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An Evaluation of Retrofit Engineering Control Interventions to Reduce Perchloroethylene Exposures in Commercial Dry-Cleaning Shops

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Real-time monitoring was used to evaluate the ability of engineering control devices retrofitted on two existing dry-cleaning machines to reduce worker exposures to perchloroethylene. In one dry-cleaning shop, a refrigerated condenser was installed on a machine that had a water-cooled condenser to reduce the air temperature, improve vapor recovery, and lower exposures. In a second shop, a carbon adsorber was retrofitted on a machine to adsorb residual perchloroethylene not collected by the existing refrigerated condenser to improve vapor recovery and reduce exposures.

Both controls were successful at reducing the perchloroethylene exposures of the dry-cleaning machine operator. Real-time monitoring was performed to evaluate how the engineering controls affected exposures during loading and unloading the dry-cleaning machine, a task generally considered to account for the highest exposures. The real-time monitoring showed that dramatic reductions occurred in exposures during loading and unloading of the dry-cleaning machine due to the engineering controls. Peak operator exposures during loading and unloading were reduced by 60 percent in the shop that had a refrigerated condenser installed on the dry-cleaning machine and 92 percent in the shop that had a carbon adsorber installed.

Although loading and unloading exposures were dramatically reduced, drops in full-shift time-weighted average (TWA) exposures were less dramatic. TWA exposures to perchloroethylene, as measured by conventional air sampling, showed smaller reductions in operator exposures of 28 percent or less. Differences between exposure results from real-time and conventional air sampling very likely resulted from other uncontrolled sources of exposure, differences in shop general ventilation before and after the control was installed, relatively small sample sizes, and experimental variability inherent in field research.

Although there were some difficulties and complications with installation and maintenance of the engineering controls, this study showed that retrofitting engineering controls may be a feasible option for some dry-cleaning shop owners to reduce worker exposures to perchloroethylene. By installing retrofit controls, a dry-cleaning facility can reduce exposures, in some cases dramatically, and bring operators into compliance with the Occupational Safety and Health Administration (OSHA) peak exposure limit of 300 ppm. Retrofit engineering controls are also likely to enable many dry-cleaning workers to lower their overall personal TWA exposures to perchloroethylene.

Keywords Dry Clean, Engineering Controls, Interventions, Perchloroethylene

An engineering control intervention study was conducted at two dry-cleaning shops in the midwestern United States. The purpose of the study was to evaluate the effectiveness of two engineering control devices for reducing worker exposure to perchloroethylene (PERC). Two different engineering controls were installed and evaluated, one in each of two shops. Results of the real-time monitoring and air sampling are reported in this paper. The effect of work practices, as well as engineering controls on worker breath and personal air samples, are reported in a companion paper. Approximately 85 percent of dry cleaners in the United States use PERC as their main cleaning solvent, nearly all the others use petroleum-based solvents (including Stoddard solvent).

PERC SYMPTOMS AND EXPOSURE LIMITS

PERC can enter the human body through both respiratory and dermal exposure or, in some cases, ingestion. Symptoms associated with occupational exposure include the following: depression of the central nervous system; damage to the liver and kidneys; impaired memory; confusion; dizziness; headache; drowsiness; and eye, nose, and throat irritation. Repeated dermal exposure may result in dry, scaly, and fissured dermatitis.[1] The International Agency for Research on Cancer (IARC) classifies PERC in group 2A as a probable human carcinogen: sufficient evidence of animal carcinogenicity and limited evidence of human carcinogenicity.[2] NIOSH considers PERC to be a potential occupational carcinogen and recommends that worker exposures be reduced.[3]

Occupational exposure to PERC is regulated by Occupational Safety and Health Administration (OSHA) standards: an 8-hour time-weighted average (TWA) of no more than 100 parts per million (ppm), a 15-minute short-term exposure limit (STEL) of 200 ppm, and a peak exposure never to exceed 300 ppm. OSHA had lowered the PEL to 25 ppm in 1989 under the Air Contaminants Standard. In July 1992, the 11th Circuit Court of Appeals vacated this standard. OSHA is currently revisiting the permissible exposure limits for PERC. The American Conference of Government Industrial Hygienists (ACGIH®) Threshold Limit Values[4] (TLVs®) are 25 ppm for an 8-hour TWA and 100 ppm for peak exposures.

