Agency (EPA), Vietnamese salons make up 35 to 40 percent of the nail salons in the U.S. Limited need for English language skills and education, ethnic business networks, and flexible work schedules brought many Vietnamese women to this profession. The compensation is comparable or even well above other service sector jobs with similar skill level and education. According to the Nail Manufacturers Association (NMA), 70% of the nail workers are self-employed. These professionals provide nail treatments including filing, polishing, applying artificial nails, manicures and pedicures.

According to industry statistics, manicure and pedicure were the most frequent services (93% and 91%) offered in nail salons in 2013; polish change and nail art were rated as 84% and 82%, respectively (Nails Magazine, 2013). Gel nails/polish cured with UV was rated as 71% and full set acrylic nail service as 55%.

Manicure is a treatment including clipping the hand nails, pushing the cuticles, shaping and filing the nails, and polishing. The treatment is called pedicure when applied to toenails.

Artificial fingernails including acrylic, gel, and silk are widely used to lengthen and strengthen the nail tips. Gels or acrylic fingernails are chosen when committing for a longer time and silks are mainly used for a shorter duration to strengthen nail tips, rather than making nails

longer (Fields, 2005-2014). Acrylic nails application has become very popular in nail salons over the past few years.

Acrylic nail treatment involves the following steps: the artificial tip is applied to the end of the natural nail with nail glue; the tip is cut to the desired length and the shape is trimmed using a buffing sand/pad, the dust is removed with a duster brush and the nail primer is applied to the nail. In the next step, the acrylic mixture (powder and solvent) is applied to the nail using a brush and the nail is trimmed using an electric filing system. In the last step, the clear coat or nail polish is applied to the nails. To remove the acrylic nails, they are soaked in a bowl containing acetone by which time; the acrylic is dissolved by the acetone.

Acrylic nails may last up to four weeks without maintenance, are very strong with relatively easy removal process; However, the application process includes the extensive use of chemicals.

Although the nail salon products are typically used in small amounts, overexposure to some chemicals in those products may impose a number of health risks including eye and skin irritation, headache, dizziness, nausea, allergic reaction, occupational asthma and respiratory problems on technicians and their clients. Therefore, these products should be used and handled properly to minimize the potential for overexposure.

Nail salon technicians are exposed to a wide variety of chemicals in the nail salons; while acetone is the most common solvent being used. A recent study on indoor air quality of beauty salons in Athens, Greece demonstrated that aromatics (toluene, xylene), ketones (ethyl acetate, acetone), and esters are the main chemicals used in the salons. These compounds are used as solvents in various nail products, formaldehyde resins, and acrylic nails (Tsigonia et al., 2010).

Table 1 represents the common chemicals used in nail salons, their applications, and health effects associated with overexposures according to the Occupational Safety and Health Administration (OSHA), and the US EPA.

A number of studies have been conducted to assess the health impacts associated with chemical exposures in nail salons. No studies have been carried out to evaluate the health effects relative to the dust exposures in nail salons.

The results obtained from a questionnaire based study in nail salons in the UK demonstrated a higher prevalence of a range of musculoskeletal and respiratory symptoms reported by nail technicians compared to their office-based controls (Harris-Roberts et al., 2011).

A study examined the potential for cognitive and neurosensory effects of occupational exposure to VOCs (e.g. solvents and methacrylate) among 33 nail technicians in Detroit, MI. According to this study, attention and processing speed of the nail technicians were poorer than the control group. No significant differences were observed in the area of learning and memory, visuospatial ability, or fine motor coordination, or on measures of depression and anxiety. However, the olfaction among the nail technicians was below the expected level. This study suggested that exposure to the low level neurotoxicants common to nail salons may result in mild cognitive and neurosensory changes (LoSasso, Rapport, & Axelrod, 2001). A similar study discovered small differences in individual scales measuring neurologic complaints, cognitive efficiency, memory, verbal learning, and academic skills among the nail technicians compared to the control group. According to this study, the extent of the symptoms greatly depended on the level of occupational exposure, workplace size and ventilation (LoSasso, Rapport, Axelrod, & Whitman, 2002).

Table 1. List of most common Chemicals in Nail Salons

| Chemicals | Usage | Symptoms of overexposure |
|-------------------------------|---|---|
| Acetone | Nail polish remover, fingernail glue remover | headache, dizziness, irritation to skin, eyes, and throat, and central nervous system depression |
| Acetonitrile | fingernail glue remover | irritated nose and throat, breathing problems, nausea, vomiting, weakness, and exhaustion |
| Butyl acetate | Nail polish, polish remover | irritation to eyes, skin, nose, mouth, and throat, headache, drowsiness, skin rash, confusion and/or haziness |
| Dibutyl phthalate | Nail polish, Nail hardener | irritation to eyes, stomach, and upper respiratory system. Prolonged exposure to high concentrations may be hazardous to human reproduction and development |
| Ethyl acetate | Nail polish, fingernail glue, polish remover | irritation to eyes, skin, nose, mouth, and throat, skin rash, confusion and/or haziness |
| Ethyl methacrylate (EMA) | Artificial nail liquid | irritation to eyes, skin, and respiratory track, and skin sensitization |
| Formaldehyde | Nail polish, Nail hardener | difficulty breathing including coughing, asthma-like attacks, and wheezing; allergic reactions; irritated eyes, skin, and throat. Formaldehyde can cause cancer |
| Isopropyl acetate | nail polish, nail polish remover | sleepiness, and irritated eyes, nose, and throat |
| Methacrylic acid | Nail primer | Skin burns and irritated eyes, skin, nose, mouth, and throat. At higher concentrations, this chemical can cause difficulty breathing |
| Methyl methacrylate (MMA) | artificial nail products, banned for use in many states | asthma; irritated eyes, skin, nose, and mouth, difficulty concentrating, loss of smell |
| Quaternary ammonium compounds | Disinfectants | irritated skin and nose and may cause asthma |
| Toluene | nail polish, fingernail glue | dry or cracked skin, headaches, dizziness, and numbness, irritated eyes, nose, throat, and lungs, damage to liver and kidneys, and harm to unborn children during pregnancy |

A few studies have been conducted to evaluate the chemical exposures in nail salons; however, no studies have been carried out to assess the dust exposures in these workplaces.

A study was conducted in Salt Lake County, Utah, in which VOC samples were collected in 12 randomly selected nail salons using summa air canisters and sorbent media for an 8-hr shift. Although methyl methacrylate has been banned for use in nail products by the State, it was found in 58% of the establishments. Similarly, formaldehyde levels were measured above the NIOSH REL (0.016 ppm) in 58% of salons (Alaves, Sleeth, Thiese, & Larson, 2013).

Another study was conducted in two nail salons in Tampa, Florida to assess the personal exposures to ethyl methacrylate (EMA) and methyl methacrylate (MMA) among the fingernail sculptors. The 8-hr time weighted average (TWA) exposure for MMA has been below the OSHA PEL of 100 ppm. No OSHA PEL has been established for EMA. Despite the ban on the use of methyl methacrylate in Florida, the personal exposure ranged between 1 and 5 ppm in these salons. The level of ethyl methacrylate was measured between 1 and 31 ppm (Marty, 2007).

An indoor air quality survey of nail salons in Boston indicated that CO₂ levels in 15 of 21 salons exceeded 800 ppm which is a surrogate for insufficient outdoor air ventilation. Also, the levels of VOCs and PM_{2.5} were found to be higher in salons with less outdoor air ventilation. A consistent trend in average exposures has been observed throughout the salons (Goldin et al., 2014).

Personal sampling for VOCs (toluene, ethyl acetate, and isopropyl acetate) among 80 workers from 20 nail salons in California indicted exposures above the guidelines recommended by the California Division of Occupational Safety and Health to prevent health symptoms including headaches, irritation, and respiratory issues. Elevated concentrations of methyl methacrylate were found in the salons during area monitoring (Quach et al., 2011).

Based on the OSHA Hazard Communication Standard, a product's material safety datasheet (MSDS) must be provided to the salon owner by the chemical manufacturer for each product containing a hazardous chemical at 1% or more. The MSDS provides information on the product ingredients, health and safety risks, exposure routes, and precautions for use and storage or actions needed in emergencies. To minimize workers' exposures in nail salons, ventilation systems, proper working practices, and personal protective equipment (PPE) including respiratory, skin, and eye protection are recommended by OSHA.

Inhalation and skin contact are considered the main routes of exposures to chemicals and dust in nail salons. The nail treatments are typically performed at a nail table with the client's hands resting on the table as the technician completes the task. The proximity of the technicians' breathing zone to the chemicals and dust during the nail treatments is a reason for concern.

To control exposures and chemical hazards in workplaces, two types of ventilation are used: general exhaust and local exhaust. The general exhaust (dilution) systems attempt to dilute the concentration of contaminants to an acceptable level. These systems introduce a relatively large volume of fresh air to the room which results in the dilution and removal of contaminants. Therefore, unlike using an LEV, the contaminants are allowed to be released into the work environment. These systems are used for materials with a low toxicity with a constant gas or vapor emission source.

In contrast, LEVs are used for highly toxic materials with high intensity sources of either particles or gases, while the emission source varies over time. These systems remove the contaminants before they can enter the breathing zone and spread through the work environment.

The main local exhaust systems developed for use in nail salons are categorized into downdraft tables and side draft LEV systems.

A downdraft table eliminates the contaminants near the table's surface using a ventilation system integrated in the table top and pulls the contaminants down through the table top. A side draft system captures the particles and vapors using a flexible duct and inlet from the area where products are placed or used. An LEV system consists of five main parts: capturing inlet, duct system, air cleaning system (filters), the blower, and the exhaust.

A minimum general ventilation supply rate of 10 L/sec (20 ft³/min) per person of outdoor air in the breathing zone with a minimum exhaust rate of 0.6 L/sec-m² (0.12 cfm/ft²) for beauty and nail salons is recommended by Standard 62.1 of American Society of Heating, Refrigeration, and Air-Conditioning Engineers, Inc. (ASHRAE, 2010). According to the 2006 Seattle Mechanical Code, the amount of outdoor air required by general ventilation per person in nail salons is 23.6 L/sec (50 ft³/min) intermittently or 9.4 L/sec (20 ft³/min) continuously per station (City of Seattle, 2006). Also, a minimum exhaust of 23.6 L/min (50 ft³/min) per station is required using local exhaust ventilation systems/downdraft tables, with no recirculation of the exhausted air (City of Seattle, 2009).

According to the Industrial Accident Prevention Association (IAPA), the capture velocity of local exhaust ventilation systems must be at least 100 ft/min for vapors and gases and 200 ft/min for dust and particles. Also, a minimum duct velocity of 1000 ft/min for vapors and gases and 4000 ft/min for heavy dust is required to inhibit heavy particles from settling in the duct (Industrial Accident Prevention Association, 2006).

Few studies have been conducted to evaluate the effectiveness of the ventilation systems in reducing nail salon exposures. However, an exposure assessment study was initiated by the Colorado Health Department and National Institute for Occupational Safety and Health (NIOSH) in 1990 when six cases of occupational asthma associated with artificial nail technicians were diagnosed. A commercially available downdraft table with charcoal filters was modified by NIOSH researchers to increase the system's air flow and the size of the plenum for more consistent flow distribution at the table's face. The charcoal filter was removed and the system ducted outdoors. The exposure assessment was performed with modified (vented) and unmodified (unvented) tables. Three-days of sampling for ethyl and methyl methacrylate with XAD-2 solid sorbent tubes found much lower concentrations of EMA using the modified table (0.6 ppm) than when using the unvented table (8.7ppm). Methyl methacrylate was not detected on sampling tubes (Spencer, Estill, McCammon, Mickelsen, & Johnston, 1997).

In 2012, the National Institute for Occupational Safety and Health (NIOSH) initiated a research project to evaluate the effectiveness of different local exhaust ventilation systems in eliminating potential exposures from nail salons. The NIOSH report states: "Results of the tracer gas capture efficiency measurement for various configurations showed the potential to reduce exposures by at least 50% - 60%." They recommended that additional studies should be conducted to:

- Determine optimum flow rates for increased capture efficiencies.
- Conduct research on the filtration used in the ventilation units.
- Provide training to nail salons operators and employees about the importance of using engineering controls for processes that involve potentially hazardous chemicals.

- Produce this information in easy to understand documents that will be made available to nail salon owners and workers (Marlow et al., 2012)

NIOSH did not plan to conduct this research.

Specific Aims

Our long-term goal was to characterize the efficiency of selected commercially available local exhaust ventilation systems at reducing nail salon workers' exposures. The specific objective of this study was to reduce the chemical and dust exposures such as solvent vapors, nail sanding dust, and acrylic powder to both workers and their clients in nail salons using the local exhaust ventilation systems. The central hypothesis was that the local exhaust ventilation systems in the nail salons can remove at least 60% of the contaminants from the breathing zones of the technicians and their clients in these workplaces. We formulated this hypothesis, in part, based on pilot data gathered from testing one ventilation system in 2011 by King County Local Hazardous Waste Management Healthy Nail Salon Program (LHWM) and the 2012 evaluation by NIOSH of a number of systems (Marlow et al., 2012).

The rationale for the proposed research was to respond to the recent complaints that were brought to the King County Local Hazardous Waste Management Program (LHWMP) regarding the health impacts (i.e. eyes and nose irritation, headaches, and skin irritation) associated with either short-term or long-term exposures to chemicals in the nail salons. We pursued this study in three specific aims:

Aim 1: Develop Standard Operating Procedures (SOP) for testing the nail salon ventilation systems.

Aim 2: Evaluate up to four local exhaust ventilation systems to determine their effectiveness at eliminating vapors and dust from the breathing zones of nail salon technicians and their clients as well as the overall systems' efficiencies.

Aim 3: Assess LEV systems for physical characteristics including flow rates, capture and face velocities and noise levels.

In this study, we examined the prediction that local ventilation will significantly reduce worker and client exposure to chemicals and dust in the nail salons. The proposed work was innovative because it fully characterized the systems' abilities to diminish real workplace exposures and better understood the potential issues with their usability in salons. The combined work proposed in Aims 1, 2, and 3 provided LHWMP with sufficient data to recommend local exhaust ventilation systems to nail salons or to offer financial assistance to nail salons to help them pay for systems.

Methods

Overall Approach

The main goal of this study was to determine the efficiency of local exhaust ventilation (LEV) systems at reducing nail salon workers' exposures to solvents used and dust generated, as they work. To understand the effectiveness of the systems, four commercially available local exhaust ventilation systems were evaluated in the Field Research and Consultation Group (FRCG) lab of the University of Washington's Department of Environmental and Occupational Health Sciences. These systems were provided to the King County Local Hazardous Waste Management Program (LHWMP) by the manufacturers. Each system was characterized for its flow rate, capture and face velocities, and noise level. To assess the efficiency of the systems at removing the contaminants from the breathing zone, acetone vapors and acrylic nail particles were generated at finger level and the respective concentrations measured in the breathing zone using real-time air monitoring instruments, with and without the systems in place. To evaluate the overall efficiency of the systems (the flow and the filtration), they were tested in an enclosed exposure chamber while exposed to a known concentration of acetone vapor. The decrease of the acetone concentration was measured over time using a real time monitor. The results obtained from each scenario were compared between the conditions when there was a control (the LEV system) and when there was no control. Each test was replicated to account for variability in source strength and various ventilation parameters.

Local Exhaust Ventilation Systems

The four LEV systems investigated were Allerair, Weller FT, Air Impurities, and Healthy Air. All systems have in common a capturing inlet, a flexible extraction arm, an inlet to the system, a pre-filter, a HEPA filter to remove particles, an activated charcoal filter or similar media to absorb the organic vapors, a blower, an exhaust, and wheels, but the specifics of each of the elements generally differed. Figure 1 indicates the common features and layout of the LEV systems.

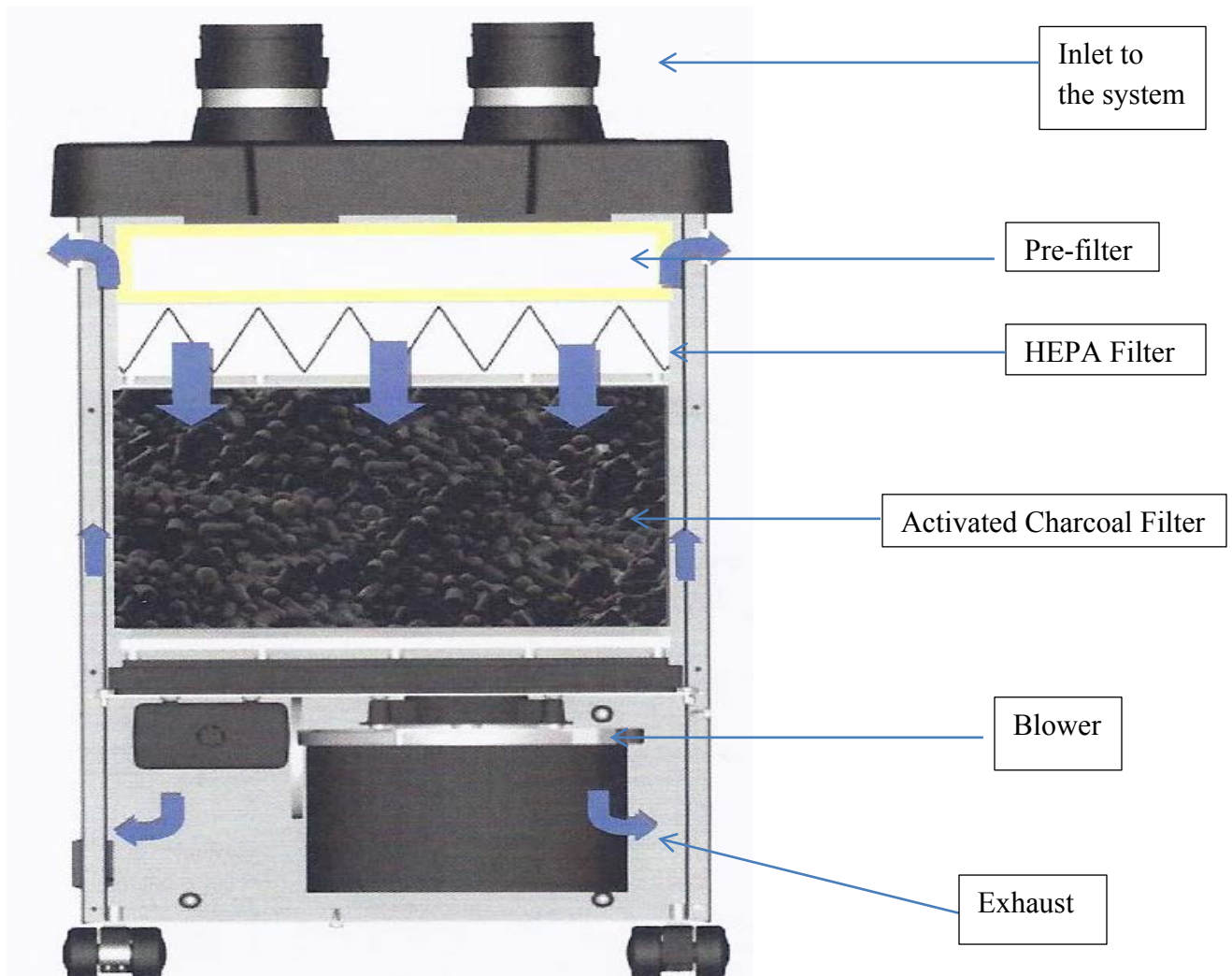


Figure 1. Schematic of an LEV System

Source: Weller FT-Brochure

Specifications

The specifications, as provided by the manufacturer for each system, and the photos are presented in Tables 2-5 and Figures 2-5, respectively.



