Applied Occupational and Environmental Hygiene
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/uaoh20

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Available online: 30 Nov 2010

To cite this article: Lynda M. Ewers, Avima M. Ruder, Martin R. Petersen, G. Scott Earnest & Linda M. Goldenhar (2002): Effects of Retrofit Emission Controls and Work Practices on Perchloroethylene Exposures in Small Dry-Cleaning Shops, Applied Occupational and Environmental Hygiene, 17:2, 112-120

To link to this article: http://dx.doi.org/10.1080/104732202317201357

Applied Occupational and Environmental Hygiene
Volume 17(2): 112–120, 2002
1047-322X/02 $12.00 + .00

Effects of Retrofit Emission Controls and Work Practices on Perchloroethylene Exposures in Small Dry-Cleaning Shops

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The effectiveness of commercially available interventions for reducing workers' perchloroethylene exposures in three small dry-cleaning shops was evaluated. Depending upon machine configuration, the intervention consisted of the addition of either a refrigerated condenser or a closed-loop carbon adsorber to the existing dry-cleaning machine. These relatively inexpensive (less than $5000) engineering controls were designed to reduce perchloroethylene emissions when dry-cleaning machine doors were opened for loading or unloading. Effectiveness of the interventions was judged by comparing pre- and postintervention perchloroethylene exposures using three types of measurements in each shop: (1) full-shift, personal breathing zone, air monitoring, (2) next-morning, end-exhaled worker breath concentrations of perchloroethylene, and (3) differences in the end-exhaled breath perchloroethylene concentrations before and after opening the dry-cleaning machine door. In general, measurements supported the hypothesis that machine operators' exposures to perchloroethylene can be reduced. However, work practices, especially maintenance practices, influenced exposures more than was originally anticipated. Only owners of dry-cleaning machines in good repair, with few leaks, should consider retrofitting them, and only after consultation with their machine's manufacturer. If machines are in poor condition, a new machine or alternative technology should be considered. Shop owners and employees should never circumvent safety features on dry-cleaning machines.

Keywords Intervention Studies, Dry-Cleaning, Perchloroethylene, Work Practices, Small Business

Perchloroethylene (PCE) is the primary solvent used in about 85 percent of dry-cleaning shops in the United States.[1] The Business America on Disc CD-ROM file includes 48,087 dry-cleaning shops in the United States, of which 70 percent (33,853) have only one to four workers.[2]

In recent years, the scientific community has grown more concerned over the health effects of PCE exposure, but effectively communicating these concerns to a widely scattered, independent industry has been difficult. During focus group sessions and interviews conducted before this study, both dry-cleaning employees and employers revealed a reluctance to believe that any adverse health effects could be related to PCE exposure, although some workers reported headaches and expressed concern about long-term effects.[3] Such beliefs make it questionable whether high-cost solutions for reducing exposures will be accomplished voluntarily without measurable machine performance improvement. Several new technologies do not use organic solvents (e.g., carbon dioxide, wet-cleaning techniques) but require a substantial financial outlay for equipment and retraining. While these technologies may eventually transform the dry-cleaning industry, they are not considered in this article.

The purpose of this field demonstration project was to evaluate the ability of relatively low-cost (less than $5000) engineering controls, retrofitted onto existing dry-cleaning machines, to reduce PCE exposures in small shops. The project represents only a part of the National Institute for Occupational Safety and Health (NIOSH) efforts to answer specific questions regarding the dry-cleaning industry. Other ongoing investigations will evaluate the effectiveness of local exhaust ventilation on dry-cleaning machines, report the results of real-time PCE measurements during machine door opening, appraise methods to communicate health effects, and further elucidate links between health effects and PCE exposures.

In this study, either a refrigerated condenser or a carbon adsorber was installed on existing dry-cleaning machines in each of three shops. Performance was evaluated by comparing PCE concentrations in workers' personal breathing zone (PBZ) air and exhaled breath samples before and after the installations.