DRY-CLEANING MACHINE DESIGN AND VAPOR RECOVERY SYSTEMS

Prior studies have identified the dry-cleaning machine as the primary source of worker exposures to PERC.[5] Real-time evaluations have shown that loading and unloading of the dry-cleaning machine have the greatest impact upon exposures. These exposures are directly related to the vapor recovery system. The vapor recovery system design and performance affect the concentration of PERC remaining in the cylinder at the end of the dry cycle, and also the amount of PERC remaining in the garments, which off-gas inside the shop after being unloaded from the machine. Air inside the machine cylinder containing PERC can easily become displaced into the worker's breathing zone during the periods of loading and unloading garments from the machine. The primary vapor recovery technologies used on dry-cleaning machines are the carbon adsorber and the refrigerated condenser.

Carbon adsorbers are capable of achieving a 95–99 percent vapor reduction by removing PERC molecules from the air.[6] Solvent-laden vapors pass over activated carbon having a high adsorption capacity. Factors, such as the flow rate of the air stream, concentration of PERC in the air stream, adsorption time, capacity of the carbon bed, humidity, temperature of the air stream, and/or age of the activated carbon, affect adsorption. Generally, air flow rate and carbon bed capacity are the most important factors. Carbon adsorption systems can handle high volumes of air having relatively low solvent concentrations and maintain a high removal efficiency. The drawbacks of carbon adsorption are the need for frequent desorbing, the possible generation of solvent contaminated wastewater, and the potential for high emissions and exposures if the carbon is not properly maintained.[7]

The second type of vapor recovery system, the refrigerated condenser, uses a refrigerant to recover the PERC. The refrigerant cools the solvent-laden air below the dew point of the vapor. Refrigerated condensers operate on the principle that the ability of air to hold a solvent in the vapor state is based on the temperature. The process can achieve 95 percent vapor control in dry-to-dry machines and 85 percent control in transfer machines. The residual concentration is reduced to the saturation concentration, based on the temperature and air volume. The lowest condensation temperature is −22°C (−8°F); however, in practice, to avoid freezing, machines operate at a minimum of −20°C (−4°F). At this temperature, the air still contains approximately 2000 ppm of PERC, although concentrations could be higher depending on air temperature, surface area, and air-flow rates.[8]

Condensers require little maintenance and minimize the potential for wastewater because steam regeneration is not required. They do require higher PERC concentrations than a carbon adsorber. Water vapor can pose a problem because it can condense and freeze, impeding gas flow and heat transfer.[6]

METHODS

Two shops were evaluated using real-time monitoring: Shops A and B. A third shop was included in the study, but real-time monitoring was not performed due to a number of complications. Each of the evaluated shops was a typical small business with fewer than 10 employees. In each shop, the owner or a close relative of the owner operated the dry-cleaning machine on a daily basis.

Shop Descriptions

Shop A

Shop A was located in a stand-alone building. The business was divided into two areas: coin laundry and dry cleaning. The coin laundry section was located near the front of the building, and customers were able to enter the store and operate the multiple washers and dryers. The coin laundry area was partitioned from the dry-cleaning area in the rear of the store by a wall and customer counter. A Suprema Model 900 S2, 30-pound machine was situated in the rear corner of the building near a small bathroom and door exiting the building. This was a dry-to-dry, nonrefrigerated machine, over 10 years old. Dry-cleaned garments were stored between the dry-cleaning machine and the customer counter.