Figure 2. Allerair Photo

Table 2. Allerair Specifications

| Technical Data | |
|------------------------------|--------------------------|
| Dimension | 20.5" (h) x 15" (d) |
| Carbon Filter | 18 lbs. of vocarb carbon |
| Rated CFM | 400 |
| Airflow Control | 3-speed |
| Flexible Arm Diameter | 3 inches |



Figure 3. Weller FT Photo

Table 3. Weller FT Specifications

| Technical Data | |
|------------------------|-----------------------------------|
| Dimension | 25.9" (h) x 13.8" (w) x 13.8" (d) |
| Weight | 39.6 lbs |
| Airflow Control | 2-speed |
| Sound Level | <50 dBA |



Figure 4. Air Impurities Photo

Table 4. Air Impurities Specifications

| Technical Data | |
|------------------------------|---------------------------------|
| Dimension | 25" (h) x 12.5" (w) x 12.5" (d) |
| Weight | 30 lbs |
| Airflow Control | Variable |
| Rated CFM (blower) | 350 |
| Sound Level at 6 feet | 58-60 dBA at low setting |



Figure 5. Healthy Air Photo

Table 5. Healthy Air Specifications

| Technical Data | |
|------------------------|-----------------------------|
| Dimension | 22" (h) x 16" (w) x 14" (d) |
| Weight | 45 lbs |
| Airflow Control | 3-speed |
| CFM | 150-200 |
| Sound Level | 51-56 dBA |

Physical Characterization of Systems

In order to assess the systems, we characterized each for its flow and velocity characteristics, and noise levels. All the stated characteristics were measured at all systems' setting.

Capture velocity is defined as the air velocity at the point where the contaminant is captured while face velocity refers to the air velocity at the hood or slot opening. The flow rate is known as the volume of the air passes through a given surface per unit time. It is defined as the product of the duct velocity and cross sectional area of the duct in which the measurements are made ($Q=A \times V$).

Capture Velocity Measurements

The capturing inlets were designed differently for each system. Allerair has a circular inlet (12 cm diameter), Weller FT has the option to use one of two inlets (the N-inlet with an semi-circular geometry-9 cm diameter and another with a semi-circle shape with 23 cm diameter), Air Impurities does not have an engineered inlet; instead its circular extension arm is

used as the capturing inlet and can be adjusted to different diameters. Healthy Air has a rectangular inlet with the fixed dimensions (15cm x 8cm). The semi-circle inlet was used for the Weller FT measurements while the capture and face velocities were measured by setting the Air Impurities' inlet at 7 cm diameter.

Capture velocities for the systems were measured from the inlet entry to 25 cm (10 inches) out, along a center line in 2.5 cm (one inch) increments using a hot wire anemometer (TSI 5725 VelociCalc). The anemometer was set to average the velocity every 10 seconds. In order to determine the velocity profile for each system, the capture velocity was also measured from the inlet entry to 10 inches along two lines to each side of the centerline in one inch increments. Depending on the diameter of the inlet, those two lines were positioned either 1 or 2 inches to either side of the centerline. To ensure the accuracy of the measurements, a grid paper was marked with the location of measuring points along the centerline and the other two lines from the inlet entry (Figure 6). The measuring points were marked as 0-10 on the grid paper while point 0 was the closest to the inlet (located right at the inlet entry) and point 10 was the farthest (10 inches away) from the entry. Both inlet and the grid paper were fixed in place on a table while the flexible arm was positioned to the straightest possible path (one bend only) to minimize the potential turbulences and energy loss. All measurements were taken 2.5 cm from the surface of the table. The systems' extraction arm lengths ranged between 91 and 144 cm (36-57 inches).

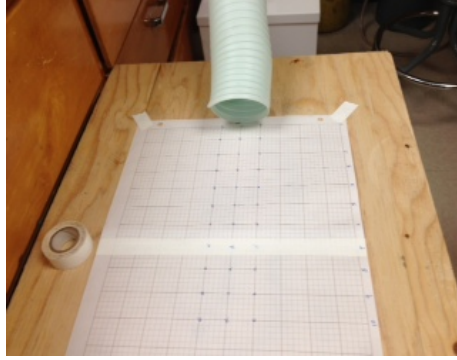


Figure 6. Capture Velocity Measurement

Face Velocity and Flow Rate Measurement

The unique shapes of the systems' inlets made it difficult to directly measure the system's face velocity. The face velocity was determined by measuring the duct velocity and multiplied the inlet's area by that velocity. A 60 cm (2 ft.) long, 5 cm inside diameter, PVC pipe extension was fabricated and inserted into the systems' inlets that allowed us to conduct velocity traverses of the duct. Two small holes were drilled in the pipe about 45 cm (~1.5 ft.) away from the tube's inlet and perpendicular to each other (in x and y directions). Four traverse points on each axis, plus a center point were selected for measurement based on the duct diameter and traverse standard data for a plain circular opening obtained from the industrial ventilation manual (ACGIH, 2007). The centerline measurement was not used in the calculations, but taken as a reference value. Velocity measurements were made with a 30 cm long Pitot tube connected to an electronic micro-manometer (TSI 5725 VelociCalc). The micro-manometer was set up to directly read out the velocity.

Traverse Points Calculation:

Extension pipe diameter: 52 mm

1st Traverse Point: $(52 \text{ mm} * 0.043) + 4\text{mm} = 6.2 \text{ mm}$

2nd Traverse Point: $(52 \text{ mm} * 0.290) + 4\text{mm}=19.08 \text{ mm}$

3rd Traverse Point: $(52 \text{ mm} * 0.710) + 4\text{mm}= 40.92 \text{ mm}$

4th Traverse Point: $(52 \text{ mm} * 0.957) + 4\text{mm}=53.76 \text{ mm}$

Center Point: $(52 \text{ mm} * 0.500) + 4\text{mm}= 30 \text{ mm}$

Note: 4 mm is added to account for the PVC pipe wall diameter.

A Pitot tube was marked with the pre-determined traverse points and the duct velocity was measured in both (x- and y-) axes perpendicular to the flow across the holes of the extension tube. In addition, a hot wire anemometer was used to measure the center point velocity to compare to the Pitot tube measurements. The velocity was averaged every 10 seconds in the duct for each of the Pitot tube traverse and each measurement was duplicated.

The measured tube velocities were averaged over the four traverse points in both directions and the flow rate of each system was determined. Flow rate was calculated using equation [1].

$$Q=A_dV_d \quad \text{Equation [1] (ACGIH, 2007)}$$

Q: Flow Rate (m^3/sec)

A: $\pi d^2/4$: Pipe Cross Sectional Area (m^2)

V: Air Velocity in the duct (m/sec)

The flow rate for each system was then used to compute the face velocity for each of the system's inlets, based on their face's area. Each system's inlet geometry was traced on a sheet of paper and the area was computed based on the appropriate formula. Knowing the duct flow rate

(Q) and area of the inlet's face (A), face velocity (V) was calculated by manipulating equation [1].

Noise Measurements

Each system's sound level was determined at the different airflow control settings by taking three, one-minute noise measurements in the hearing zone of the nail technician using a personal noise dosimeter (Model: 3M Noise Pro Quest Technology Inc.). The meter was calibrated using a sound level calibrator (3M Quest) at 1,000 Hz at 114 dB as a reference output. The sound level meter was always in the slow response mode, measuring A-weighted sound levels. Systems were tested in a quiet conference room under the same conditions on a single day. Each system's flexible arm was extended on a table in a straight position, the inlet was fixed in place, and the technician was sitting approximately 1 m from the center of each system while the dosimeter's microphone was clipped on the nail technician's shoulder nearest to the LEV system. The sound level of each system was then compared with the baseline (the quiet office setting sound level) when there was no ventilation system operating. The arithmetic means and standard deviations of the three noise measurements were calculated.

Systems' Efficiency in Breathing Zone

To evaluate the systems' ability to remove contaminants from the air before reaching the workers' breathing zones, we generated particles and acetone vapors at finger level and monitored them in the breathing zone of a technician.

To simulate the dust and solvent exposures in nail salons, the study's standard operating procedures (SOP) were developed from the realistic conditions in salons and tutorial videos

found on the internet. Currently, acrylic nail application is one of the most common procedures used in nail salons because they are harder than the real nails and can last up to four weeks without maintenance therefore, it was chosen as the standard method for our experiment. Two sets of porcelain glove mandrels (hand molds) were purchased for this purpose and four prepared acrylic nails were glued on each hand set for each experiment. The thumbs were excluded from the experiment because of their awkward position. The acrylic nails were prepared in advance by applying two layers of a mixture of acrylic powder (CND sculpting powder, Creative Nail Design, Inc.) and acrylic solvent (CND sculpting liquid, Creative Nail Design, Inc.) on each clear plastic artificial nail (Lamour Eden nail tips) using a brush. The acrylic powders were selected in pink or red color to give better visibility during the grinding process. Nails were attached to the mandrel using a small amount of “super glue” (KDS Nail Products).

Dust and organic vapor capture efficiency experiments were consecutively run for each system. The first and last sets of experiments on each day were “no control” (NC) scenarios with no ventilation system used. The first task of each experiment set was nail grinding to generate dust. Nails were then wiped with cotton balls saturated with 2 ml of acetone to replicate the nail polish removal in the salons. After wiping, 40 ml of acetone was poured into a bowl and let sit in front of the nail technician to simulate the soaking of acrylic nails to remove them. Each experiment which included grinding, wiping, and nail removal took about 25 minutes and used 2 of the porcelain mandrels.

Dust Capture Efficiency

To evaluate dust capture efficiency, a technician was sitting on one side of a nail salon table with the porcelain mandrels facing him (Figure 7). The nail technician was a staff member

trained to be able to conduct the nail technician jobs. The acrylic nails were glued on the mandrels and were let dry for a few seconds. The mandrels were placed within 18 cm (7 inches) of the LEV inlet. The manufacturer of the Weller FT recommended placing the inlet as close as possible to the nails when grinding. However, in our experiment, the closest possible distance from the inlet was within 18 cm due to the large size of the mandrels. An electric nail filing system (Medicool's Turbo file II, 20,000 RPM motor) was used to file/grind each acrylic nail for 60 seconds in all directions (up and down, left and right) to remove the rough edges and make it smooth. The filing system speed was set at medium (6500 RPM) and medium grit red sanding bands (Medicool, Inc.) used for grinding. The duration of grinding was determined from watching acrylic nail application in salons and YouTube tutorial videos. Grinding is typically done for 60-70 seconds on each acrylic nail.

Airborne dust levels were monitored in real-time using a personal Thermo pDR-1500 that estimates the mass concentration of the particles using a photometric monitor (light scattering sensing configuration). The total particle inlet was used for the pDR to measure the dust level generated from grinding process because it would be more representative of the particles generated from the grinding process than a respirable particle inlet. The exposure was measured with the sampling tube inlet within 30 cm (1 foot) of the technician's mouth. The measurements were averaged every 5 seconds and duplicated on different days to account for variation. The lab temperature and relative humidity were monitored and logged on each day of experimentation using a TSI Q-Trak (TSI 7565).

Eight fingers were ground with, and 8 fingers ground without the ventilation system in place. Each ventilation system's centerline capture velocity was measured with the hot wire anemometer and checked with the previous measurements for consistency before running the

experiment. The extraction arms were adjusted to the straightest possible path during experiments to minimize the energy loss and turbulences. All systems were tested at their highest fan setting.



Figure 7. Nail Grinding with LEV System

Organic Vapor Capture Efficiency

To assess the solvent capture efficiency, the nail polish removal process was replicated. For this purpose, the same set of nails used for grinding was wiped with two cotton balls saturated with 2 ml of acetone (one cotton ball for each hand). Acetone was added to the cotton balls using a 100-1000 μ l Eppendorf micropipette in an adjacent room. After saturation, each cotton ball was immediately transferred to the experiment location and wiped on each nail for 3 seconds to mimic the nail polish removal process. After use, the cotton ball was returned to the adjacent room. Following that, the next cotton ball was prepared and used for the next hand.

To remove acrylic nails in salons, the nails are soaked in a bowl containing acetone for 10-15 minutes (Figure 8). In order to simulate the acrylic nail removal scenario in the lab, a bowl was filled with 40 ml of acetone in front of the technician and let sit for 10 minutes. The glass beaker used to transfer the acetone was immediately removed from the experiment location after pouring the acetone to minimize the bias from other sources/interferences.

To monitor the acetone exposure, tubing attached to a MiniRAE 2000 (PGM, 7600) photoionization detector (PID) was clipped in the technician's breathing zone during the acetone swab application and nail removal processes. This instrument uses an ultraviolet (UV) light source to ionize a gas sample and detect its concentration in parts per million (ppm). It was calibrated with 100 ppm of isobutylene span gas at the beginning of each experiment day. All the measurements were averaged every second and adjusted for acetone by applying the manufacturer's recommended correction factor of 1.1.

The collection efficiency for each system for both airborne dust and acetone vapors was calculated by comparing the average concentrations at the breathing zone with and without LEV in use (Equation 2). The dust and VOC measurements were duplicated for each system and condition; as a result we had two monitoring dates for each system including NC. The dust and VOC data were analyzed with respect to the experiment days and systems to test for temporal variability and collection efficiency. Data were approximately log-normal distributed; consequently, geometric mean concentrations were used for these comparisons.

$$\% \text{ Capture Efficiency} = 100 * (GM_{NC} - GM_{LEV}) / (GM_{NC}) \quad \text{Equation [2]}$$



Figure 8. Open Acetone Container Experiment

System's Overall Efficiency

To measure the efficiency of the LEV systems as a whole, we tested them in a static isolated exposure chamber. This test was similar to Clean Air Delivery Rate (CADR) test to rate free standing room air cleaning systems (Ramona, 2006).

The chamber is made of aluminum frame and glass panels with a volume of 4 m³ [2.7 m (h) x 1.2 m (w) x 1.2 m (d)]. Two bulkheads were fabricated on one of the walls to fit the electric cords or sampling probes/tubes (Figures 9 and 10). To isolate the exposure chamber, all the holes were covered with mylar sheets and aluminum foil tape. The aluminum foil tape was selected to minimize the chance of reactivity with acetone. Prior to the system efficiency experiments, the chamber was tested for potential leaks and well mixing. This was done by placing a tripod in the chamber with three Teflon tubes at different heights: 6 ft., 4 ft., and 1 ft. from the floor. One end of each tube was located on the tripod while the other end was run through the bulkhead in the chamber where it was connected to the PID, which was outside of the chamber. The PID's inlet was attached to each of the tubes after sampling for approximately 30 seconds at each location. Two small battery powered mixing fans were placed and run in the chamber, one on the right corner and the other on the tripod both at a height of 3 ft.

A glass pan was placed on a cart in the chamber, eight ml of acetone poured into the pan, the pan rocked back and forth to spread out the acetone on the bottom of the pan, and the chamber door was closed. The PID started monitoring the acetone vapor concentration when the door was closed. Concentrations were logged once a second. The acetone concentration rose until reaching the equilibrium concentration of approximately 1200 ppm after about six minutes.

To test for leaks and losses to the chamber, the concentration was monitored for 45 minutes before opening the chamber door.

Measurements from all locations indicated that the acetone in the chamber was well mixed and there was little loss over time in the timeframe of our interest, approximately 30 minutes. These tests were also run at the end of the experiments.

For the efficiency tests, each LEV system was placed in the chamber, one at a time, with its extraction arm adjusted to the straightest possible path in the center of the chamber. Each LEV system had its electrical cord running through a bulkhead in the chamber so it could be turned on and off remotely.

In order to measure the concentration decrease over time without taking too long or being too quick, we chose a target concentration of approximately 1000 ppm. This concentration is well below the Lower Explosive Limit (LEL) of 2.5% (25,000 ppm) and the Immediately Dangerous to Life and Health (IDLH) level of 2,500 ppm, which is defined as 10% of the LEL. In theory, to achieve this concentration in the 4 m³ chamber, it would require the addition of 12 mL of acetone. After the mixing and loss test, we reduced the amount to eight ml to prevent the concentration from getting too high.

For the LEV tests, after closing the chamber's door, the acetone concentration was monitored with the PID at the 4 ft. height for all experiments. When the acetone was completely evaporated and the level was stabilized at roughly 1200 ppm, the LEV system was turned on. The ventilation system was turned off after the concentration in the chamber had dropped to approximately 8 ppm. The PID was then disconnected and the data downloaded.