Generalization of the quantitative results of a field demonstration to all dry-cleaning establishments is necessarily limited. Individual differences among shops may overwhelm the effects of engineering controls. Even within the context of this demonstration, each dry-cleaning facility must be viewed as a separate study because of differences in such factors as dry-cleaning machine types, work practices, shop layouts, and engineering controls. However, the advantages of a quasi-experimental field demonstration over controlled experiments in a laboratory setting are a) the more complete understanding of the factors determining worker exposures and b) practical lessons learned from modifying machines within operating dry-cleaning shops.[4]

BACKGROUND

Health Hazards Related to PCE Exposure

PCE enters the body through respiratory and, to a lesser extent, dermal exposure. Acute exposure affects the nervous system (confusion, headache, drowsiness) and irritates skin and mucous membranes.[5,6] Chronic exposure has been associated with neurological, cardiac, respiratory, reproductive, hematological, and urinary damage.[7,8] The International Agency for Research on Cancer (IARC) classifies PCE in group 2A as a probable human carcinogen with sufficient evidence of animal carcinogenicity and limited evidence of human carcinogenicity.[8–10] IARC mentions esophageal and cervical cancers, and non-Hodgkin s lymphoma. Bladder and cervical cancers are consistently found to be associated with dry-cleaning exposure.[11]

The Occupational Safety and Health Administration (OSHA) permissible exposure limits for PCE include an 8-hour time-weighted average (TWA) concentration of 100 parts per million (ppm) (678 mg/m^3), a 200 ppm ceiling concentration, and a maximum peak exposure of no more than 300 ppm.[12] The American Conference of Governmental Industrial Hygienists (ACGIH®) classifies PCE as an A3 "confirmed animal carcinogen with unknown relevance to humans" and has assigned a threshold limit value (TLV®) of 25 ppm for an eight-hour TWA and a short-term exposure limit (STEL) of 100 ppm (a 15-minute TWA that should not be exceeded at any time during a workday).[13] ACGIH also recommends a Biological Exposure Index (BEI) of 5 ppm concentration in exhaled breath taken preshift after at least two consecutive days of exposure.[13,14] NIOSH classifies PCE as a potential occupational carcinogen and recommends that occupational exposures be reduced and the number of workers exposed be limited.[15]

Possible Interventions to Reduce Solvent Exposure

The dry-cleaning industry is in transition, and, over time, several "generations" of machines have evolved (Table I). The older wet-transfer process, where clothing is manually removed from

TABLE I
Dry-cleaning processes commonly utilized in the United States

Generation	Machine type	Primary characteristics
First	Wet-transfer	- Separate washing and drying machines - Clothing transferred manually
Second	Dry-to-dry Vented	- Single combination washer and dryer machine - Water-cooled condenser for solvent recovery - Aeration of clothing at end of cycle - Air vented to atmosphere
Third	Dry-to-dry Closed loop	- Single combination washer and dryer machine - Refrigerated condenser for solvent recovery - No aeration step
Fourth	Dry-to-dry Closed loop Secondary control	- Single combination washer and dryer machine - Refrigerated condenser for solvent recovery - No aeration step - Carbon adsorber for removal of residual solvent vapors from machine drum
Fifth	Dry-to-dry Closed loop Secondary control Detector	- Single combination washer and dryer machine - Refrigerated condenser for solvent recovery - No aeration step - Carbon adsorber for removal of residual solvent vapors from machine drum - Detector for level of solvent vapors within drum, prevents door opening if above a set point

the washing machine to a separate drying machine, has largely been replaced with the single combination washer/dryer, called a dry-to-dry machine. Dry-to-dry machines are categorized by their vapor recovery system. Fugitive solvent emissions are directly related to the machine's vapor recovery system, which governs the concentration of PCE remaining in the cleaning cylinder at the end of the dry cycle and the amount of PCE remaining in the garments or other items. The vapor recovery system is important; prior studies indicated that up to 70 percent of the total daily worker PCE exposure can occur when the dry-to-dry machine door is open for loading and unloading.[16] Our initial assumption was that reducing the amount of solvent escaping from the dry-cleaning machine during door opening could be an efficient engineering control for an existing dry-cleaning machine from both worker exposure and cost effectiveness perspectives.