Shop B

Shop B was on the end of a row of businesses in a single-story strip mall. The front of the store consisted of glass panels. This shop had a ceiling that was over 20 feet high. The pressing area was located along the right side of the shop closest to the adjacent businesses. The dry-cleaning machine was near the rear of the shop approximately 12 feet in front of the exit. The dry-cleaning machine was a Forenta Model D-345, 45-pound machine. This machine, which was approximately two years old, was dry-to-dry and refrigerated. Garment storage racks were situated along the left side of the shop. There was a sliding door in the wall near the customer counter so that customers could drive by to pay for and pick up their garments without leaving their cars.

The Process

In each of the evaluated shops, garments were brought to the customer counter and were examined and tagged for identification. Prior to being loaded into the dry-cleaning machine, garments were inspected and sorted according to weight, color, and finish. Garments with visible, localized stains were treated at the spotting station with a wide variety of organic solvents. Generally, one person operated the dry-cleaning machines and performed spot removal.

Dry cleaning is a three-step process, involving the following: washing, extracting, and drying. At the start of the washing process, clothes were manually loaded through the front door into the cylinder of the machine. After the door was closed, PERC was automatically pumped into the cylinder. Water-based detergent was automatically injected into each load. The contents of the machine cylinder were then agitated, which allowed the solution to remove soils. Following this step, the clothes were spun at a high speed to extract the solvent. After the solvent was removed, the fabric was tumbled dry. Garments removed from the machine were pressed to remove wrinkles and to restore their original shape. Once the garments were completely pressed, they were wrapped in plastic and stored on an overhead rack to await customer pickup.

Description of the Engineering Control Interventions

Engineering controls were retrofitted to the existing dry-cleaning machines. Both controls were designed to reduce the concentration of PERC in the dry-cleaning machine cylinder at the end of the dry cycle. A diagram of a typical dry-cleaning machine and the engineering controls that were added is shown in Figure 1.

Shop A

In Shop A, a refrigerated condenser was installed on a vented, nonrefrigerated, dry-to-dry dry-cleaning machine. The original water-cooled condenser was replaced to reduce the air temperature during the drying cycle and recover more solvent from the air.

In the original dry-cleaning machine in Shop A, PERC in the exhaust air was adsorbed by a single-pass activated carbon filter. During the drying process, air passed through a fan,