The CADR value was calculated for each system by first calculating the chamber's background acetone decay rate and then subtracting that value from the acetone decay rate measured for each system. The decay constant was calculated by measuring the concentration drop off over time, taking the natural logarithm of the concentration and regressing that versus time (Equation 3). The slope of the curve is equal to the decay rate in units of inverse time. The CADR is calculated by multiplying the slope by the volume of the chamber (Equation 4). The CADR represents the overall efficiency of the systems as a combination of sorbent filter efficiency and flow rate (Ramona, 2006).

$$C_{t_i} = C_i e^{-kt_i} \quad \text{Equation [3]}$$

Where:

C_{t_i} = concentration at time t_i (ppm)

C_i = concentration at $t = 0$

k = decay rate constant (seconds⁻¹)

t_i = time (seconds)

The CADR is then calculated using the following equation:

$$\text{CADR} = V(k_e - k_n) \quad \text{Equation [4]}$$

Where:

CADR = clean air delivery rate (ft³/min)

V = volume of test chamber, (4 ft³)

k_e = decay rate with LEV, sec⁻¹

k_n = natural decay rate (without LEV), sec⁻¹

The CADR value can be considered as a flow rate. The percent difference between CADR estimates and flow measured with the pitot-tube can be calculated using equation [5]

$$\% \text{ Difference} = 100 * (\text{Decay based flow} - \text{Pitot based flow}) / (\text{Pitot based flow}) \quad \text{Equation [5]}$$



Figure 9. Exposure Chamber Experiment

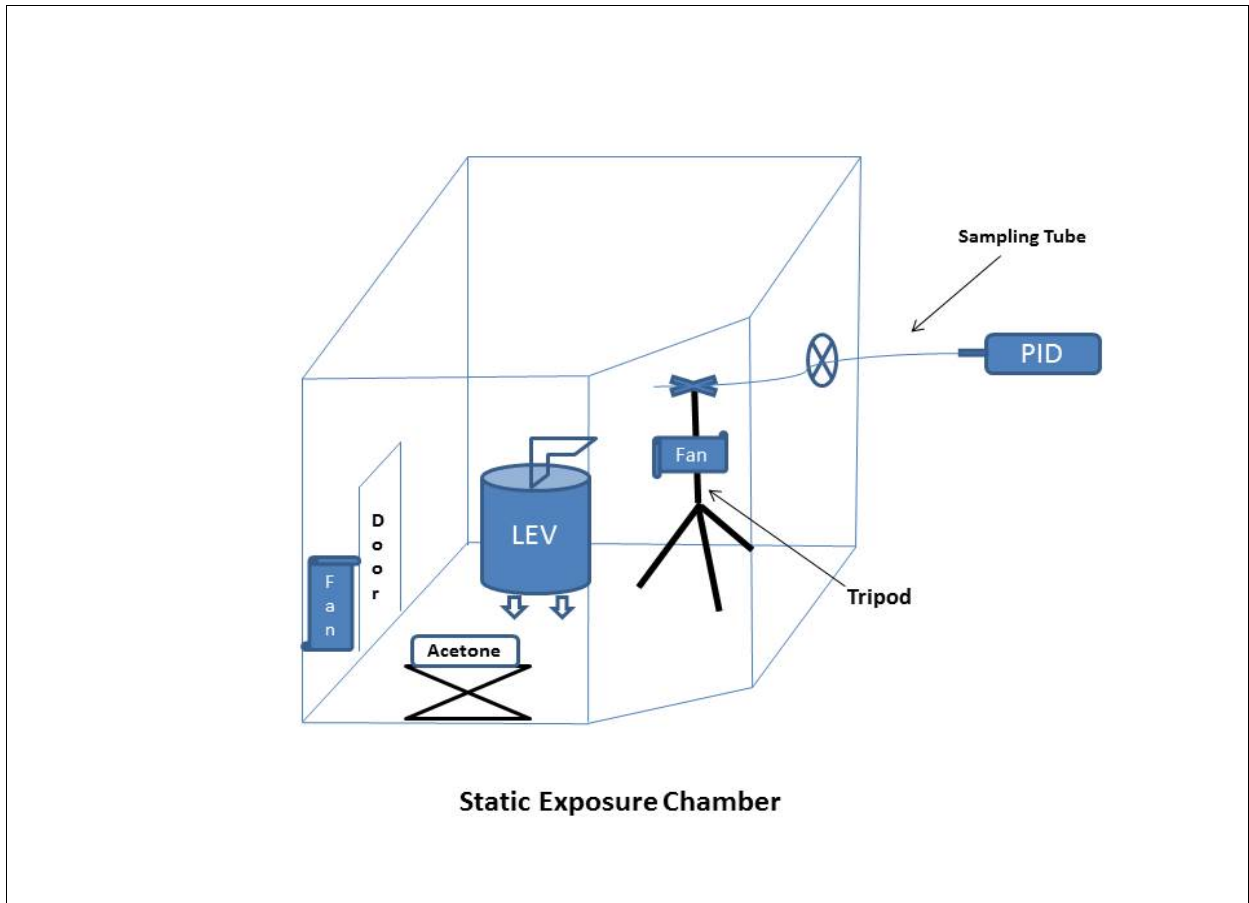


Figure 10. Schematic of Exposure Chamber

Results

Physical Characteristics

Flow Rate, Capture and Face Velocity

Air flow rates for the four systems tested ranged from 0.0232 m³/sec to 0.0364 m³/sec at their high settings, with the Air Impurities system having the highest air flow rate and Weller FT having the lowest flow (Table 6, Appendix I).

Similarly, the face velocity was measured as the lowest for Weller FT at all settings and as the highest for Air Impurities (Table 7). The higher and lower flow rates contributed to the velocity trends observed for each system. As mentioned in the methods section, the Weller FT semi-circle inlet was used for all measurements including flow, capture and face velocities, and efficiency tests. The capture and face velocities for Air Impurities were measured using a 7 cm inlet diameter.

The similar trend is observed as the capture velocities evaluated at 5 cm and 12.5 cm from the inlets at all systems' settings (Table 8). The capture velocity profiles for each system are shown in Figures 11-14 and Appendix II. As the distance from the inlet becomes larger, the capture velocity decreases. It is the highest at point 0 (right at the inlet) and the lowest 10 inches away from the inlet. Also, the capture velocity decreased from the centerline to the either side toward the tube walls. The higher rates of energy loss and turbulences at or near the walls due to the tube geometry contribute to this finding. The peak capture velocity was measured along the centerline for all systems except for Air Impurities which is an inch off of the center line (to one side of the centerline-Figure 13).

Table 6. Flow Rates of LEV Systems measured by Pitot-Tube

| Flow Rates (m³/sec) | | | |
|---------------------------------------|-------------|---------------|------------|
| Unit/Setting | High | Medium | Low |
| Allerair | 0.0232 | 0.0194 | 0.0123 |
| Weller FT | 0.0225 | N/A | 0.00571 |
| Air Impurities | 0.0364 | N/A | 0.0346 |
| Healthy Air | 0.0347 | 0.0304 | 0.0211 |

Table 7. Face Velocity of LEV Systems

| Face Velocity (m/sec) | | | |
|------------------------------|-------------|---------------|------------|
| Unit/Setting | High | Medium | Low |
| Allerair | 2.05 | 1.71 | 1.09 |
| Weller FT | 1.08 | N/A | 0.274 |
| Air Impurities | 9.45 | N/A | 8.98 |
| Healthy Air | 2.89 | 2.53 | 1.75 |

Table 8. Average Capture Velocity measured at 5 cm and 12.5 cm from System's Inlet

| Unit/Setting | Cap. Vel. @ 5 cm (2") from inlet (m/sec) | | | Cap. Vel. @ 12.5 cm (5") from inlet (m/sec) | | |
|-----------------------|---|---------------|------------|--|---------------|------------|
| | High | Medium | Low | High | Medium | Low |
| Allerair | 1.51 | 1.19 | 0.670 | 0.540 | 0.439 | 0.268 |
| Weller FT | 1.13 | N/A | 0.335 | 0.379 | N/A | 0.0949 |
| Air Impurities | 3.21 | N/A | 2.41 | 0.559 | N/A | 0.495 |
| Healthy Air | 2.08 | 1.77 | 1.26 | 0.649 | 0.560 | 0.460 |

Capture Velocity Profiles

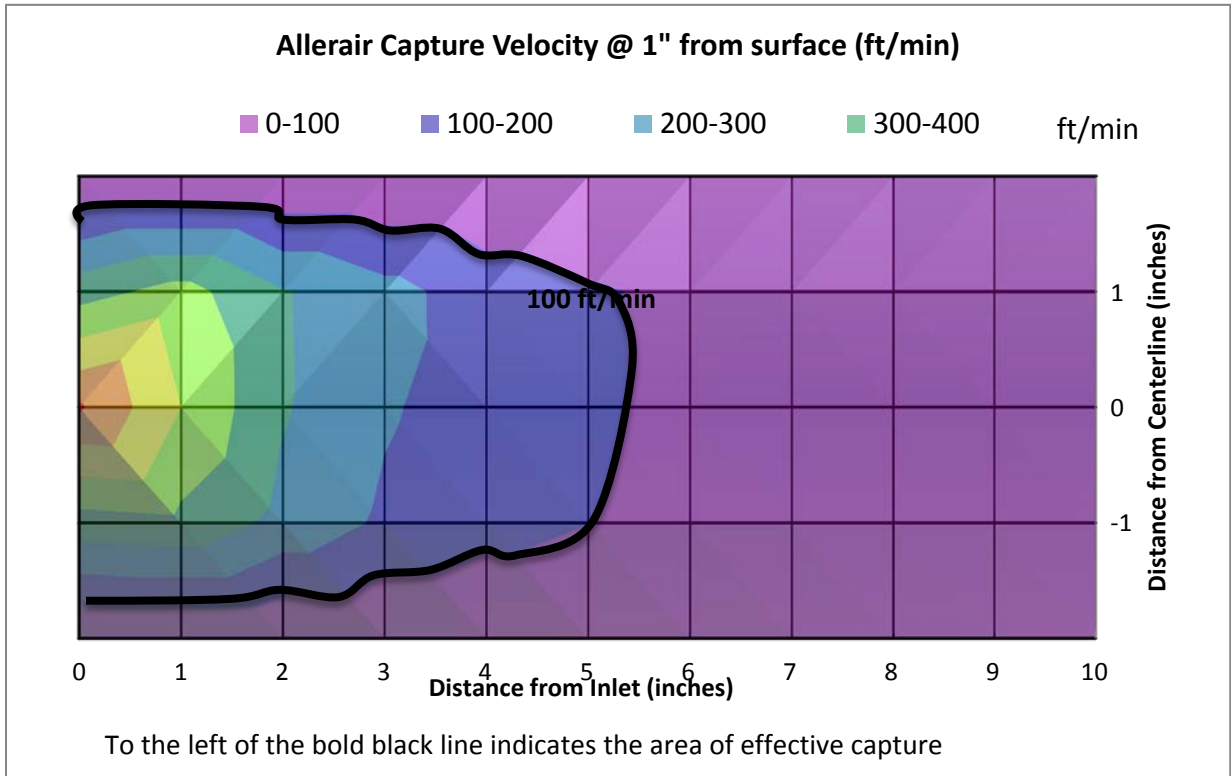


Figure 11. Allerair Capture Velocity Profile for High Setting

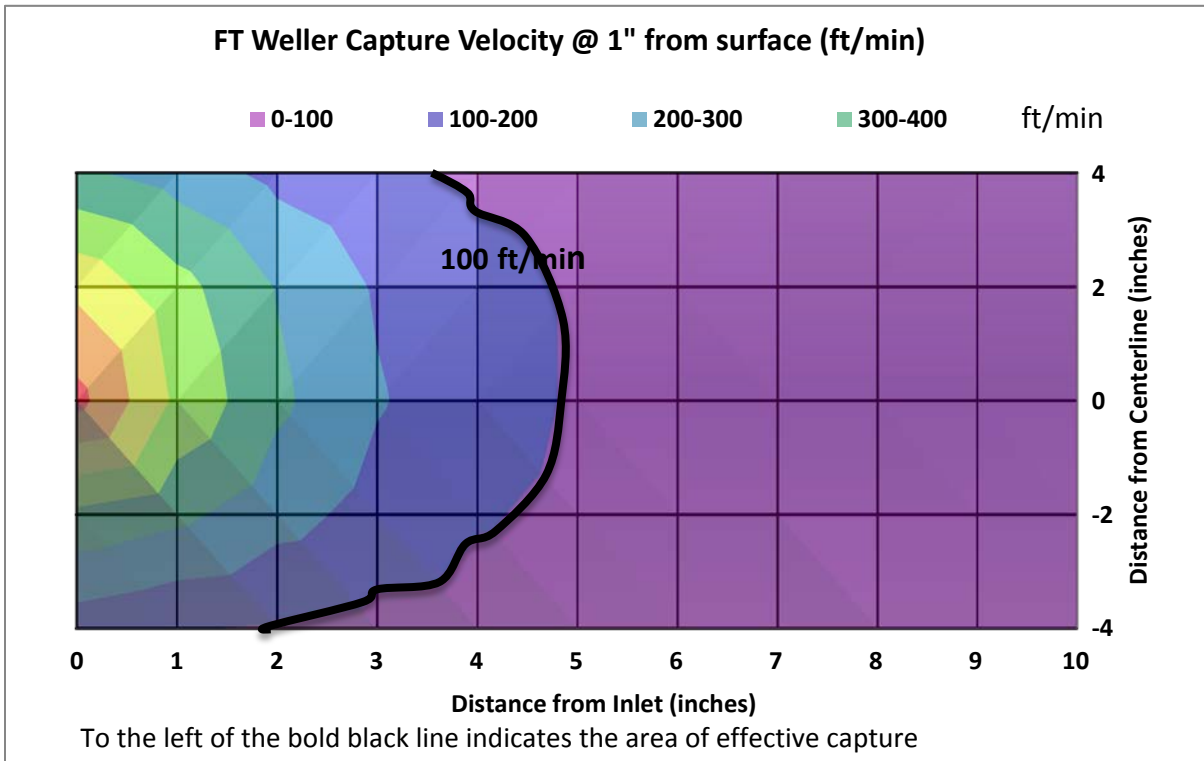


Figure 12. Weller FT Capture Velocity Profile for High Setting

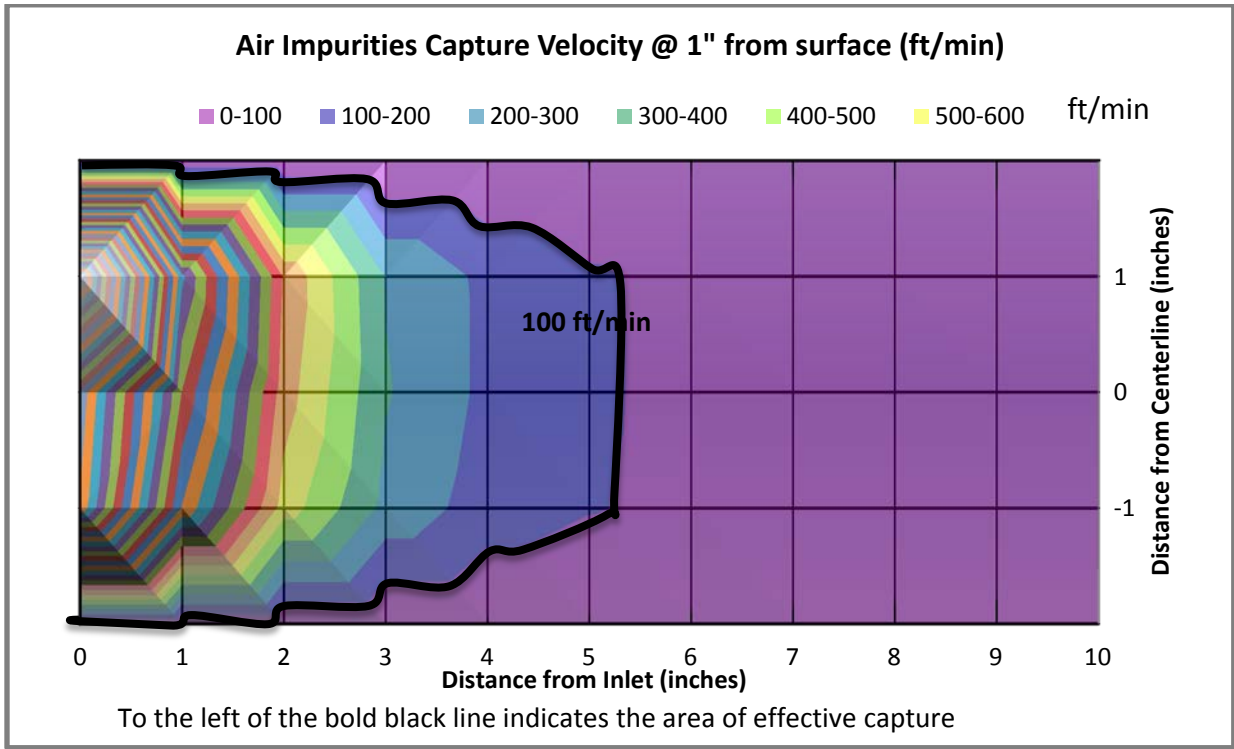


Figure 13 . Air Impurities Capture Velocity Profile for High Setting

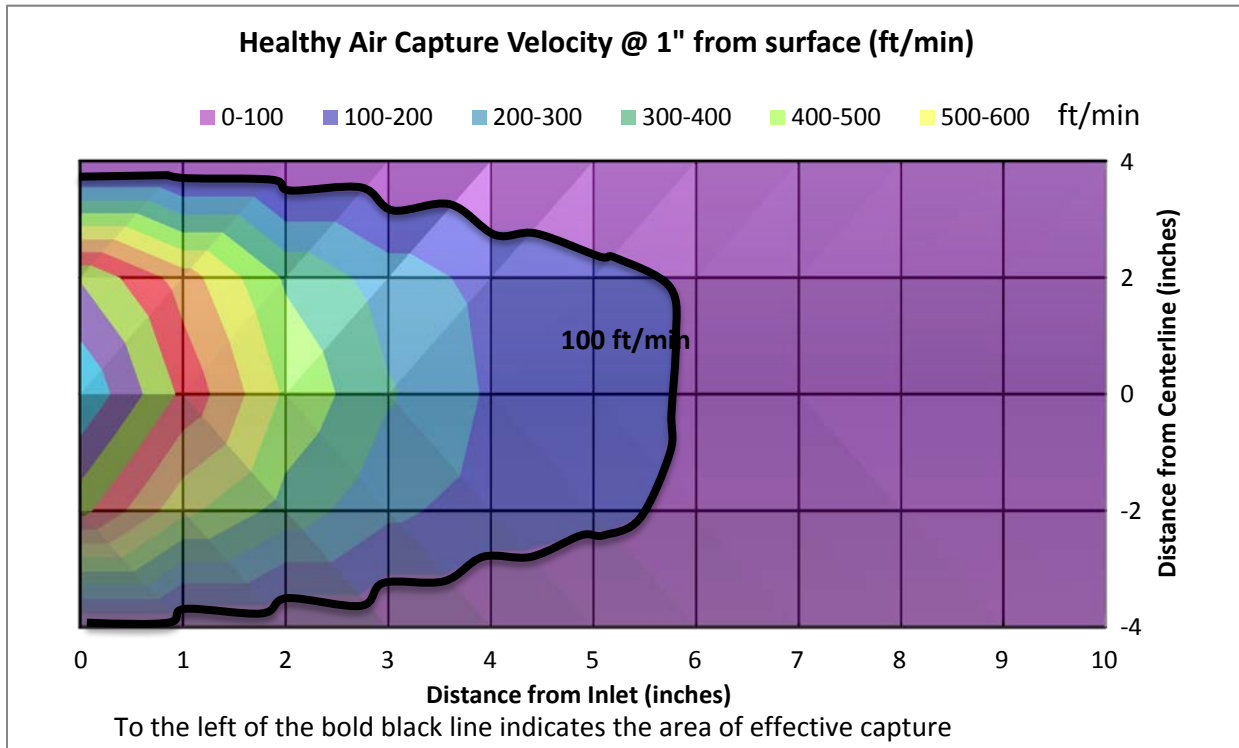


Figure 14 . Healthy Air Capture Velocity Profile for High Setting

Noise Measurements

Noise levels for the four systems ranged from 58 dBA to 71 dBA at their high setting (Table 9). Comparing the systems at their high setting, Weller FT has the lowest noise level, comparable to the quiet office setting noise level, and Healthy Air is the loudest. However, all noise levels are considerably below the OSHA Permissible Exposure Limit (PEL) of 90 dBA as an 8-hr time weighted average (TWA).

Table 9 . Noise Level of Systems

| System and Setting | Noise Level (dBA) | |
|-----------------------|-------------------|-------------|
| | Average | Stand. Dev. |
| Weller FT | | |
| High | 58.6 | 1.0 |
| | | |
| Air Impurities | | |
| High | 64.5 | 0.3 |
| | | |
| Allerair | | |
| High | 64.8 | 1.6 |
| Medium | 59.9 | 0.2 |
| Low | 52.0 | 0.4 |
| | | |
| Healthy Air | | |
| High | 70.9 | 0.3 |
| Medium | 67.5 | 0.4 |
| Low | 61.6 | 3.2 |
| | | |
| Baseline | | |
| Quiet Office | 53.8 | 2.7 |

Systems' Efficiency at Breathing Zone

The real-time dust and VOC data were imported into Microsoft Excel spreadsheets and organized. The PID data were adjusted for the background VOC level. Since the total VOC exposures were based on an isobutylene calibration, the PID data were adjusted for acetone concentrations by applying the correction factor of 1.1 (RAE, 2005).