Vapor recovery systems commercially available for retrofitting dry-to-dry machines include refrigerated condensers and carbon adsorbers. Water-cooled condensers, which are found on some machines, cannot achieve the low temperatures of refrigeration units, and PCE cylinder concentrations are 30,000 ppm or higher at the end of the wash cycle.[17] Refrigerated condensers control solvent emissions by using a refrigerant to cool solvent-laden air below the dew point of PCE. Theoretically, this process can achieve 95 percent vapor reduction in dry-to-dry machines and, in practice, has been shown to reduce the PCE concentration within the dry-cleaning machine cylinder to less than 9000 ppm.[17]

Carbon adsorbers are considered to be secondary controls because they are generally used in conjunction with a condenser. The standard, small carbon canisters found on many dry-cleaning machines have been shown to become saturated after about one day of use and, by themselves, cannot control solvent emissions.[16] The closed-loop carbon adsorber systems referenced in this article utilize heating coils for regeneration of carbon. They can achieve 95–99 percent solvent vapor reduction by removing PCE molecules from air passing over activated carbon.[18]

METHODS

Selection of Dry-Cleaning Shops for Study

From a database created from Business America on Disc® CD-ROM,[2] candidate shops from eight counties in southern Ohio and northern Kentucky were selected for study. An introductory letter was sent to all owners (> 200), seeking those interested in participating in the intervention. Five responded and, of these, three were chosen, based on predetermined selection criteria: Eligible shops were those (1) with a single dry-to-dry machine, (2) using PCE as the only dry-cleaning solvent, and (3) having sufficient space for the control equipment. Shops with state-of-the-art equipment, obviously leaking machines, open waterproofing tanks, or transfer machines were not eligible.

Shop Descriptions and Engineering Controls

Shop A had a full-time dry-cleaning machine operator and a presser, and several part-time employees to wait on customers, clean the shop, and deliver clothes. The front part of the store contained a coin laundry area, which was partially separated from the rear dry-cleaning area by a floor-to-ceiling partition. A 15-foot-wide opening joined the two areas. An approximately 10-year-old Suprema® Model 900 S2, 30-pound capacity, second-generation, vented, dry-to-dry machine, incorporating a water-cooled condenser and a small carbon adsorber, was situated in a corner of the dry-cleaning area. This area also contained spotting and pressing stations, and several comfort fans. A rear door, adjacent to the dry-cleaning machine, provided some general ventilation when temperatures in the shop became uncomfortable.

Shop B was a two-year-old business, employing a full-time dry-cleaning machine operator and a presser, as well as several part-time pressers. The dry-cleaning machine, purchased new at the time the shop was opened, was a third-generation, closed-loop refrigerated, dry-to-dry Forenta® Model D-345, with a 45-pound capacity. The plan of the shop was more open than that of shop A, with a 20-foot-high ceiling and no barriers to air flow between the front and rear doors. A large ceiling supply fan forced outside air through the shop, with several smaller, portable comfort fans located in the pressing area.

Shop C had a full time machine operator and a presser, and several part-time employees to wait on customers. The machine operator, who also managed Shop C, was the second generation to do so and had assisted in operations since a teenager. The operator usually ran the dry-cleaning machine and remained at the shop only during the morning and early afternoon. Similar to Shop B, no permanent barriers existed between the front and rear doors, although hanging garments occluded the open plan. A small fan in the rear wall provided exhaust ventilation, and several portable comfort fans were present. The second-generation, vented Detrex® Model 20-H, 25-pound dry-cleaning machine was over 20 years old. It had a water-cooled condenser and had been retrofitted with a Diversitron® azeotropic recovery device. Azeotropic devices are a little-used technology in which PCE is bubbled through water, forming a low boiling point aerosol that allows more PCE recovery than in a condenser alone.[1]

The dry-cleaning operation in all shops was relatively consistent. Garments were tagged, inspected, and sorted according to weight, color, and finish. Those with visible, localized stains were treated at a spotting station, generally by the same person who operated the dry-cleaning machine. The dry-to-dry process required three steps within the same machine: washing, extracting, and drying. Prior to washing, clothes were manually loaded into the cylinder, and the machine was programmed to automatically dispense PCE into the cylinder, inject detergent, and agitate the contents. Extraction consisted of spinning the contents at a high speed to remove PCE, followed by heated tumbling to dryness. Finally, garments were manually pressed, hung, and wrapped in plastic.