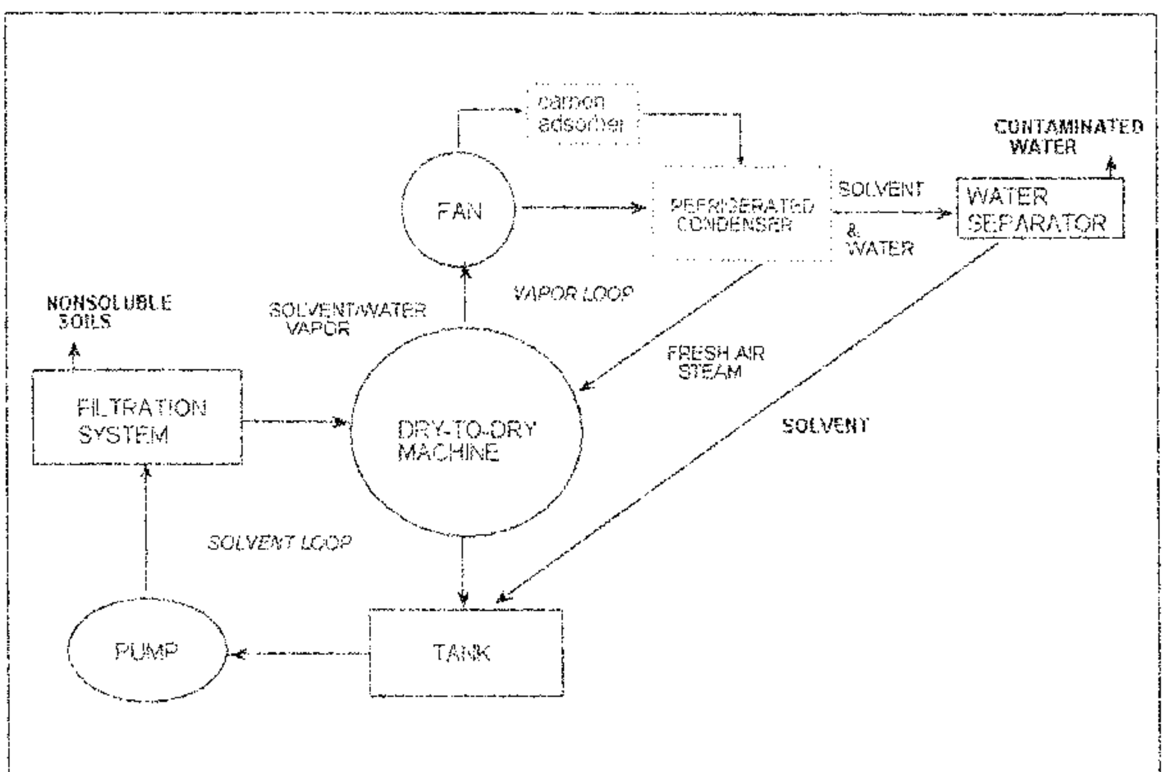

FIGURE 1
Diagram of a typical dry-cleaning machine and the two dry-cleaning interventions.

water-cooled air cooler, air heater, garment drum, and lint filter. The solvent vapors condensed on the recovery condenser and flowed to the water separator. Air from the recovery condenser had a temperature of approximately 30°C (86°F) that will reduce solvent concentrations in the machine cylinder to approximately 30,000 ppm. Concentrations can range from 25,000 to 75,000 ppm, depending upon cooling water and air temperatures. Air was then heated to recover new solvent from the garment load. The drying temperature, 50°C to 70°C (122°F to 158°F), was regulated by a thermostat that controls a steam valve. Drying was completed when the solvent behind the air cooler had been reduced to such a concentration that any further expenditure of time and energy would be inefficient. At the end of the drying process, fresh air was drawn in through a trap. Air passed through the load to a single-pass, carbon adsorber that exhausted outside of the building during the dry cycle.

The machine in Shop A was converted from a nonrefrigerated to a refrigerated machine. On refrigerated machines, the air is maintained at considerably lower temperatures than nonrefrigerated machines. These machines utilize a refrigerated unit and two air heaters that act as a heat exchanger. The more powerful heater is fed with hot gas from the refrigeration unit. The remaining heat is supplied by a small auxiliary heater. At the end of the drying process, the air contains substantially lower quantities of PERC than that in a machine having a water-cooled condenser (approximately 2000 ppm compared to 30,000 ppm). The solvent concentration depends on the temperature and air volume.

Shop B

In Shop B, a closed-loop, carbon adsorber was installed as a secondary control on a dry-to-dry, refrigerated dry-cleaning machine. This device was activated at the end of the dry cycle. It was designed to route PERC vapors from the drum, button trap, and lint trap through the carbon to capture residual PERC vapors that had not been captured by the refrigerated condenser. This device did not exhaust outside the machine but directed the drying air through the carbon bed and then back to the garment drum for several minutes at the end of the dry cycle. This control added approximately 5 minutes to the length of the dry cycle.

Cylinder concentrations are important for reducing exposures during loading and unloading.[9] Very low cylinder concentrations can be accomplished by using both a refrigerated condenser and closed-loop, carbon adsorber. During the main drying cycle, the solvent-laden air recirculated through the refrigerated condenser, which vaporized and recovered most of the residual solvent. While passing through the cooling coil, PERC vapors condensed and flowed to the separator, where water was removed. Liquid PERC flowed back into the machine tank. A drying sensor, which measured solvent flow between the refrigerated condenser and water separator, automatically switched the system to the cool-down/deodorize step. During this part of the cycle, the air was cooled in the refrigerated condenser before passing through the carbon adsorber and returning to the drying drum. An interlock on the machine door ensured that the machine door could not be opened until the drying/vapor recovery process reached completion. To maintain its effectiveness, the carbon adsorption system required thermal desorption after approximately 20 loads.