To analyze the collected data from the efficiency study, an Analysis of Variance (ANOVA) statistical model was chosen. ANOVA assumes a normal distribution for its analysis and tests the means of several groups for equality and variances. Since our study data sets for dust and VOCs appeared to be log-normally distributed, they were log transformed prior to analysis to provide a normal distribution for ANOVA. All of the data that were less than or equal to zero reported by the pDR and PID were replaced with a value of 0.1 prior to the natural log transformation because it is not possible to take the logarithm of numbers less than or equal to zero. This corresponds to 7.5 % of the PDR data and approximately 2 % of the PID data. Neither of the instruments displayed negative values during the monitoring, but only after the logged data were inspected. The pre- and post- transformed distributions are shown in Figures 15-16 for dust and 22-23 for VOC using histograms and Q-norm plots. After transformation, the data exhibit more normally distributed appearances (Figure 16 and Figure 23).

In addition to the normality assumption, ANOVA assumes that the observations are independent from each other. However, in our study real-time monitors averaged the dust level every five second and acetone level every second, which resulted in having datasets with a large number of data points that were not independent from each other. As a result, the p-values could have been underestimated by the ANOVA model.

Dust Capture Efficiency

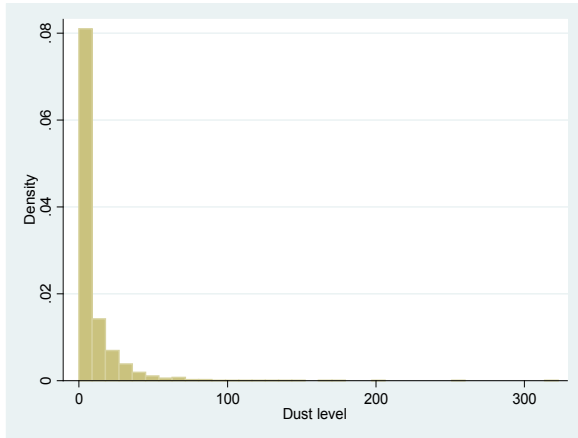


Figure 15 . Dust Pre-transformed Distribution

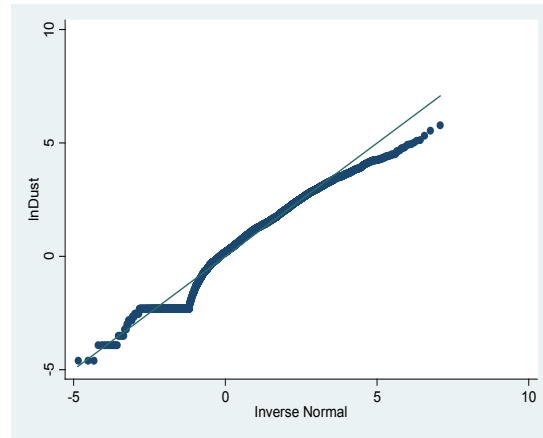


Figure 16. Dust Post-transformed Distribution

As stated in the methods section, dust and VOC measurements were duplicated on different days to account for variation, respectively; the data were analyzed by monitoring dates. ANOVA reported a $p\text{-value} < 0.001$ demonstrating the significance of day effect in dust exposure measurements with and without LEV systems. The mean dust concentrations, confidence intervals (CI), and capture efficiencies for each system and monitoring date are represented in Table 10. The resolution of the pDR was reported as $0.1 \mu\text{g}/\text{m}^3$ by the manufacturer, however; the unit presented the dust exposures with two significant figures. Based on the resolution, the means and CIs were truncated to one significant figure.

To visualize the day effect, the dust exposure for no control setting is presented by box plots in figure 18. For better resolution, the outliers were dropped from the graphics but not from the calculated values, instead, the 99th percentiles are listed above the upper whiskers.

The general components of a box plot are shown in figure 17. The band inside the box is the median or 50th percentile, the bottom and top of the box are the first quartile (Q1: 25th percentile) and third quartile (Q3: 75th percentile), respectively. The upper whisker is the largest value below the upper inner fence ($Q3 + 1.5 * IQR$) and the lower whisker is the smallest value

above lower inner fence [$Q1-1.5*IQR$], where the interquartile range ($IQR = Q3-Q1$). The potential outliers are points beyond those fences and are presented as individual points on either side of the whiskers.

Table 10. Geometric Mean Dust Concentrations by Monitoring Date and Systems

| Systems/Run | Monitoring Date | Geometric Mean ($\mu\text{g}/\text{m}^3$) | 95% Conf. Interval ($\mu\text{g}/\text{m}^3$) | % Capture Efficiency |
|-------------------------|------------------------|---|---|-----------------------------|
| Allerair 1 | 1/29/2014 | 1.6 | 1.5 - 1.9 | 90 |
| Allerair 2 | 4/4/2014 | 0.9 | 0.8 - 1.0 | |
| Weller FT 1 | 1/29/2014 | 4.0 | 3.7 - 4.4 | 80 |
| Weller FT 2 | 4/4/2014 | 0.8 | 0.7 - 0.9 | |
| Air Impurities 1 | 1/29/2014 | 5.4 | 5.2 - 5.7 | 67 |
| Air Impurities 2 | 2/4/2014 | 4.6 | 4.3 - 4.9 | |
| Air Impurities 3 | 4/4/2014 | 0.7 | 0.7 - 0.8 | |
| Healthy Air 1 | 1/22/2014 | 3.5 | 3.3 - 3.7 | 71 |
| Healthy Air 2 | 4/4/2014 | 2.6 | 2.3 - 2.9 | |
| NC 1 | 1/22/2014 | 9.1 | 8.0 - 10.4 | N/A |
| NC 2 | 1/29/2014 | 11.9 | 10.4 - 13.6 | N/A |
| NC 3 | 2/4/2014 | 9.5 | 8.2 - 11.0 | N/A |
| NC 4 | 4/4/2014 | 12.7 | 11.9 - 13.5 | N/A |

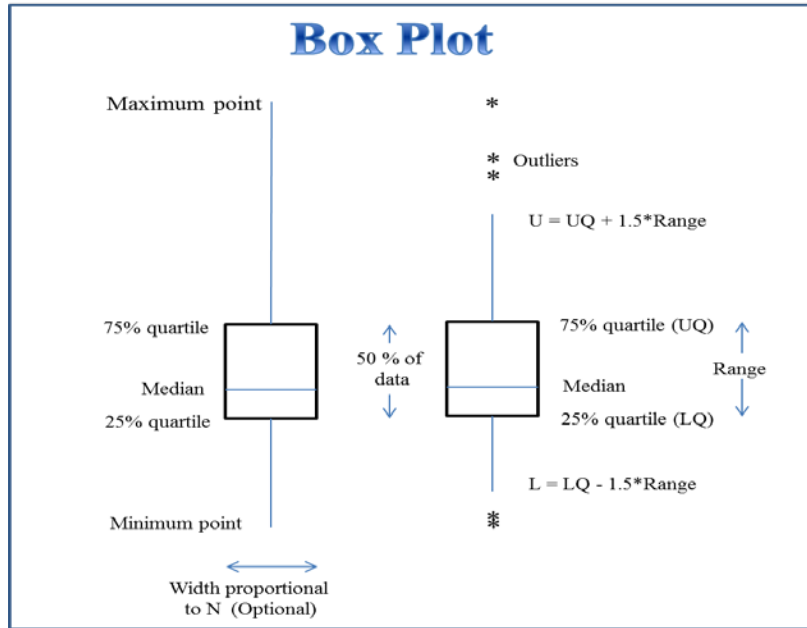


Figure 17. Box Plot Components

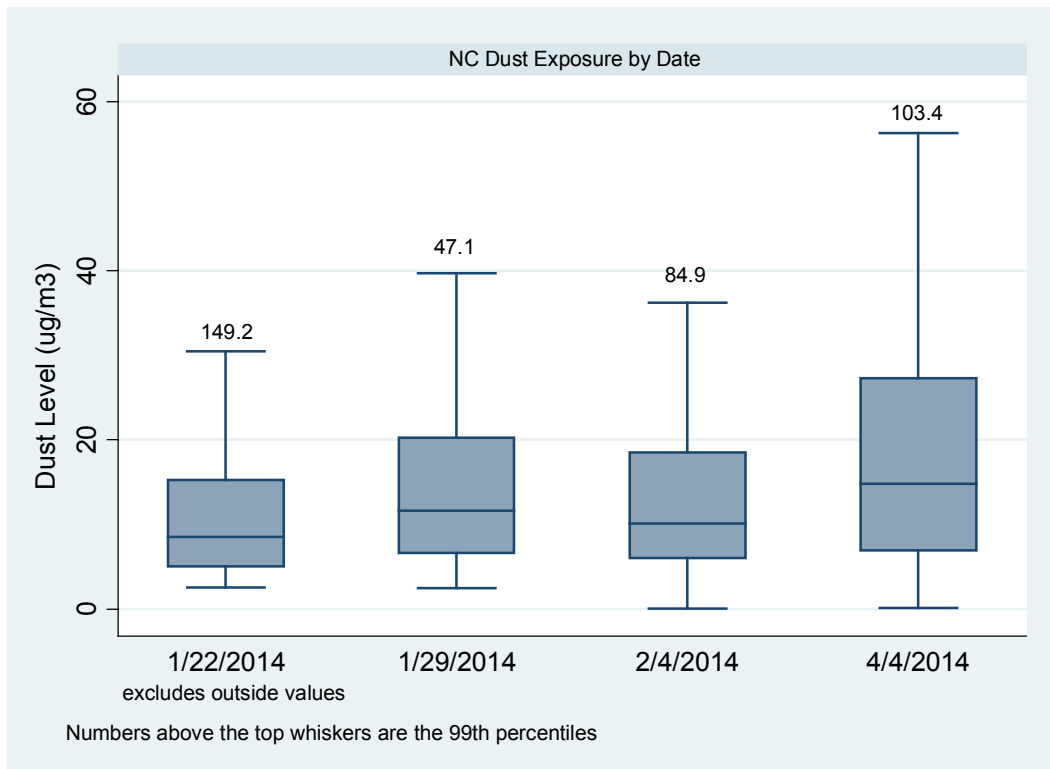


Figure 18 . “No Control” Dust Exposure by Monitoring Date

Comparison of Systems with and Without No Control

As presented by the box plots, the exposures are significantly lower with the controls than exposures with no control (Figure 19) and this difference is statistically significant (p-value<0.001). Between systems variability was evaluated by comparing the average dust level excluding the NC condition from the analysis (Figure 20). This comparison shows that the systems performed inconsistently with respect to the dust exposure and this dissimilarity was statistically significant (p-value<0.001). This statistical significance means that at least one of the systems was different from the others. However, all of the systems were able to effectively minimize the exposures compared with NC condition. Figure 20 is similar to Figure 19 but the “no control” box was eliminated from the graphics for better scale visibility.

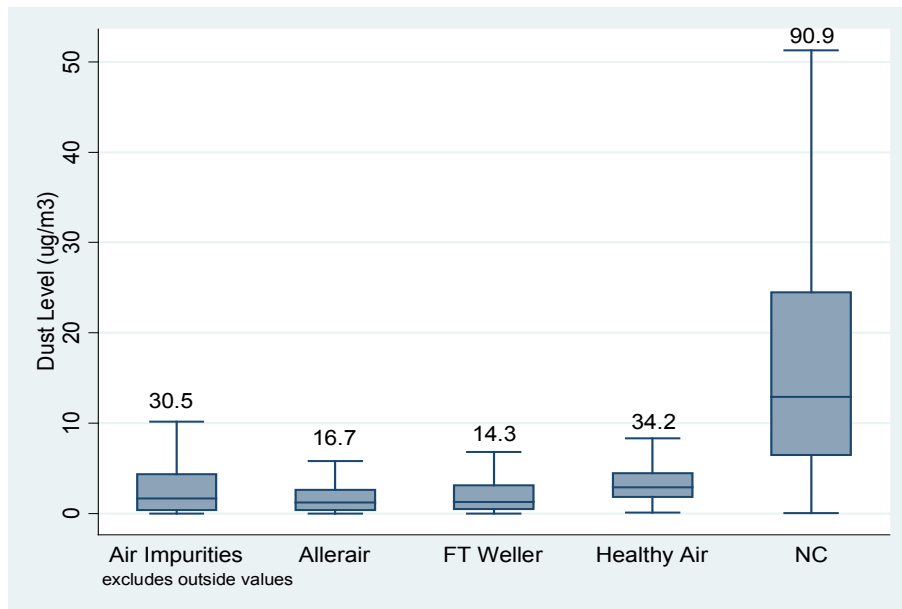


Figure 19. Comparison of Systems with NC

Note: Numbers above the top whiskers are the 99th percentiles.

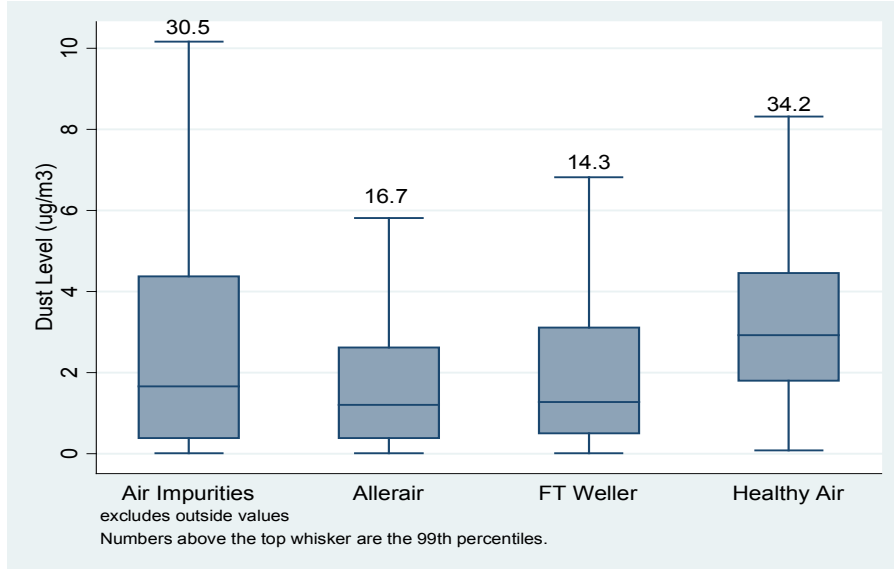


Figure 20. Comparison of Systems excluding NC
Note: Numbers above the top whiskers are the 99th percentiles.

Comparison of Dust Exposure between Control and No Control by Date

Comparison of the average dust exposures between control and no control conditions on each experiment day is summarized in Table 11. The mean dust level for control on each day was averaged over all LEV systems' dust levels. A consistent exposure trend is observed between controls and no controls throughout the experiment days as illustrated in Figure 21. However, the exposures vary from day to day.

Table 11. Comparison of Mean Dust Exposures between Control and No Control Scenarios by Date

| Monitoring Date | 1/22/2014 | | 1/29/2014 | | 2/4/2014 | | 4/4/2014 | |
|-------------------------------------|-----------|------------|-----------|-------------|-----------|------------|-----------|-------------|
| | Control | No Control | Control | No Control | Control | No Control | Control | No Control |
| Geometric Mean (µg/m ³) | 3.5 | 9.1 | 3.3 | 11.9 | 4.6 | 9.5 | 1.1 | 12.7 |
| 95% CI (µg/m ³) | 3.3 - 3.7 | 7.9 - 10.3 | 3.1 - 3.6 | 10.4 - 13.6 | 4.3 - 4.9 | 8.2 - 10.9 | 1.0 - 1.2 | 11.9 - 13.5 |

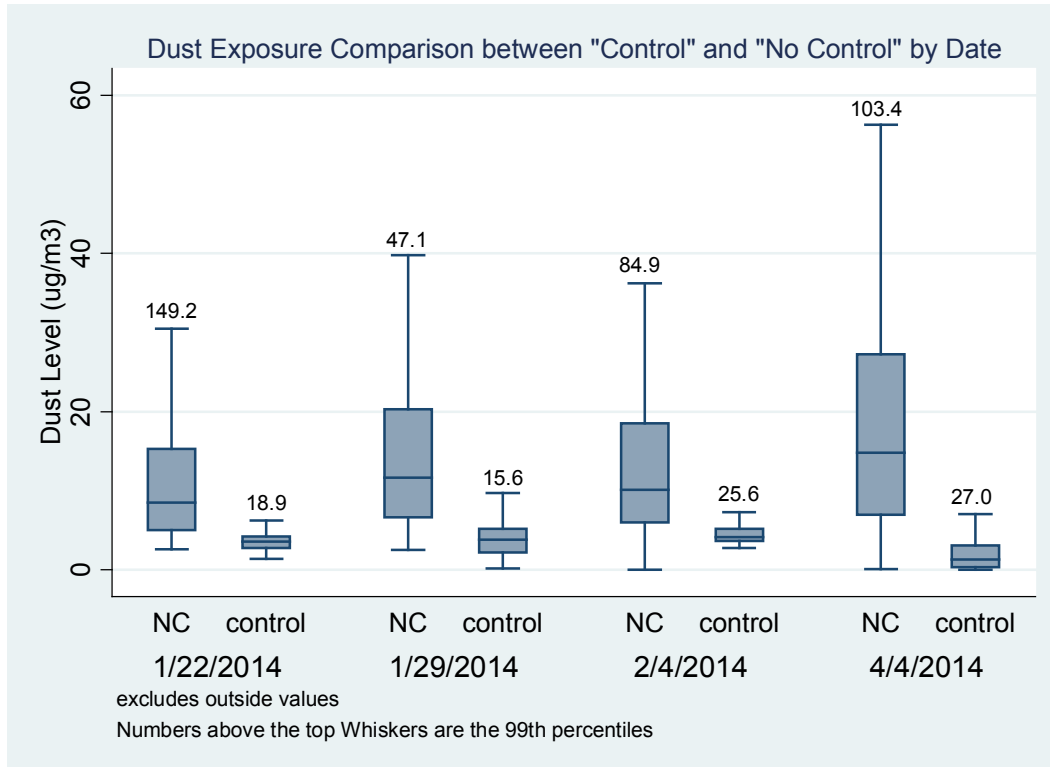


Figure 21. Comparison of Dust Exposures between “Control” and “No Control” by Date

Volatile Organic Compounds (VOC) Capture Efficiency

Two experiments were used for VOC measurements: 1) Wipe Nails and 2) Open Acetone Container (Acetone Bowl). The pre- and post- transformed distributions are shown in Figures 22-23 for data from both experiments. Again, data are much more normal in appearance after transformation.

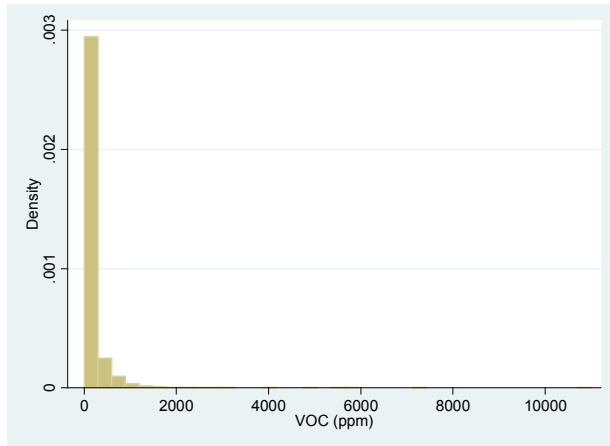


Figure 22 . VOC Pre-transformed Distribution

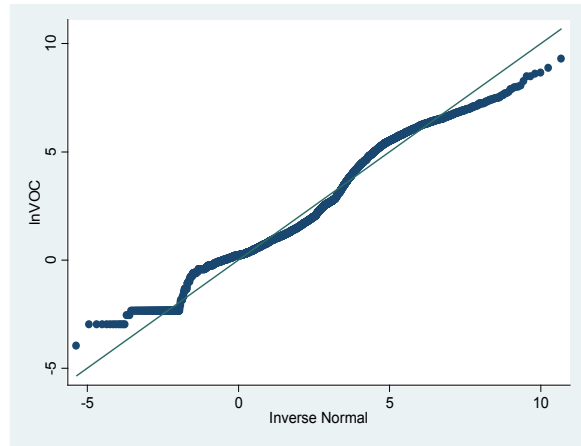


Figure 23 . VOC Post-transformed Distribution

Acetone Exposures by Experiment and Date

A day to day variation in acetone exposure measurements for both experiments is observed (Tables 12 & 13). ANOVA indicates that the day effect is statistically insignificant for the nail wiping experiment (p-value=0.07) while it is significant for the acetone bowl experiment (p-value<0.001).

Table 12. Geometric Mean VOC Concentrations for Nail Wiping by Monitoring Date and Systems

| Wipe Nails | | | | %Capture Efficiency |
|------------------|----------|----------------------|--------------------------|---------------------|
| Systems/Run | Date | Geometric Mean (ppm) | 95% Conf. Interval (ppm) | |
| Allerair 1 | 2/3/2014 | 2.01 | 1.20 - 3.35 | 93 |
| Allerair 2 | 4/4/2014 | 2.10 | 1.41 - 3.15 | |
| Weller FT 1 | 2/3/2014 | 8.25 | 6.21 - 10.96 | 83 |
| Weller FT 2 | 4/4/2014 | 1.98 | 1.04 - 3.75 | |
| Air Impurities 1 | 2/4/2014 | 4.71 | 3.97 - 5.58 | 80 |
| Air Impurities 2 | 4/4/2014 | 9.73 | 5.37 - 17.46 | |
| Healthy Air 1 | 2/3/2014 | 9.68 | 7.22 - 13.03 | 77 |
| Healthy Air 2 | 4/4/2014 | 4.26 | 2.12 - 8.56 | |
| NC 1 | 2/3/2014 | 29.78 | 17.71 - 49.90 | N/A |
| NC 2 | 2/4/2014 | 56.94 | 40.04 - 80.64 | N/A |
| NC 3 | 4/4/2014 | 31.50 | 21.54 - 46.06 | N/A |

Table 13. Geometric Mean Concentrations for Acetone Container Experiment by Monitoring Date and Systems

| Acetone Bowl | | | | %Capture Efficiency |
|------------------|----------|----------------------|--------------------------|---------------------|
| Systems/Run | Date | Geometric Mean (ppm) | 95% Conf. Interval (ppm) | |
| Allerair 1 | 2/3/2014 | 9.00 | 7.89 - 10.26 | 97 |
| Allerair 2 | 4/4/2014 | 1.83 | 1.75 - 1.90 | |
| Weller FT 1 | 2/3/2014 | 3.97 | 3.75 - 4.20 | 98 |
| Weller FT 2 | 4/4/2014 | 1.67 | 1.49 - 1.86 | |
| Air Impurities 1 | 2/4/2014 | 1.11 | 0.92 - 1.35 | 98 |
| Air Impurities 2 | 4/4/2014 | 2.02 | 1.88 - 2.18 | |
| Healthy Air 1 | 2/3/2014 | 14.25 | 13.87 - 14.59 | 92 |
| Healthy Air 2 | 4/4/2014 | 5.75 | 5.53 - 5.99 | |
| NC 1 | 2/3/2014 | 332.29 | 304.90 - 360.32 | N/A |
| NC 2 | 2/4/2014 | 180.73 | 167.00 - 195.78 | N/A |
| NC 3 | 4/4/2014 | 52.77 | 48.42 - 57.40 | N/A |

Temporal variability in acetone exposure is illustrated in Figure 24 for both experiments by only showing the “no control” condition.

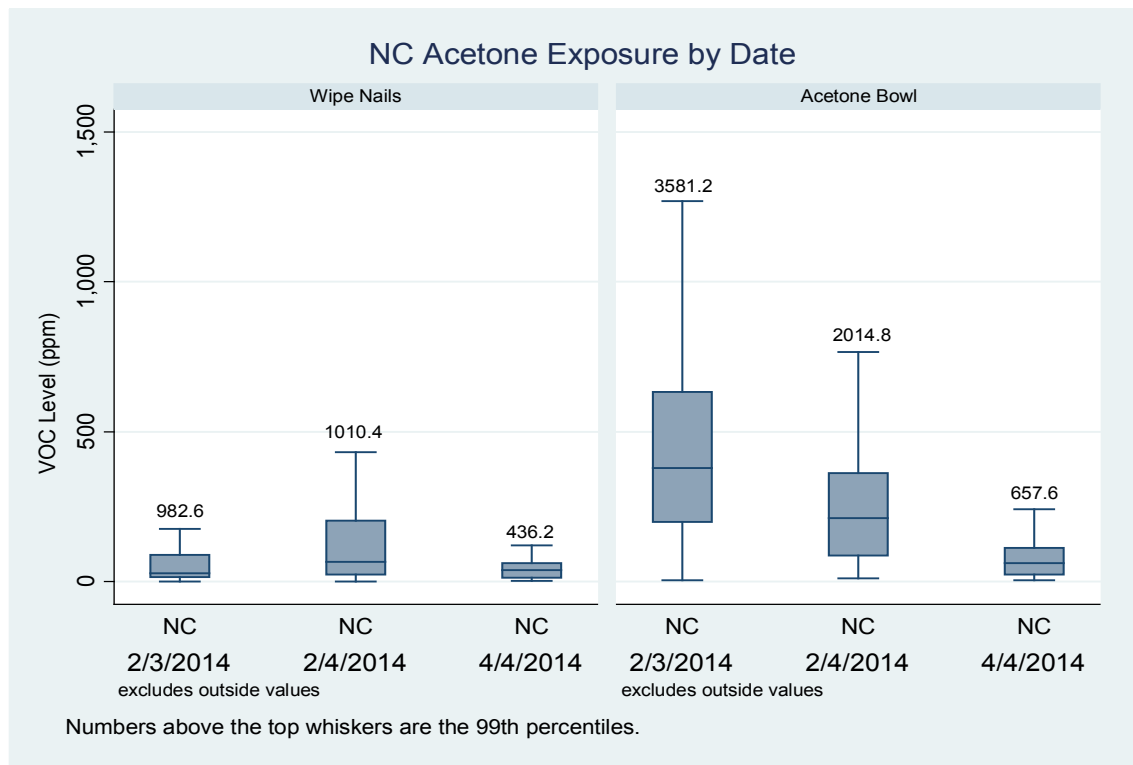


Figure 24 . Comparison of NC Acetone Exposures by Date

Comparison of LEV Systems with and without NC

Use of each LEV system resulted in significantly lower acetone exposures compared to the “no control” condition (Figure 25).

All LEV systems performed efficiently to minimize the acetone exposures, however; the ANOVA indicated a significant difference with a p-value<0.001. Similar to the dust box plots, the outliers are excluded from the figures but not from the data calculations. Though, the 99th percentiles are shown on the upper whiskers to represent the distribution upper bound (Figure 26).

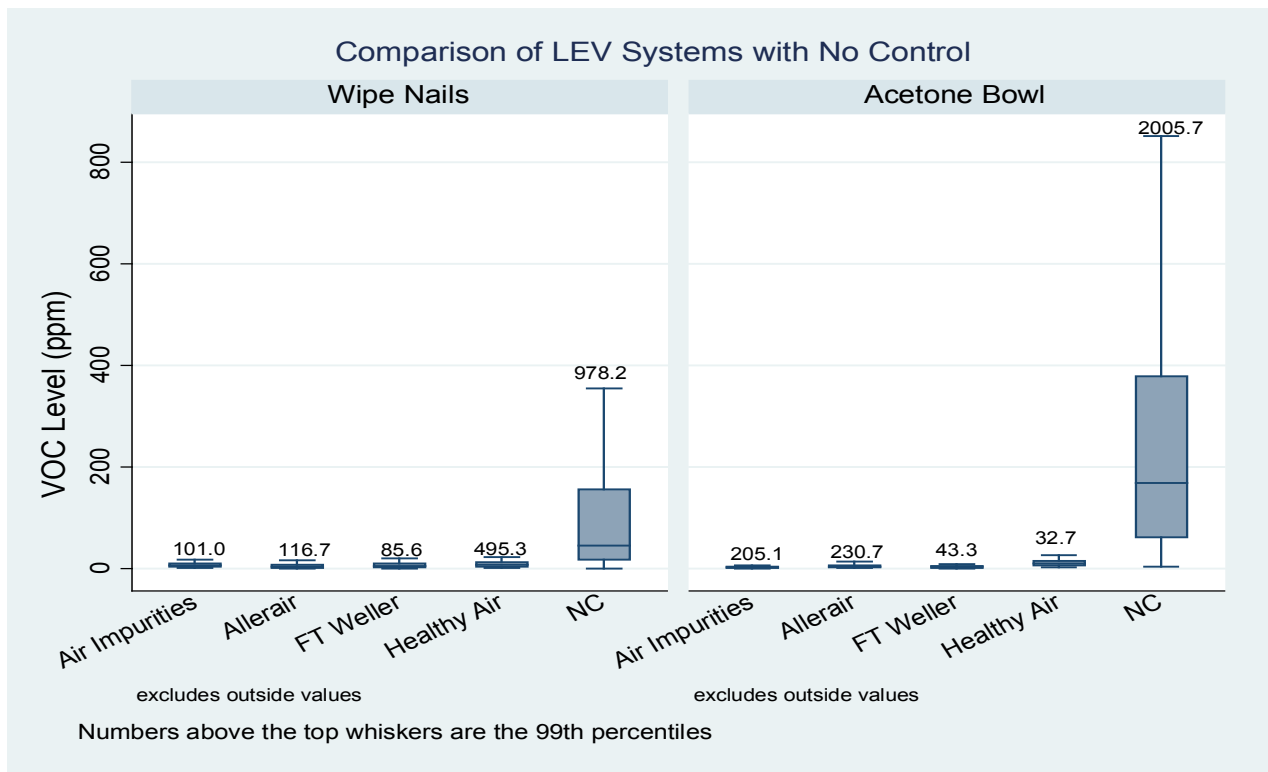


Figure 25. Comparison of Systems with NC

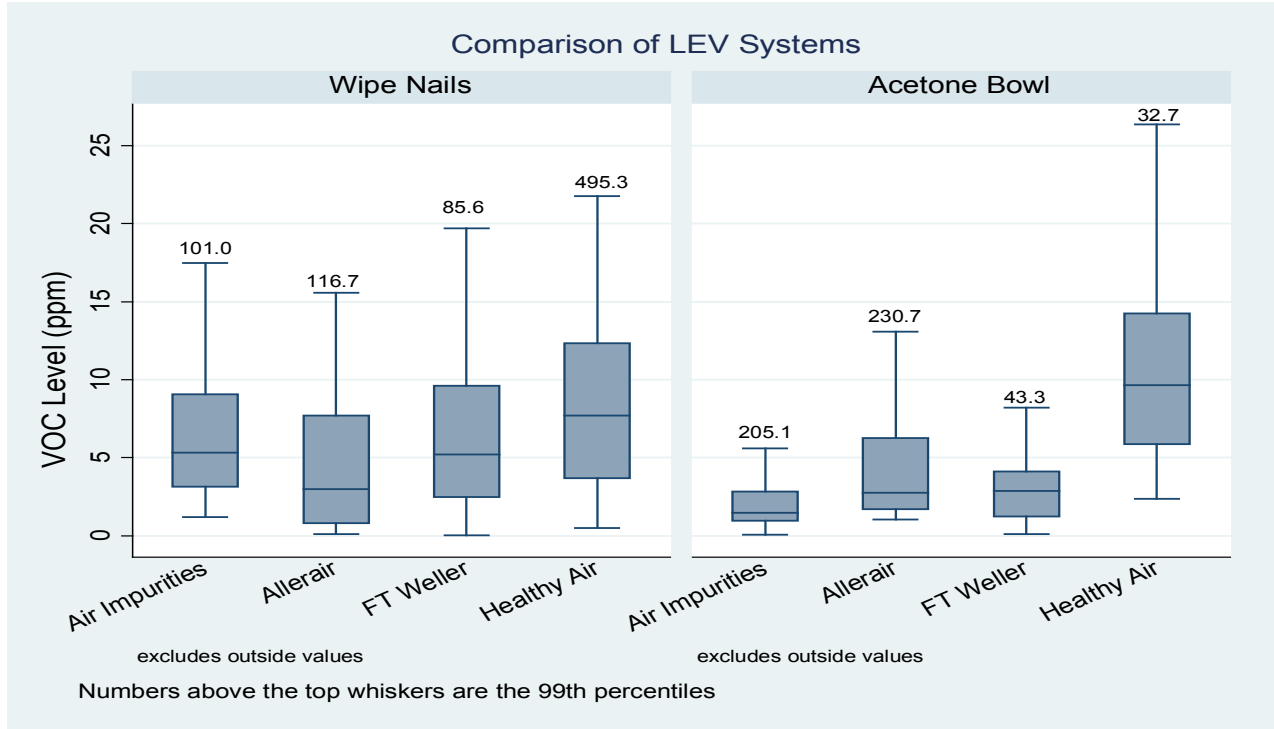


Figure 26 . Comparison of Systems without NC

Comparison of Acetone Exposure between Conditions by Date and Experiment

Acetone exposures were averaged over all LEV systems and then compared to the average exposures of NC condition for each experiment and monitoring day. The geometric means and 95% confidence intervals are summarized in Table 14.

Table 14. Comparison of Acetone Exposure between Conditions and Days

| Wipe Nails Experiment | | | | | | |
|---|----------|-------------|----------|-------------|----------|------------|
| Monitoring Data | 2/3/2014 | | 2/4/2014 | | 4/4/2014 | |
| Scenario | Control | No Control | Control | No Control | Control | No Control |
| Geometric Mean ($\mu\text{g}/\text{m}^3$) | 4.6 | 29.7 | 4.7 | 56.8 | 3.4 | 31.5 |
| 95% CI ($\mu\text{g}/\text{m}^3$) | 3.5-6.1 | 17.7-49.9 | 3.9-5.6 | 40.0-80.6 | 2.5-4.7 | 21.5-46.1 |
| Acetone Bowl Experiment | | | | | | |
| Monitoring Data | 2/3/2014 | | 2/4/2014 | | 4/4/2014 | |
| Scenario | Control | No Control | Control | No Control | Control | No Control |
| Geometric Mean ($\mu\text{g}/\text{m}^3$) | 7.8 | 332.3 | 1.1 | 180.9 | 2.4 | 52.8 |
| 95% CI ($\mu\text{g}/\text{m}^3$) | 7.4-8.3 | 304.9-360.5 | 0.9-1.3 | 167.0-195.8 | 2.3-2.6 | 48.4-57.4 |

A side by side comparison between control and no control conditions based on the acetone exposure can be seen in Figure 27 while the blue and red plots represent the control and no control conditions, correspondingly. The first set of plots is for the nail wiping experiment and the second set is the acetone bowl experiment. These data show the temporal variation in exposure measurements.

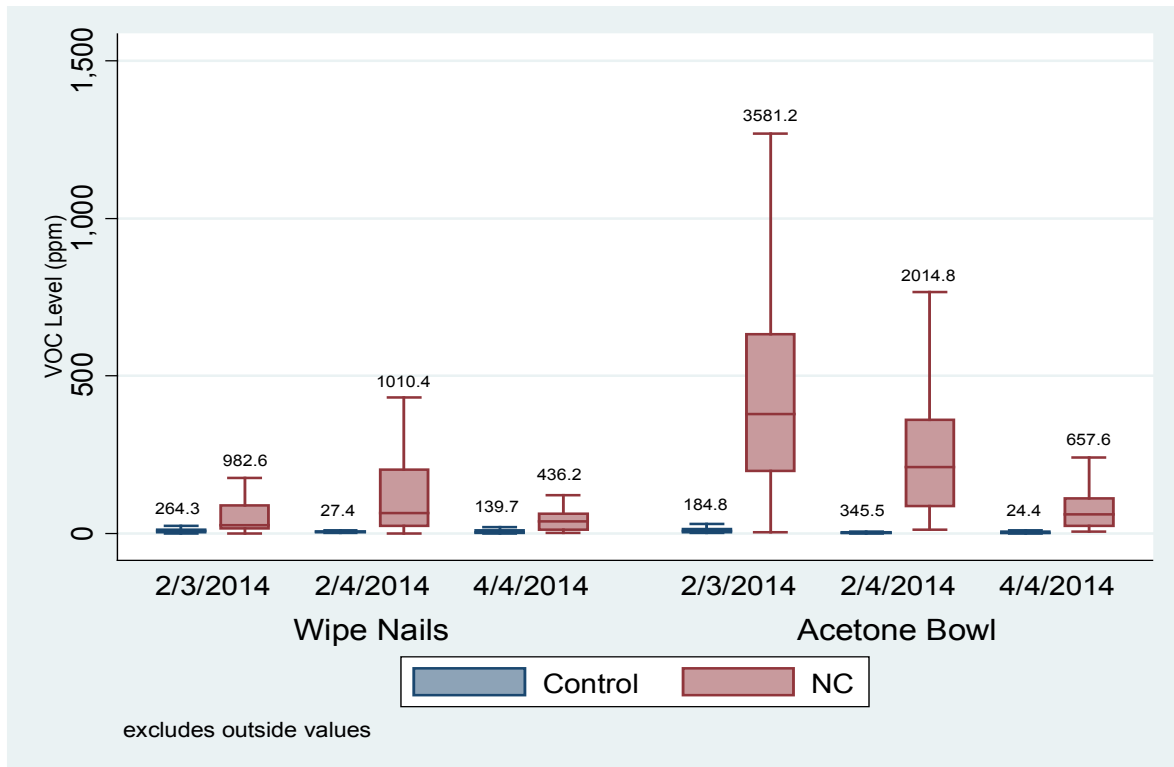


Figure 27. Comparison of Acetone Exposures between Conditions and Days

Percent Capture Efficiency

LEV systems' dust and VOC capture efficiencies are listed in table 15. The efficiencies were averaged over all systems for each experiment. The average VOC capture efficiency of all systems is calculated as 83% and 96% for nail wiping and acetone container experiments,

respectively. The average dust exposure of all LEV systems is reported as 77%. Overall, all systems performed well in removing dust and acetone from the technician’s breathing zone when comparing to the “no control” scenario (Table 15).