Evaluation of the Engineering Controls

Each shop was evaluated both before and after the intervention using three forms of monitoring: (a) real-time monitoring using flame ionization detector (FID), photo ionization detectors and videotapes of multiple door opening events and day; (b) personal and area air samples; and (c) breath analysis. A small number of area PERC samples was also taken, and information on environmental factors, which could have influenced the PERC levels at the time of the evaluation (e.g., temperature, humidity, general ventilation, etc.) was collected. Results of the breath analysis are reported in the companion article.

Real-Time Video Exposure Monitoring

During real-time video exposure monitoring, data were recorded on an electronic data logger (Metrosonics MS-3200) and downloaded to a portable computer. A video camera was used to record worker activities while real-time exposure data was collected. This videotape was later used to analyze tasks, code data, and to determine which work activities and movements resulted in the highest exposures.[10,11]

Real-time video exposure monitoring was used to evaluate the effect of machine design changes (retrofit engineering controls) on worker exposure to PERC. Real-time video exposure monitoring was performed on approximately three different days prior to installation of the engineering controls and three days after installation of the engineering controls. Real-time video exposure monitoring was performed each time the machine operator loaded or unloaded the dry-cleaning machine. Real-time video exposure monitoring of PERC exposures was performed using two air sampling instruments: a photo ionization detector (Microtip IS3000 PHOTOVAC Inc., Thornhill, ON, Canada) having a 10.6 EV ultraviolet lamp and a flame ionization detector (FID)/photo ionization detector (PID) TVA-1000. Both instruments provide an analog output response proportional to the concentration of ionizable pollutants present in the air. The instruments were calibrated using 100 ppm isobutylene span gas and five standard concentrations of PERC gas. Instrument readings and actual PERC concentrations were used to construct calibration curves.

Personal and Area Air Sampling

Personal air samples were collected in the breathing zone of the workers using charcoal sorbent tubes with a flow rate of 0.2 liters per minute (L/min) in approximately two-hour intervals throughout the workday, following NIOSH Method 1003.[12]

Area samples were collected in each shop approximately 18 inches directly above the dry-cleaning machine door.

RESULTS

Results of Video Exposure Monitoring

Each of the engineering controls that was installed had a statistically significant effect on reducing worker instantaneous exposures during loading and unloading. Pre- and post-data were compared using analysis of variance (ANOVA). Details concerning the results are shown in Table I and are described below.

During analysis of the data, exposure concentrations were analyzed in two ways. Exposures were compared before and after the intervention. Each time a loading or unloading task occurred, concentration measurements were gathered and recorded every second. A typical loading or unloading task took approximately 60 seconds. When the data were analyzed and coded, the average exposure and the peak exposure were determined for each activity (Table I). The average exposure was simply the average of all the measurements recorded during the activity. The peak exposure was the average of the highest concentrations measured during all repetitions of a particular activity.

Shop A Results

A diagram of the real-time monitoring results for operator peak and mean exposures during loading and unloading of the dry-cleaning machine is shown in Figure 2. The following summarizes the real-time monitoring results for Shop A, which had a refrigerated condenser retrofitted to its currently existing non-refrigerated machine:

- Peak exposures during loading and unloading: On average, peak exposures were reduced from 1950 to 1011 ppm. This is a reduction of approximately 48 percent.
- Average exposures during loading and unloading: On average, operator exposures were reduced from 1139 to 456 ppm. This is a reduction of approximately 60 percent.