Table 15. Capture Efficiency of LEV Systems at Breathing Zone

| Unit | %Capture Efficiency at breathing zone | | |
|---------------------------|--|------------------------|------|
| | Wiping nails with cotton ball saturated with acetone | Open Acetone Container | Dust |
| Healthy Air | 77 | 92 | 71 |
| Allerair | 93 | 97 | 90 |
| Weller FT | 83 | 98 | 80 |
| Air Impurities | 80 | 98 | 67 |
| Average | 83 | 96 | 77 |
| Standard Deviation | 7 | 3 | 10 |

Overall Systems’ Efficiency (Static Exposure Chamber Test)

Decay Rate of Acetone and Clean Air Delivery Rate

To obtain the natural decay rate, k_n , for the test chamber, we measured the decay rate of acetone when there was a no LEV system in place. As Figure 28 represents, the concentrations were log transformed and a linear regression of the concentration over time was conducted. According to equation [3], the test chamber decay rate was very low, 0.00006 s^{-1} , demonstrating a relatively tight seal of the chamber. This value is used to help calculate the system’s CADR values using equation [4].

The CADR values presented in Table 16 in both (ft^3/min) and (m^3/sec) units. This is a measure of filter efficiency and flow rate, in combination. The air decay rates are also graphically presented in Figure 28 for the first of the three trials for each of the LEV systems.

The decay rates were only measured at the highest LEV setting. As indicated in Figure 28, Air Impurities has the highest CADR value due to the steepest decay slope.

Table 16. Clean Air Delivery Rates

| Unit | Clean Air Delivery Rate (ft ³ /min) | Clean Air Delivery Rate (m ³ /sec) |
|----------------|--|---|
| Healthy Air | 77.8 | 0.0367 |
| Allerair | 66.7 | 0.0315 |
| Weller FT | 56.5 | 0.0267 |
| Air Impurities | 125.5 | 0.0592 |

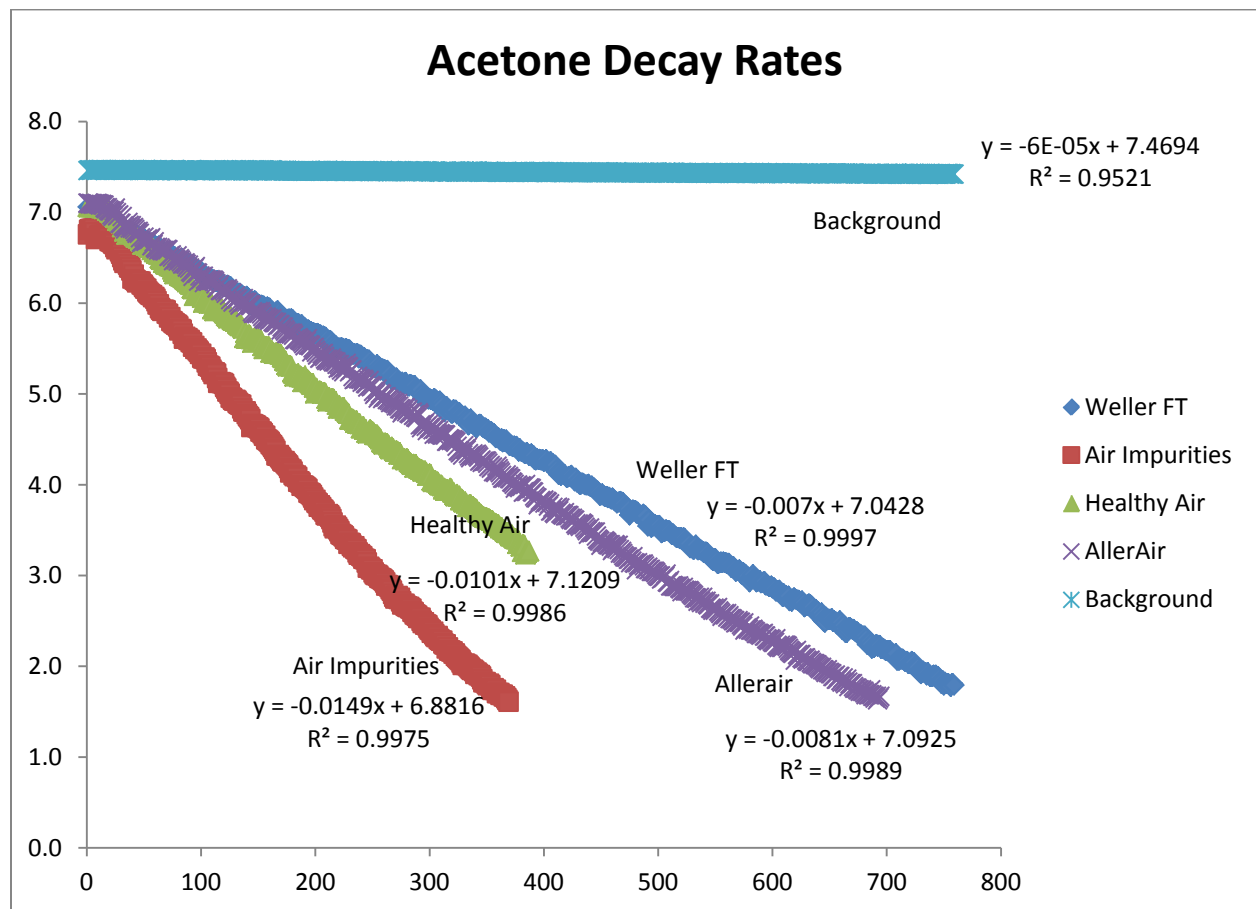


Figure 28. Decay Rates for LEVs and NC Scenarios

Percent Difference between Pitot-based Flow and CADR Estimates

The CADR value can be considered as a flow rate and compared to the pilot tube-based flow measurements. The CADR estimates of flow rates are higher than the flows measured by the pitot tube. The percent differences between CADR estimates and pitot-based flow rates were calculated using equation [5] and presented in Tables 17-20 for each system. Air Impurities has the highest percent difference and Healthy Air has the lowest.

Flow Rates Comparison

Table 17. Allerair Decay- and Pitot-based Flow Rates

| Allerair | | |
|--------------|--|---|
| | (m ³ /sec) | (m ³ /sec) |
| Trial | Decay Based Flow | Pitot Based Flow |
| 1 | 0.032 | 0.023 (49.2 ft ³ /min) |
| 2 | 0.032 | |
| 3 | 0.032 | |
| Average | 0.032 (67.8 ft³/min) | |
| Stdev. | 0.000 | |
| % Difference | 39% | |

Table 18. Weller FT Decay- and Pitot-based Flow

| Weller FT | | |
|--------------|--|---|
| | (m ³ /sec) | (m ³ /sec) |
| Trial | Decay Based Flow | Pitot Based Flow |
| 1 | 0.028 | 0.023 (47.7 ft ³ /min) |
| 2 | 0.028 | |
| 3 | 0.027 | |
| Average | 0.027 (52.7 ft³/min) | |
| Stdev. | 0.000 | |
| % Difference | 17% | |

Table 19. Air Impurities Decay- and Pitot-based Flow

| Air Impurities | | |
|----------------|---------------------------------------|---|
| | m ³ /sec | m ³ /sec |
| Trial | Decay Based Flow | Pitot Based Flow |
| 1 | 0.060 | 0.036 (77.1 ft ³ /min) |
| 2 | 0.061 | |
| 3 | 0.060 | |
| Average | 0.060 (127 ft³/min) | |
| Stdev | 0.001 | |
| % Difference | 67% | |

Table 20. Healthy Air Decay- and Pitot-based Flow Rates

| Healthy Air | | |
|--------------|--|---|
| | m ³ /sec | m ³ /sec |
| Trial | Decay Based Flow | Pitot Based Flow |
| 1 | 0.040 | 0.035 (73.5 ft ³ /min) |
| 2 | 0.038 | |
| 3 | 0.034 | |
| Average | 0.038 (80.2 ft³/min) | |
| Stdev | 0.003 | |
| % Difference | 8.6% | |

The LEV systems were ranked based on the physical characteristics and capture efficiencies (Table 21). Rank number one indicates the best performance. For noise, the lowest level is the best performer, while for the capture velocity and capture efficiencies the highest values are ranked first.

Table 21. Ranking of LEV Systems' Measurements

| Rank | V_{Capture}^a at 12.5 cm from inlet (High Setting) | Noise Level^b (High Setting) | Acetone Capture Efficiency^c (Nail Wiping) (High Setting) | Dust Capture Efficiency^d (High Setting) |
|-------------|---|---|--|---|
| 1 | Healthy Air | Weller FT | Allerair | Allerair |
| 2 | Air Impurities | Air Impurities | Weller FT | Weller FT |
| 3 | Allerair | Allerair | Air Impurities | Healthy Air |
| 4 | Weller FT | Healthy Air | Healthy Air | Air Impurities |

^aThe higher capture velocity is better

^bThe lower noise level is better

^cThe higher capture efficiency is better

^dThe higher capture efficiency is better

Discussion

Physical Characteristics

All measured flow rates were found to be lower than the flow rates specified by the manufactures for Allerair, Air Impurities, and Healthy Air Systems. No information was provided on flow rate of the Weller FT system by the manufacturer to compare with our measured flow rate. The difference in flow rates is likely a result of different measurements techniques, setups, or conditions including measuring the flow directly into the blower without any other components (such as filters) upstream rather than measurement at the inlet or in the tube.

Performing the nail treatments within 4-5 inches from the inlet is recommended for all systems at their high settings to meet the minimum required capture velocity of 100 ft/min criteria set by IAPA.

The inlet geometry plays a key role in dictating the face velocity of the systems and it is reduced as the inlet area increases at a constant flow rate. To illustrate, Allerair and Weller FT exhibit similar flow rates but the face velocity of Allerair is notably higher than Weller FT's due to the different inlet geometry and area. A system with a larger inlet will have a lower face velocity, but may be able to impact a larger area around the inlet.

The noise level measured for Weller FT at approximately 59 dBA was slightly higher than the manufacturer's specification of 50 dBA. The noise level for Healthy Air system was rated between 51-56 dBA by the manufacturer; however, our measurements indicated a range of 61-71 dBA for that system. The difference in levels could be due to the distance from source

where the measurements taken. The measurement distance has not been specified by the Healthy Air manufacturer. Our noise level for the Air Impurities system was slightly higher than the manufacturer's specifics (58-60 dBA). However, we took all the measurements at one meter from the system at its high setting, while Air Impurities measured them at approximately two meters from the source at low setting. The noise level decreases as the distance increases from the source. No information was provided on noise level of the Allerair system by the manufacturer.

System's Efficiency at Breathing Zone

Dust

Exposures with LEV systems were significantly lower than the "no control" levels. The dust exposure reductions ranged between 77 and 93%, as compared to the "no control" condition. Statistical analysis of dust exposures exhibited a significant temporal variation for each system. In other words, comparing the geometric mean concentrations of dust, the LEV systems either acted differently, the source strength differed, or the transport mechanisms differed on each experimental day (p-value<0.001). No relationship between temperature and relative humidity were observed. Other factors that have not been measured may also have played a role (e.g. the technician distance from the table, whether the technician leaning more or less towards the table, or the exact tube location in the breathing zone). Although both system performance and day effect contributed to the variability of the dust level, the day effect contribution was greater than the system effect, according to the statistical analysis results.

In general, the measured dust levels from grinding on nails were relatively low for all systems including NC conditions. Using a photometric, semi-quantitative, real-time method to

measure the dust exposures at relatively low levels, may have introduced variability in the measurements due to monitoring close to the instrument's limit of detection. Because our final measure, collection efficiency, is a relative term, bias, if present, would be reduced. The instrument is only sensitive to particles between 0.1 μm and 10 μm ; therefore, we would expect low levels of dust due to the nature of the source, grinding, which would tend to produce more coarse particles. However, taking this into account, the dust level varied from system to system and from systems to "no control" conditions. As stated, no other studies have been conducted to evaluate the dust level in nail salons or for nail grinding process; therefore, we were unable to compare the dust exposures to the similar exposures.

Acetone

Acetone exposures were substantially lower for the LEV systems compared to NC condition, with capture efficiencies ranging from 77% to 98% for the different systems and an average of 90%. The average acetone exposure in our experiments ranged between 454 ppm and 540 ppm with no controls averaged over 10 minutes, which is notably higher than 8-hr time weighted average (TWA) acetone exposure (~ 16 ppm) measured in nail salons in Boston. However, our measurements were task based and not for a full working shift and we employed a different measurement technique (PID and not the colorimetric tubes). Our task-based acetone exposures were well below the OSHA permissible exposure limit (PEL) of 1000 ppm for an 8-hr TWA.

Day to day variation in the mean acetone concentrations was observed for each system and experiment including the "no control" scenario. Accounting for the day variation, the p-value was statistically insignificant for nail wiping experiment (p-value=0.0732) and significant

for the second condition (p -values <0.001). The difference in the mean concentrations by monitoring days could be explained by the source strength, the transport of contaminant to the sampling inlet, or performance of the systems.

The statistical model suggested less variability due to the day effect and more due to the system effect for nail wiping experiment. However, for the acetone bowl experiment, both day and system effects were significantly contributing with greater variability due to the day effect. The opposite trends for the experiments could be due to the type of activity (nail wiping vs. acetone bowl).

The between systems variability was statistically significant for both experiments (p -values <0.001) indicating that at least one system acted differently from the others.

Overall Systems Efficiency

As part of this study, the clean air delivery rate (CADR) was computed to evaluate the volume of fresh air delivered to the room by each system. The CADR value is a measure of flow rate and filter collection efficiency in conjunction.

Air leakage was the likely cause of the greater decay-based flow (or CADR estimate) than the pitot-based flow for the Allerair and Air Impurities systems. Measuring air flow at the inlet using a pitot-tube does not account for upstream air leaks. Air could leak into the system from the top lid/metal-plastic connections (i.e. bolts), or due to the improper seals particularly around the carbon filtration unit. This would allow air entering the system and filtration media without entering the system's inlet. The decay-based flow rate increases as more air leaks into the system. If a filter bed reaches its maximum capacity or there is a leakage around the bed, then the CADR value would become smaller than the pitot-based flow rate. However, the CADR

value could vary in favor of either air leakage into the system or the filter capacity maxed out, or both, though given the distinct exponential decrease in the acetone concentration, it is unlikely that the beds were saturated.

Similar to the pitot-based flow, the CADR value is the highest for Air Impurity and the lowest for Weller FT. However, that might not be the case in a realistic condition since the CADR values were evaluated in a perfectly isolated well mixed environment.

Conclusions

This study examined the effectiveness of four commercially available local exhaust ventilation systems at reducing the dust and VOC exposures in nail salons. The efficiency of the systems were evaluated by two different methods: One, the efficiency of the systems at the technician's breathing zone, and two, the overall efficiency of the systems in a static exposure chamber. Results showed that the dust and VOC exposures could be significantly decreased in a nail technician's breathing zone by the LEV systems. Depending on the system, the particle capture efficiency ranged between 67 and 90% compared with NC condition. Similarly, the VOC exposures were reduced between 77 and 98% using the LEV systems for both nail wiping and acetone bowl experiments.

The systems' overall efficiencies were presented by clean air delivery rate (CADR) values which are a measure of filter collection efficiencies and flow rates in combination.

The flow rates have been estimated by two different techniques: One, pitot tube measurements in the tube near the inlet and two, in the exposure chamber using the decay rates. The flow rates were observed to be higher using the decay rate method than the pitot tube method, which indicates potential air leakage into blower.

As part of this study, each system was characterized for its physical attributes including flow rate, capture and face velocity, as well as personal noise level. The noise level for all systems was below the OSHA PEL of 90 dBA for an 8-hr TWA exposure. Although the LEV systems exhibited different physical characteristics including the velocities and flow rates, they all were effectively capable of reducing the dust and chemical exposures.

These LEV systems were not designed to exhaust air outdoors and it can be counted as one of their usability limitations. As a result, the contaminants can be recirculated back into the salons if the filter capacity is maxed out. Also, these systems may not be in accordance with WA state building code due to the lack of outdoor exhausting of the systems.

Nail salon technicians may be exposed to volatile organic compounds or dust at levels that can cause symptoms or discomfort. The exposures may be affected by the frequency of treatments, chemical applications, and the number and type of chemicals/solvents are being used in the salon. Symptoms associated with the various compounds in nail salons include irritation to eyes and nose, headache, dizziness, drowsiness, etc. The LEV systems may help in minimizing these exposures and related health risks. However, systems' efficiencies greatly depend on the correct application of the systems, distance of the task/nail treatment to the inlet, the path of the flexible arm, system's fan setting, and filter capacity/longevity.