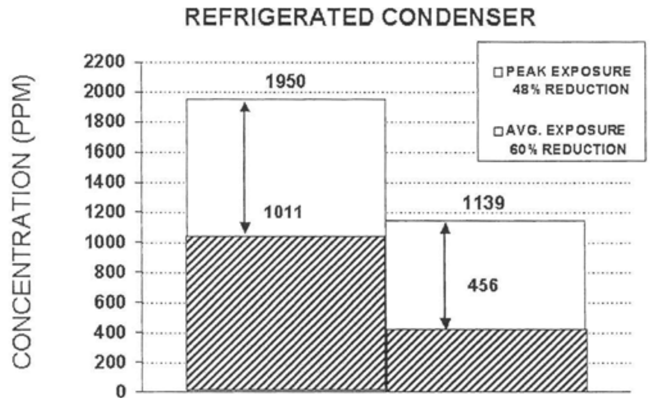

FIGURE 2
Real-time operator exposure reduction for the dry-cleaning machine retrofitted with a refrigerated condenser (Shop A).

Shop B Results

Diagrams of the real-time monitoring results for operator exposure during loading and unloading of the dry-cleaning machine are shown in Figures 3 and 4. The results for Shop B, which had a carbon adsorber added to a refrigerated dry-to-dry machine as a secondary control, are shown below:

- Peak exposures during loading and unloading: On average, peak exposures were reduced from 648 to 69 ppm. This is a reduction of approximately 89 percent.
- Average exposures during loading and unloading: On average, operator exposures were reduced from 353 to 29 ppm. This is a reduction of approximately 92 percent.

Results of TWA Analyses

One person usually specialized in operating the dry-cleaning machine, while others primarily pressed garments or waited on the counter. Because of the small shop size, only two workers per shop participated in this study. In both shops the machine

TABLE I
Summary of real-time monitoring results (machine operator exposures to PERC during loading and unloading)

Summary statistics (pre and post)	Shop A mean exposure, ppm			Shop B mean exposure, ppm		
	Mean*	S.D.	n	Mean*	S.D.	n
Mean exposure (pre)	1,139.3	709.6	14	352.9	202.4	14
Mean exposure (post)	456.4	268.2	19	29.4	20.8	15
Peak exposure (pre)	1,950.0	925.4	14	647.6	285.6	14
Peak exposure (post)	1,011.0	373.8	19	69.2	57.0	15

*Significant at the $\alpha = 0.05$ level.
S.D. = standard deviation.
n = number of observations.

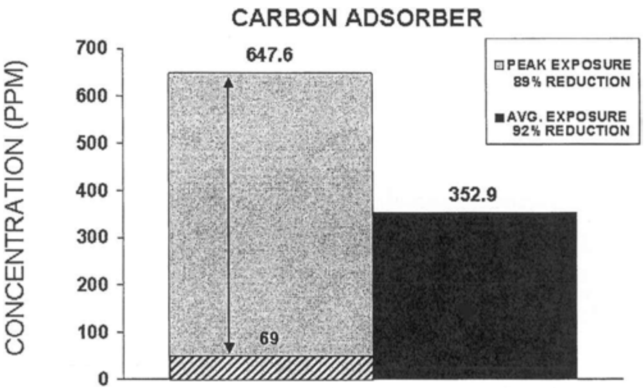

FIGURE 3
Real-time operator exposure reduction for the dry-cleaning machine retrofitted with a closed-loop, carbon adsorber (Shop B).

operators had the highest TWA exposures (Table II). These results are consistent with the conclusions of previous studies.

Several environmental factors were routinely measured during the field study and were evaluated to determine their effect on estimates of exposure: the number of loads cleaned per day, temperature, relative humidity, and barometric pressure measured within the shop each sampling day. The mean values of these factors are presented in Table III. Only one such environmental factor was significantly correlated with the log TWAs of workers: the temperature in Shop B.