References

- Air Impurities Removal Systems. (2013). Salon Pure Air. Oct 5, 2013, from <http://www.airsystems-inc.com/products/salon-pure-air/>
- Alaves, V. M., Sleeth, D. K., Thiese, M. S., & Larson, R. R. (2013). Characterization of indoor air contaminants in a randomly selected set of commercial nail salons in Salt Lake County, Utah, USA. *Int J Environ Health Res*, 23(5), 419-433. doi: 10.1080/09603123.2012.755152
- Allerair. (2011). Allerair Air Purifiers for Beauty Salons and Spas. Retrieved Nov 2, 2013, from http://www.electrocorp.net/beauty_salons_and_spas.php
- American Conference of Governmental Industrial Hygienists. (2007). *Industrial Ventilation A Manual of Recommended Practice for Design* (ACGIH 26 ed.). Cincinnati Ohio: Signature Publications.
- Antonchuk, O. (2008). *Evaluation of Local Exhaust Ventilation for Welding*. (Master of Science), University of Washington. Retrieved from http://books.google.com/books/about/Evaluation_of_Local_Exhaust_Ventilation.html?id=uG3jPgAACAAJ
- ASHRAE. (2003). *Ventilation for Acceptable Indoor Air Quality*. Atlanta, GA: ASHRAE/ANSI.
- Berens, R. J., & Weigle, C. G. (1995). Noise measurements during high-frequency oscillatory and conventional mechanical ventilation. *Chest*, 108(4), 1026-1029.
- City of Seattle. (2006). 2006 Seattle Mechanical Code. Retrieved March 29, 2014, from http://www2.iccsafe.org/states/seattle2006/seattle_mechanical/mechanical_frameset.htm
- City of Seattle. (2009). 2009 Seattle Mechanical Code. Retrieved June 10, 2014, from http://www.seattle.gov/dpd/cs/groups/pan/@pan/documents/web_informational/s048010.pdf
- Environmental Protection Agency. (2005). EPA Aims to Lessen Potential Chemical Risks to Vietnamese Nail Salon Workers at July 17 Workshop. Retrieved May 2014, from <http://yosemite.epa.gov/opa/admpress.nsf/90829d899627a1d98525735900400c2b/f2001a81d72d0425852570d60070ff4d!opendocument>
- Environmental Protection Agency. (2007). Protecting the Health of Nail Salon Workers. Retrieved April 2014, 2014, from <http://www.epa.gov/dfe/pubs/projects/salon/nailsalonguide.pdf>
- Fields, L. (2014). Artificial Nails: Acrylics, Gels, and Silks. Retrieved May 20, 2014, from <http://www.webmd.com/beauty/nails/artificial-nails-acrylics-gels-silks>

- Goldin, L. J., Ansher, L., Berlin, A., Cheng, J., Kanopkin, D., Khazan, A., . . . Allen, J. G. (2014). Indoor air quality survey of nail salons in Boston. *J Immigr Minor Health, 16*(3), 508-514. doi: 10.1007/s10903-013-9856-y
- Harris-Roberts, J., Bowen, J., Sumner, J., Stocks-Greaves, M., Bradshaw, L., Fishwick, D., & Barber, C. M. (2011). Work-related symptoms in nail salon technicians. *Occup Med (Lond), 61*(5), 335-340. doi: 10.1093/occmed/kqr096
- Healthy Air. Source Capture Ventilation System for Nail Salons. Retrieved Oct 3, 2013, from http://aerovexsystems.com/images/uploads/files/Nail_Source.pdf
- Industrial Accident Prevention Association. (2006). Ventilation. Retrieved February 9, 2014, from http://www.iapa.ca/pdf/2003_feb_Ventilation.pdf
- King County Local Hazardous Waste Management. Healthy Nail Salons. Retrieved Sep 20, 2013, from <http://www.lhwmp.org/home/health/nail-salons.aspx>
- LoSasso, G. L., Rapport, L. J., & Axelrod, B. N. (2001). Neuropsychological symptoms associated with low-level exposure to solvents and (meth)acrylates among nail technicians. *Neuropsychiatry Neuropsychol Behav Neurol, 14*(3), 183-189.
- LoSasso, G. L., Rapport, L. J., Axelrod, B. N., & Whitman, R. D. (2002). Neurocognitive sequelae of exposure to organic solvents and (meth)acrylates among nail-studio technicians. *Neuropsychiatry Neuropsychol Behav Neurol, 15*(1), 44-55.
- Marlow, D. A., Looney, T., & Reutman, S. (2012). An Evaluation of Local Exhaust Ventilation Systems for Controlling Hazardous Exposures in Nail Salons: CDC/NIOSH.
- Marty, A. (2007). *Ethyl Methacrylate and Methyl Methacrylate Exposure among Fingernail Sculptors*. (Master of Science), University of South Florida, University of South Florida, Scholar Commons Retrieved from <http://scholarcommons.usf.edu/etd/2278/> (2278)
- Nail Magazine. (2012-2013). 2012-2013 Nail Industry Statistics. Retrieved May 11, 2014, from <http://files.nailsmag.com/Market-Research/NAILSbb12-13stats.pdf>
- Nail Manufacturers Council. Nail Salon Workers: Health and Safety, Working Conditions, Compensation, and Demographics. Retrieved May 10, 2014, from <http://www.probeauty.org/docs/nmc/NailSalonWorkerSafety.pdf>
- Naiouk (2011a). Beginners Guide to Acrylic Nails. Retrieved Sep 29, 2013, from <https://www.youtube.com/watch?v=-4gdLcqRISg>
- Naiouk. (2011b). How to Remove Acrylic Nails Tutorial Video by Naio Nails. Retrieved Oct 2, 2013, from <https://www.youtube.com/watch?v=75S-1659B3s>
- Naiouk. (2011c). Infill an Acrylic Nail Tutorial Video by Naio Nails. Retrieved September 23, 2013, from <https://www.youtube.com/watch?v=eRXTmilcyic>

- Naiouk. (2012). Stunning Leopard and Tiger Print Acrylic Nail Tutorial by Naio Nails. Retrieved Oct 9, 2013, from <https://www.youtube.com/watch?v=H79Criw-uAU>
- Occupational Safety and Health Administration. Health Hazards in Nail Salons. Retrieved April 24, 2014, 2014, from <https://www.osha.gov/SLTC/nailsalons/chemicalhazards.html>
- OSHA. (1999). Ventilation Investigation. Retrieved March 26, 2014, from https://www.osha.gov/dts/osta/otm/otm_iii/otm_iii_3.html#3
- Quach, T., Gunier, R., Tran, A., Von Behren, J., Doan-Billings, P. A., Nguyen, K. D., . . . Reynolds, P. (2011). Characterizing workplace exposures in Vietnamese women working in California nail salons. *Am J Public Health, 101 Suppl 1*, S271-276. doi: 10.2105/ajph.2010.300099
- RAE Inc. (2005). Mini RAE 2000 Portable VOC Monitor PGM-7600. Retrieved Oct 2, 2013, from http://www.equipcoservices.com/pdf/manuals/rae_minirae_2000.pdf
- Ramona, S. (2006). Test Method for Rating Performance of Portable Room Air Cleaners. Washington DC: ANSI/AHAM.
- Rock, T. (2010). Acrylic Nail Application Process. Retrieved May 25, 2014, from <http://acrylicnailsonline.com/the-process-of-acrylic-application/>
- Roelofs, C., Azaroff, L. S., Holcroft, C., Nguyen, H., & Doan, T. (2008). Results from a community-based occupational health survey of Vietnamese-American nail salon workers. *J Immigr Minor Health, 10*(4), 353-361. doi: 10.1007/s10903-007-9084-4
- Spencer, A. B., Estill, C. F., McCammon, J. B., Mickelsen, R. L., & Johnston, O. E. (1997). Control of ethyl methacrylate exposures during the application of artificial fingernails. *Am Ind Hyg Assoc J, 58*(3), 214-218. doi: 10.1080/15428119791012865
- Tsigonia, A., Lagoudi, A., Chandrinou, S., Linos, A., Evlogias, N., & Alexopoulos, E. C. (2010). Indoor air in beauty salons and occupational health exposure of cosmetologists to chemical substances. *Int J Environ Res Public Health, 7*(1), 314-324. doi: 10.3390/ijerph7010314
- Weller FT. (2012). Weller FT Beauty Line Products. Retrieved October 3, 2013, from <http://wellerft.com/beauty-line-products.aspx>
- Williams, L. Choosing Between Gel Nails and Acrylic Nails. Retrieved May 15, 2014, 2014, from http://skincare.lovetoknow.com/Gel_Nails_Acrylic_Nails
- Yu, K. P., Lee, G. W., Huang, W. M., Wu, C. C., Lou, C. L., & Yang, S. (2006). Effectiveness of photocatalytic filter for removing volatile organic compounds in the heating, ventilation, and air conditioning system. *J Air Waste Manag Assoc, 56*(5), 666-674.

Appendices

Appendix I

Allerair Flow Rate Measurements

Table 22. Allerair High Setting Tube Velocity and Flow Rate Measurements

| Allerair High Setting Pitot-tube Velocity Measurements | | | | |
|---|---------------------------------------|---------------|--------------------|-------------------|
| Velocity Measurements in Y-direction (ft/min) | | | | |
| Traverse Points | Run 1 | Run 2 | Run Average | Run Stdev |
| 1st | 1864 | 1878 | 1871 | 10 |
| 2nd | 1956 | 2213 | 2085 | 182 |
| 3rd | 2483 | 2394 | 2439 | 63 |
| 4th | 2070 | 1975 | 2023 | 67 |
| Average Velocity | | | 2104 | |
| STDEV | | | 240 | |
| Velocity Measurements in X-direction (ft/min) | | | | |
| Traverse Points | Run 1 | Run 2 | Run Average | Run Stdev. |
| 1st | 2165 | 2101 | 2133 | 45 |
| 2nd | 2473 | 2468 | 2471 | 4 |
| 3rd | 2304 | 2428 | 2366 | 88 |
| 4th | 1829 | 1752 | 1791 | 54 |
| Average Velocity | | | 2190 | |
| STDEV | | | 301 | |
| | Average of X and Y | 2147 | | |
| | Pipe Area (ft²) | 0.0228 | | |
| | Flow Rate (ft³/min) | 49.1 | | |

Table 23. Allair Medium Setting Tube Velocity and Flow Rate Measurements

| Allair Medium Setting Pitot-tube Velocity Measurements | | | | |
|---|--|---------------|--------------------|-------------------|
| | Velocity Measurements in Y-direction (ft/min) | | | |
| Traverse Points | Run 1 | Run 2 | Run Average | Run Stdev. |
| 1st | 1644 | 1658 | 1651 | 10 |
| 2nd | 1918 | 1928 | 1923 | 7 |
| 3rd | 1967 | 1981 | 1974 | 10 |
| 4th | 1628 | 1583 | 1606 | 32 |
| Average Velocity | | | 1788 | |
| STDEV | | | 187 | |
| | | | | |
| | Velocity Measurements in X-direction (ft/min) | | | |
| Traverse Points | Run 1 | Run 2 | Run Average | Run Stdev. |
| 1st | 1886 | 1650 | 1768 | 167 |
| 2nd | 2018 | 2032 | 2025 | 10 |
| 3rd | 1853 | 1865 | 1859 | 8 |
| 4th | 1527 | 1592 | 1560 | 46 |
| Average Velocity | | | 1803 | |
| STDEV | | | 194 | |
| | | | | |
| | Average of X and Y | 1796 | | |
| | Pipe Area (ft²) | 0.0228 | | |
| | Flow Rate (ft³/min) | 40.9 | | |

Table 24. Allerair Low Setting Tube Velocity and Flow Rate Measurements

| Allerair Low Setting Pitot-tube Velocity Measurements | | | | |
|--|--|---------------|--------------------|-------------------|
| | Velocity Measurements in Y-direction (ft/min) | | | |
| Traverse Points | Run 1 | Run 2 | Run Average | Run Stdev. |
| 1st | 1042 | 1093 | 1068 | 36 |
| 2nd | 1191 | 1202 | 1197 | 8 |
| 3rd | 1284 | 1201 | 1243 | 59 |
| 4th | 1083 | 1060 | 1072 | 16 |
| Average Velocity | | | 1145 | |
| STDEV | | | 89 | |
| | | | | |
| | Velocity Measurements in X-direction (ft/min) | | | |
| Traverse Points | Run 1 | Run 2 | Run Average | Run Stdev. |
| 1st | 1020 | 1028 | 1024 | 6 |
| 2nd | 1347 | 1329 | 1338 | 13 |
| 3rd | 1289 | 1199 | 1244 | 64 |
| 4th | 1011 | 905 | 958 | 75 |
| Average Velocity | | | 1141 | |
| STDEV | | | 179 | |
| | | | | |
| | Average of X and Y | 1143 | | |
| | Pipe Area (ft²) | 0.0228 | | |
| | Flow Rate (ft³/min) | 26.1 | | |

Weller FT Flow Rate Measurements

Table 25. Weller FT High Setting Tube Velocity and Flow Rate Measurements

| Weller FT High Setting Pitot-tube Velocity Measurements | | | | |
|--|--|---------------|--------------------|-------------------|
| | Velocity Measurements in Y-direction (ft/min) | | | |
| Traverse Points | Run 1 | Run 2 | Run Average | Run Stdev. |
| 1st | 1941 | 1945 | 1943 | 3 |
| 2nd | 2034 | 2019 | 2027 | 11 |
| 3rd | 2297 | 2203 | 2250 | 66 |
| 4th | 1950 | 1852 | 1901 | 69 |
| Average Velocity | | | 2030 | |
| STDEV | | | 156 | |
| | | | | |
| | Velocity Measurements in X-direction (ft/min) | | | |
| Traverse Points | Run 1 | Run 2 | Run Average | Run Stdev. |
| 1st | 2170 | 2165 | 2168 | 4 |
| 2nd | 2322 | 2331 | 2327 | 6 |
| 3rd | 2356 | 2279 | 2318 | 54 |
| 4th | 1766 | 1797 | 1782 | 22 |
| Average Velocity | | | 2148 | |
| STDEV | | | 255 | |
| | | | | |
| | Average of X and Y | 2089 | | |
| | Pipe Area (ft²) | 0.0228 | | |
| | Flow Rate (ft³/min) | 47.6 | | |

Table 26. Weller FT Low Setting Tube Velocity and Flow Rate Measurements

| Weller FT Low Setting Pitot-tube Velocity Measurements | | | | |
|---|---------------------------------------|---------------|--------------------|-------------------|
| Velocity Measurements in Y-direction (ft/min) | | | | |
| Traverse Points | Run 1 | Run 2 | Run Average | Run Stdev. |
| 1st | 558 | 537 | 548 | 15 |
| 2nd | 519 | 575 | 547 | 40 |
| 3rd | 595 | 562 | 579 | 23 |
| 4th | 440 | 430 | 435 | 7 |
| Average Velocity | | | 527 | |
| STDEV | | | 63 | |
| Velocity Measurements in X-direction (ft/min) | | | | |
| Traverse Points | Run 1 | Run 2 | Run Average | Run Stdev. |
| 1st | 509 | 572 | 541 | 45 |
| 2nd | 577 | 608 | 593 | 22 |
| 3rd | 575 | 561 | 568 | 10 |
| 4th | 408 | 443 | 426 | 25 |
| Average Velocity | | | 532 | |
| STDEV | | | 74 | |
| | Average of X and Y | 529 | | |
| | Pipe Area (ft²) | 0.0228 | | |
| | Flow Rate (ft³/min) | 12.1 | | |

Air Impurities Flow Rate Measurements

Table 27. Air Impurities High Setting Tube Velocity and Flow Rate Measurements

| Air Impurities High Setting Pitot-tube Velocity Measurements | | | | |
|---|--|---------------|--------------------|-------------------|
| | Velocity Measurements in Y-direction (ft/min) | | | |
| Traverse Points | Run 1 | Run 2 | Run Average | Run Stdev. |
| 1st | 3229 | 3376 | 3303 | 104 |
| 2nd | 3653 | 3522 | 3588 | 93 |
| 3rd | 3486 | 3582 | 3534 | 68 |
| 4th | 2912 | 2953 | 2933 | 29 |
| Average Velocity | | | 3339 | |
| STDEV | | | 298 | |
| | | | | |
| | Velocity Measurements in X-direction (ft/min) | | | |
| Traverse Points | Run 1 | Run 2 | Run Average | Run Stdev. |
| 1st | 3787 | 3663 | 3725 | 88 |
| 2nd | 3813 | 3824 | 3819 | 8 |
| 3rd | 3306 | 3342 | 3324 | 25 |
| 4th | 2735 | 2820 | 2778 | 60 |
| Average Velocity | | | 3411 | |
| STDEV | | | 474 | |
| | | | | |
| | Average of X and Y | 3375 | | |
| | Pipe Area (ft²) | 0.0228 | | |
| | Flow Rate (ft³/min) | 77.0 | | |

Table 28. Air Impurities Low Setting Tube Velocity and Flow Rate Measurements

| Air Impurities Low Setting Pitot-tube Velocity Measurements | | | | |
|--|--|---------------|--------------------|-------------------|
| | Velocity Measurements in Y-direction (ft/min) | | | |
| Traverse Points | Run 1 | Run 2 | Run Average | Run Stdev. |
| 1st | 3336 | 3313 | 3325 | 16 |
| 2nd | 3565 | 3332 | 3449 | 165 |
| 3rd | 3043 | 3319 | 3181 | 195 |
| 4th | 2836 | 2723 | 2780 | 80 |
| Average Velocity | | | 3183 | |
| STDEV | | | 291 | |
| | | | | |
| | Velocity Measurements in X-direction (ft/min) | | | |
| Traverse Points | Run 1 | Run 2 | Run Average | Run Stdev. |
| 1st | 3471 | 3560 | 3516 | 63 |
| 2nd | 3440 | 3486 | 3463 | 33 |
| 3rd | 3233 | 3283 | 3258 | 35 |
| 4th | 2692 | 2672 | 2682 | 14 |
| Average Velocity | | | 3230 | |
| STDEV | | | 382 | |
| | | | | |
| | Average of X and Y | 3207 | | |
| | Pipe Area (ft²) | 0.0228 | | |
| | Flow Rate (ft³/min) | 73.1 | | |

Healthy Air Flow Rate Measurements

Table 29. Healthy Air High Setting Tube Velocity and Flow Rate Measurements

| Healthy Air High Setting Pitot-tube Velocity Measurements | | | | |
|--|--|---------------|--------------------|-------------------|
| | Velocity Measurements in Y-direction (ft/min) | | | |
| Traverse Points | Run 1 | Run 2 | Run Average | Run Stdev. |
| 1st | 3284 | 3435 | 3360 | 107 |
| 2nd | 3428 | 3566 | 3497 | 98 |
| 3rd | 3133 | 3206 | 3170 | 52 |
| 4th | 2588 | 2670 | 2629 | 58 |
| Average Velocity | | | 3164 | |
| STDEV | | | 381 | |
| | | | | |
| | Velocity Measurements in X-direction (ft/min) | | | |
| Traverse Points | Run 1 | Run 2 | Run Average | Run Stdev. |
| 1st | 3406 | 3484 | 3445 | 55 |
| 2nd | 3419 | 3672 | 3546 | 179 |
| 3rd | 3331 | 3491 | 3411 | 113 |
| 4th | 2737 | 2689 | 2713 | 34 |
| Average Velocity | | | 3279 | |
| STDEV | | | 381 | |
| | | | | |
| | Average of X and Y | 3221 | | |
| | Pipe Area (ft²) | 0.0228 | | |
| | Flow Rate (ft³/min) | 73.4 | | |

Table 30. Healthy Air Medium Setting Tube Velocity and Flow Rate Measurements

| Healthy Air Medium Setting Pitot-tube Velocity Measurements | | | | |
|--|--|---------------|--------------------|-------------------|
| | Velocity Measurements in Y-direction (ft/min) | | | |
| Traverse Points | Run 1 | Run 2 | Run Average | Run Stdev. |
| 1st | 2801 | 2402 | 2602 | 282 |
| 2nd | 3059 | 3228 | 3144 | 120 |
| 3rd | 2436 | 2837 | 2637 | 284 |
| 4th | 2486 | 2486 | 2486 | 0 |
| Average Velocity | | | 2717 | |
| STDEV | | | 292 | |
| | | | | |
| | Velocity Measurements in X-direction (ft/min) | | | |
| Traverse Points | Run 1 | Run 2 | Run Average | Run Stdev. |
| 1st | 2852 | 2876 | 2864 | 17 |
| 2nd | 3176 | 3273 | 3225 | 69 |
| 3rd | 3142 | 3063 | 3103 | 56 |
| 4th | 2538 | 2474 | 2506 | 45 |
| Average Velocity | | | 2924 | |
| STDEV | | | 316 | |
| | | | | |
| | Average of X and Y | 2821 | | |
| | Pipe Area (ft²) | 0.0228 | | |
| | Flow Rate (ft³/min) | 64.3 | | |