The TWA operator exposures are presented in Table IV, and area air samples collected directly above the machine door are shown in Table V. Neither of the differences of the personal or area TWAs between pre- and post-intervention was statistically

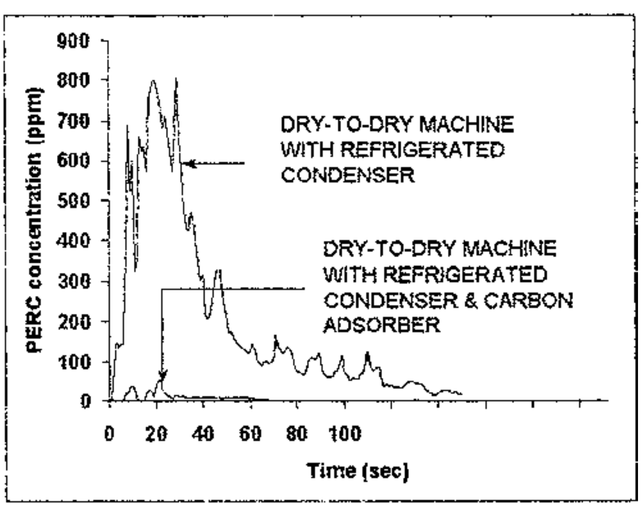

FIGURE 4
Comparison of pre- and post-operator exposures for Shop B during loading and unloading the dry-cleaning machine.

TABLE II
Geometric mean TWA (ppm) for each shop by job task

Employees categorized by primary task	Shop A mean TWA (GSD)+	Shop B mean TWA (GSD)+
Dry-cleaning machine operator	26.2 (1.32)** (n = 11)	2.83 (2.06) (n = 8)
Garment presser	12.2 (1.40)** (n = 6)	1.66 (2.30) (n = 7)

+Geometric standard deviation.
**Significant difference between jobs at the $\alpha = 0.001$ level.

significant. The difference between the machine operator mean exposures in Shop A represents a 28 percent decrease in the TWAs after the intervention. The area samples collected above the dry-cleaning machine door fell by approximately 22 and 42 percent, respectively. The fact that these differences are not significant is possibly due to differences between general ventilation within the shop before and after the control was installed, relatively small sample sizes, and the experimental variability inherent in field research. Neither of the evaluated shops was air-conditioned, and workers relied upon opened doors and fans for their thermal comfort. It was noted during the study that doors exiting the building near the dry-cleaning machines were opened, and general ventilation fans were operating more often before the control was installed as compared to after installation. These differences likely acted to lower worker TWA exposures to PERC prior to the intervention.

DISCUSSION

This article presents the results of a study to determine the effectiveness of reducing worker exposure to PERC by retrofitting engineering controls to existing dry-cleaning machines. These controls were evaluated using real-time measurements during loading and unloading of garments from the dry-cleaning machine and TWAs calculated from personal air monitoring of participating workers and area air samples.

Air sampling and real-time monitoring results for the machine operator were mixed, with the real-time results being more dramatic. Real-time monitoring indicated that average exposures to PERC during door opening events could be reduced as much

TABLE III
Arithmetic means of environmental factors

Environmental factors	Shop A	Shop B
Number of loads/day	6.3 (1.40)	5.0 (1.51)
Temp. °C (SD)	18.2 (2.32)	18.2 (2.70)
Rel. humidity % (SD)	39.3 (3.30)	48.4 (15.36)
Barometric pressure (inches mercury)	29.5 (0.35)	29.5 (0.29)

(Standard deviation.)

TABLE IV
Machine operator mean TWA exposures (ppm) pre- and post-intervention

	Machine operators mean TWA (std. dev.)	
	Shop A	Shop B
Pre	31.33 (11.75) (n = 5)	3.43 (2.88) (n = 5)
Post	22.58 (4.52) (n = 4)	3.59 (1.44) (n = 3)

as 92 percent by retrofitting the machines with both engineering controls. After the intervention, the machine in Shop B was equipped with a refrigerated condenser and closed-loop, carbon adsorber. This machine configuration provided excellent protection to the worker because it kept TWA exposures well below 5 ppm and dramatically reduced instantaneous exposures to below the OSHA ceiling of 300 ppm.

The measurements in this study confirmed conclusions in other papers, that door opening events are a major source of exposure. Results of this study are also similar to those of several NIOSH studies in which local exhaust ventilation was used to reduce mean short-term exposures to PERC during door opening events by as much as 78 percent[13] and machines equipped with both refrigerated condenser and closed loop carbon adsorbers were capable of effectively controlling short-term exposures to PERC.[14,15]

Although real-time reductions in machine operator exposures to PERC were quite large, the TWA reductions were not as great, and TWA exposures for the operator of the machine with the carbon adsorber added increased slightly. These results may be due in part to the many sources of PERC exposure present in dry-cleaning shops. These sources include not only air displacement from the machine drum during loading and unloading, but also leaks from the machine, garment off-gassing, machine maintenance, and tank filling operations.[9,16,17] Loading and unloading the dry-cleaning machine has been shown to account for as much as 70 percent of a dry-cleaning worker's full-shift TWA exposure to PERC in an earlier study;[5] however, this figure will vary from shop to shop.

TABLE V
Mean TWA area samples (ppm) pre- and post-intervention (taken directly above dry-cleaning machine door)

	Area samples mean TWA (std. dev.)	
	Shop A	Shop B
Pre	45.85 (12.53) (n = 5)	4.85 (3.30) (n = 5)
Post	35.78 (7.45) (n = 4)	2.82 (1.03) (n = 3)

Other factors that may affect exposure include local and general ventilation, machine design, machine capacity, clothing fabrics, number of loads per day, use of personal protective equipment (PPE), and work practices. Each of these factors has inherent variability and is difficult to control during field evaluations.

Overall, the results of this engineering intervention support the hypothesis that the single most effective way of controlling machine operators' exposures to PERC is to prevent solvent escape from the dry-cleaning machine during loading or unloading of garments. Engineering controls are most effective when the machine is in good repair and the machine operator follows good work practices. Factors such as work habits cannot be ignored. During this study, workers were repeatedly observed opening machine doors while PERC was present in the machine. Gloves were rarely worn and respirators were never used. Maintenance of the machines resulted in very high exposures. All of these factors affect the amount of personal exposure received.

CONCLUSIONS AND RECOMMENDATIONS

Based upon the results of this study, the following conclusions and recommendations may be made. Dry-cleaning machines equipped with both a refrigerated condenser and a continuous loop carbon adsorber that operates at the end of the dry cycle are effective at reducing worker exposures to perchloroethylene. These machines are particularly effective at controlling the brief short-term PERC exposures that occur during garment loading and unloading.

Machine manufacturers should only sell new dry-cleaning machines equipped with both control systems because these machines, unlike many of the earlier machines, are capable of complying with the OSHA peak exposure limit of 300 ppm. Machine manufacturers should facilitate the installation of retrofits for older machines with less effective control systems by providing technical assistance and instructions to the shop owners. To address the problem of operators opening the machine door during mid-cycle, machine manufacturers should install door locks on all machines to prevent workers from opening the door until the entire dry cycle has ended.

Dry-cleaning shop owners who plan to continue using PERC, rather than switching to an alternative cleaning method, and cannot afford brand new equipment, should consider retrofitting existing dry-cleaning machines with more stringent control systems to reduce their workers' exposures. Both of these controls may be purchased for around $5000, and the refrigerated condenser will provide the added benefit of significantly reducing solvent usage costs. Workers should be educated so they understand how PERC enters their bodies and what the potentially harmful health effects are. They should also receive training in appropriate work habits that minimize exposure. By making these relatively inexpensive changes and stressing exposure prevention, each dry-cleaning shop owner can make a positive change in the health of workers.

DISCLAIMER

Mention of any company or product does not constitute endorsement by the National Institute for Occupational Safety and Health (NIOSH) or the Centers for Disease Control and Prevention (CDC).

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