Table 31. Healthy Air Low Setting Tube Velocity and Flow Rate Measurements

| Healthy Air Low Setting Pitot-tube Velocity Measurements | | | | |
|---|--|---------------|--------------------|-------------------|
| | Velocity Measurements in Y-direction (ft/min) | | | |
| Traverse Points | Run 1 | Run 2 | Run Average | Run Stdev. |
| 1st | 1639 | 1506 | 1573 | 94 |
| 2nd | 2161 | 2275 | 2218 | 81 |
| 3rd | 1930 | 1829 | 1880 | 71 |
| 4th | 1740 | 1730 | 1735 | 7 |
| Average Velocity | | | 1851 | |
| STDEV | | | 275 | |
| | | | | |
| | Velocity Measurements in X-direction (ft/min) | | | |
| Traverse Points | Run 1 | Run 2 | Run Average | Run Stdev. |
| 1st | 2158 | 1981 | 2070 | 125 |
| 2nd | 2251 | 2255 | 2253 | 3 |
| 3rd | 2194 | 2059 | 2127 | 95 |
| 4th | 1710 | 1819 | 1765 | 77 |
| Average Velocity | | | 2053 | |
| STDEV | | | 207 | |
| | | | | |
| | Average of X and Y | 1952 | | |
| | Pipe Area (ft²) | 0.0228 | | |
| | Flow Rate (ft³/min) | 44.5 | | |

Appendix II

Capture Velocity Profiles

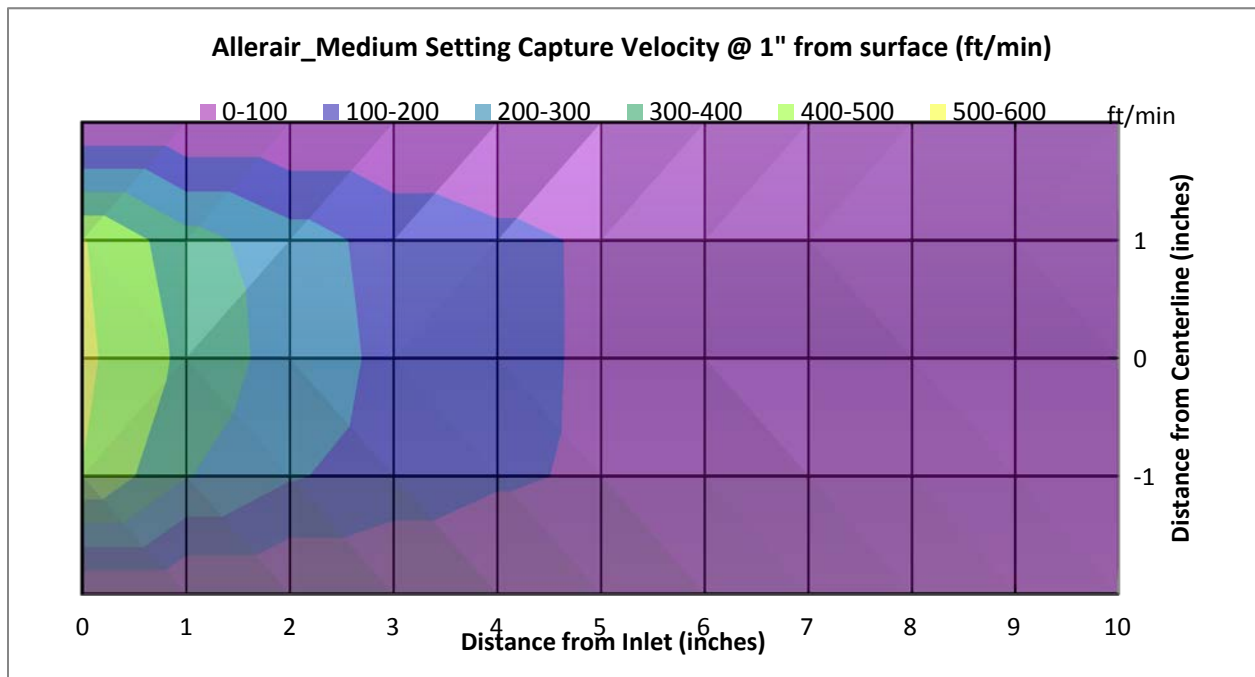


Figure 29. Allerair Capture Velocity Profile for Medium Setting

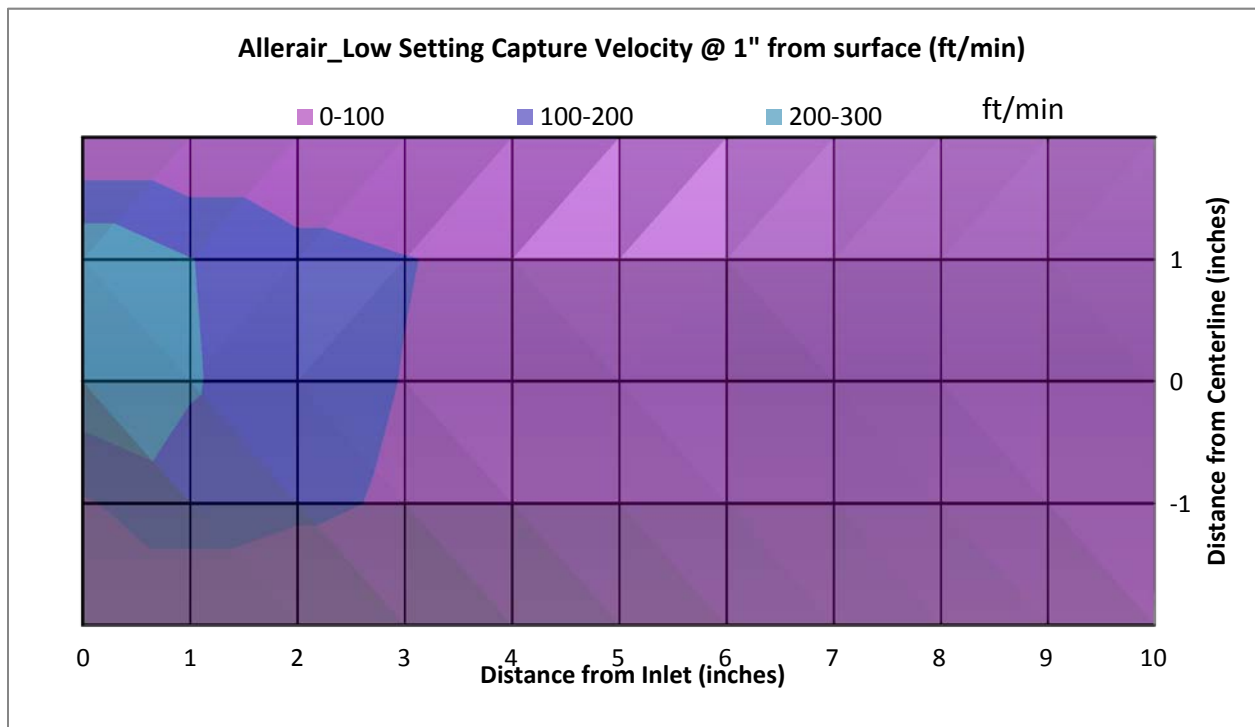


Figure 30. Allerair Capture Velocity Profile for Low Setting

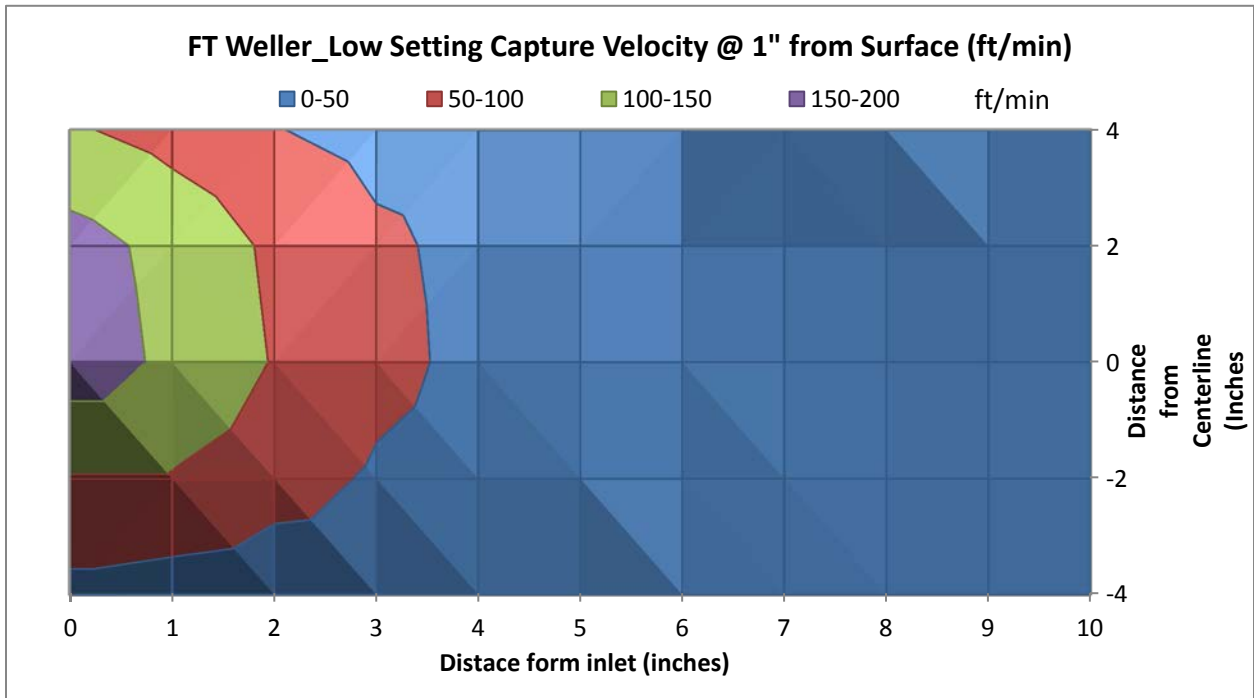


Figure 31. Weller FT Capture Velocity Profile for Low Setting

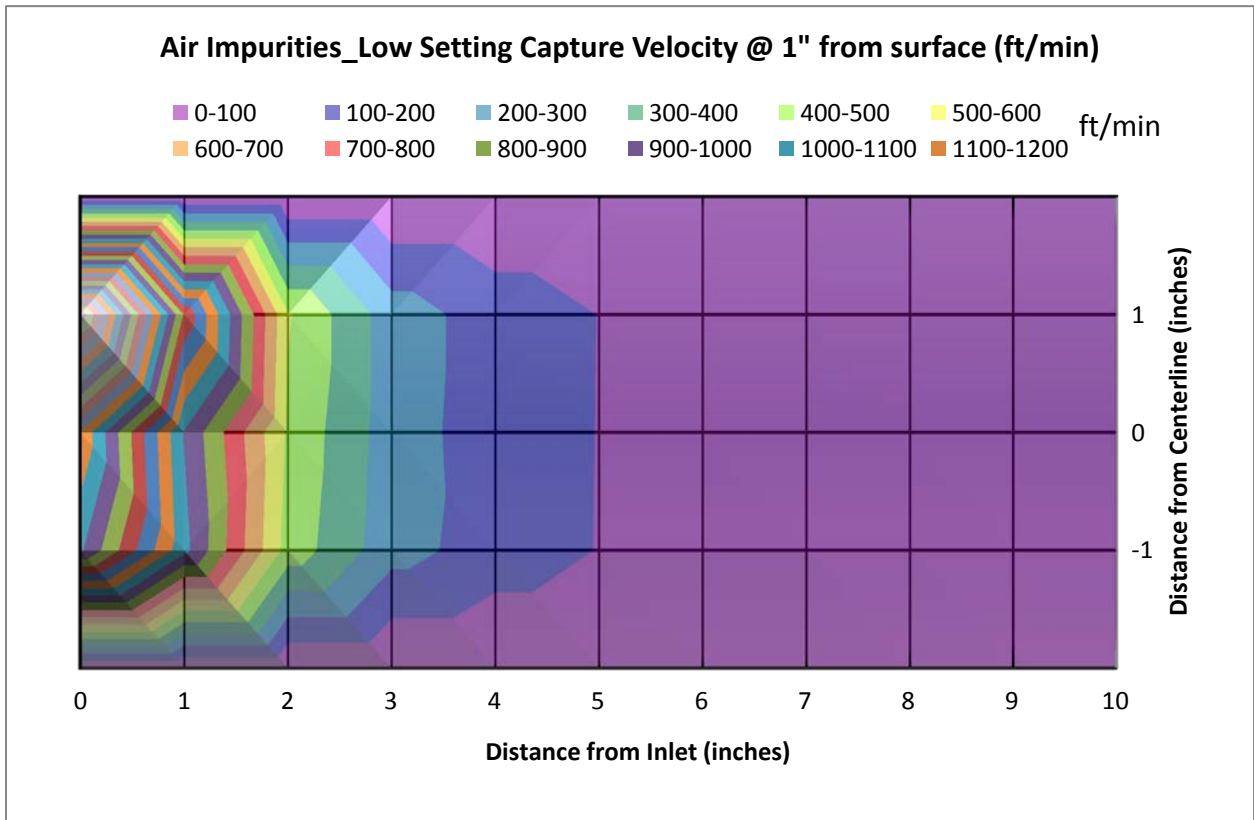


Figure 32 . Air Impurities Capture Velocity Profile for Low Setting

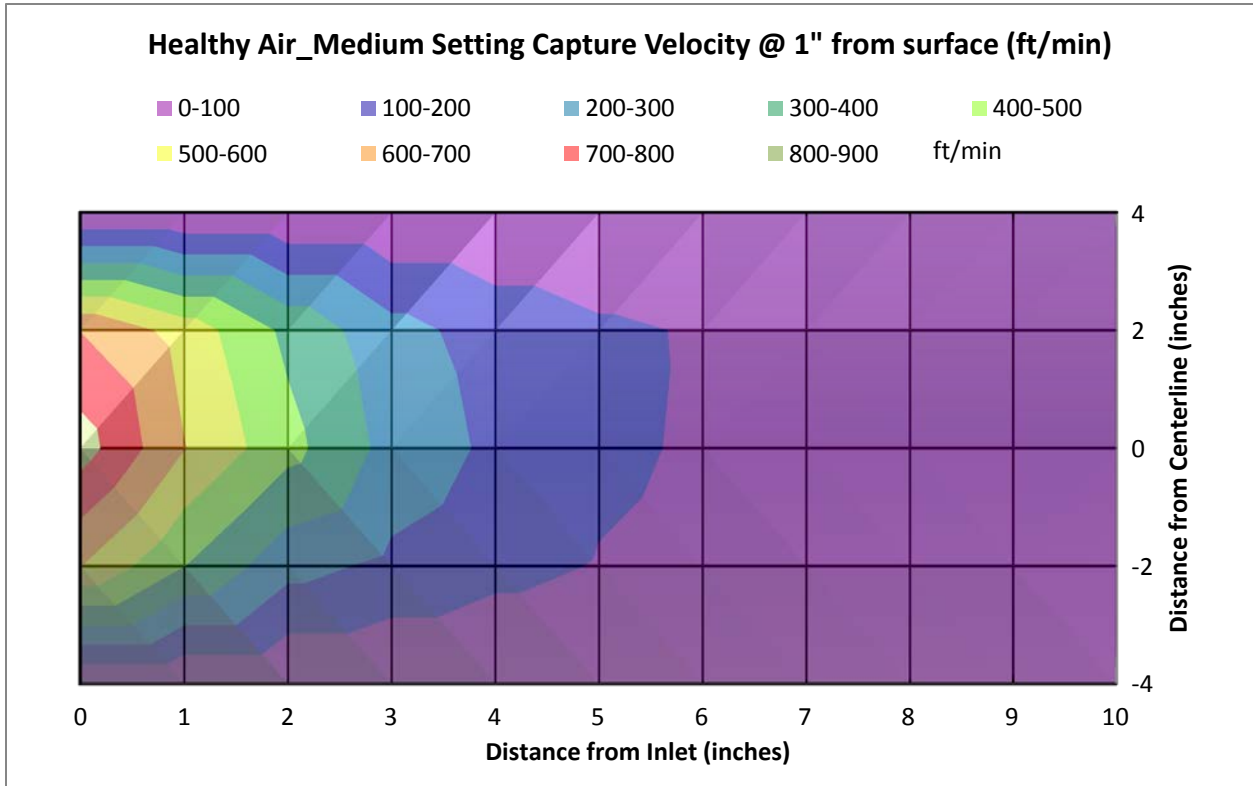


Figure 33. Healthy Air Capture Velocity Profile for Medium Setting

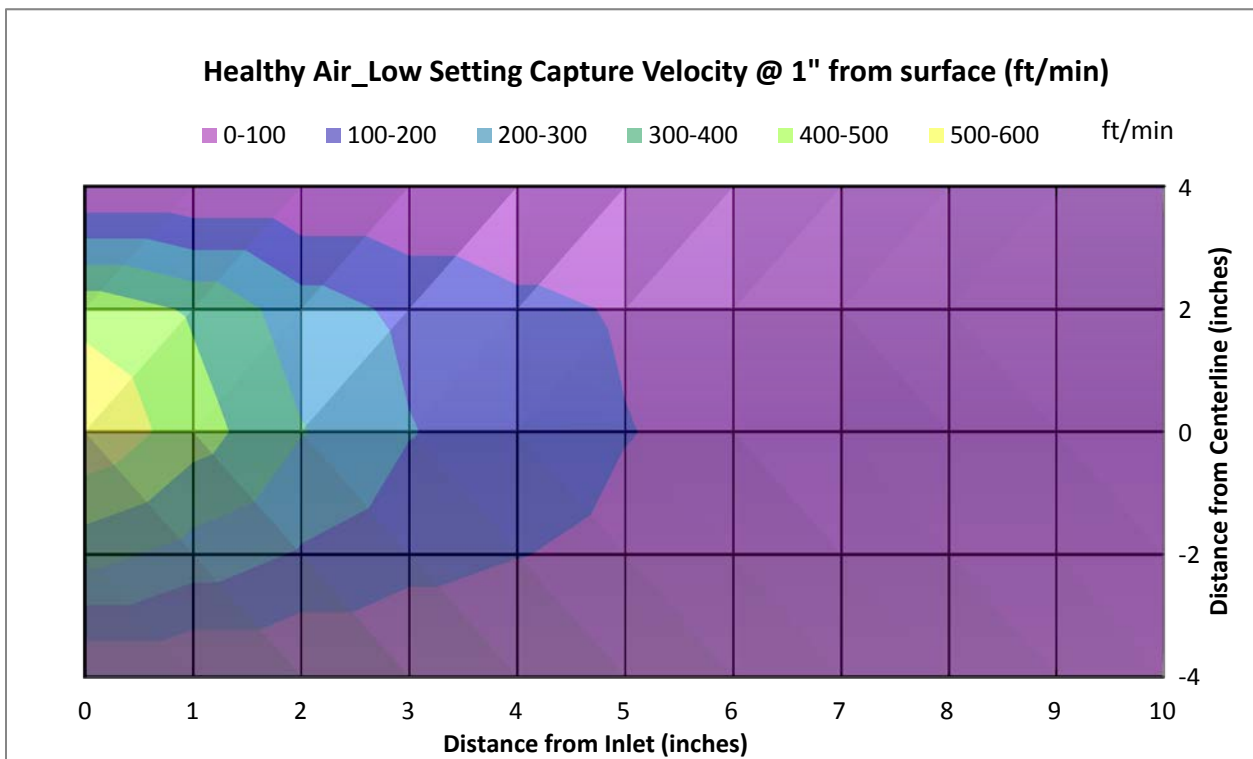


Figure 34. Healthy Air Capture Velocity Profile for Low Setting