Engineering controls were retrofitted to the existing dry-cleaning machines at the three shops to reduce the concentration of PCE in the dry-cleaning machine cylinder at the end of the drying cycle. In Shop A, a 5-ton cooling capacity refrigerated condenser by PROS® was installed on the vented, dry-to-dry machine in place of its original water-cooled condenser and single-pass carbon adsorber. The cycle was modified to eliminate the aeration step by replacing it with a cool down step (a second- to third-generation machine conversion). In Shop B, a 60-pound closed-loop carbon adsorber by Forenta was installed as a secondary control in addition to the existing, factory-installed refrigerated condenser (a third- to fourth-generation machine conversion). The carbon adsorber unit was originally designed as an optional device for this model dry-cleaning machine. In Shop C, a 5-ton cooling capacity refrigerated condenser by PROS replaced the water-cooled condenser and azeotropic recovery device (a modified second- to third-generation machine conversion).

METHODS

PCE exposures in each shop were evaluated before and after the intervention, using PBZ air samples and exhaled breath samples, as well as observations on work practices, which we thought might influence PCE levels at the time of the evaluation. Full-shift PBZ air samples were collected using charcoal solid sorbent tubes with a flow rate of 0.2 L/min following NIOSH Method 1003.[19] Samples were analyzed by gas chromatography using a Hewlett-Packard® Model 5890A equipped with a flame ionization detector. Breath samples were collected and analyzed using NIOSH Method 3704,[20] developed in conjunction with this study. Workers were asked to move outside the shop to an area of expected low PCE concentration. They breathed normally several times, held their breath for 10 seconds (to allow the PCE in the lungs to come into equilibrium with that in the blood), and then exhaled through a tube containing Dry-Rite desiccant into a Tedlar bag. Three sequential breath samples were combined into one bag. Analysis was performed using a portable Photovac 10S Plus Digital Gas Chromatograph. Each sample was run in triplicate, as soon as possible, and not later than 24 hours after collection.

Ideally, breath samples were collected six times per sampling day for each worker: in the morning before the worker entered the shop, immediately before and after two unloading or loading (door-opening) events of the dry-cleaning machine, and at the end of the work day. Differences between breath samples collected less than five minutes before and after each door-opening event (called peak samples) were calculated for the operators. In addition, each worker's breath was collected the morning after the sampling day, before the worker entered the shop. These next-day samples were always taken after at least two consecutive days of exposure, so that the BEI of 5 ppm would be a relevant exposure criterion. Some samples were missed because of irregularities in the workers' schedules.

Study Design

The original design of the study was to monitor each of the three shops one day per week for three weeks before the engineering control was installed and for one day per week for three weeks following the installation. Each shop was monitored on the same day of the week because PCE bioaccumulates throughout the week; Shop A was monitored on Fridays, Shop B on Wednesdays, and Shop C on Thursdays. Originally, six subjects, a machine operator and an assistant at each shop, agreed to participate in the study, but the assistant at Shop C terminated employment before the engineering control was installed and is not included in this article.

Modern dry-cleaning machines are complex and, because few machines are retrofitted, there is a lack of experienced people to do the work. The installations of engineering controls were not as straightforward as expected, resulting in delays and modifications of the experimental design (especially, additional weeks of preintervention monitoring). In Shop A, the addition of a refrigerated condenser accentuated preexisting temperature control problems with the machine, a condition that had to be remedied before the intervention functioned properly; the repair required over two weeks. Directions for the installation in Shop B were not available, which resulted in a delay of three days.

Unrelated to our activities, the machine at Shop C began to leak at a gasket at the rear of the machine. It was decided to repair the leaking prior to retrofitting the machine. The repairs delayed the retrofit by five weeks. During periods when retrofits were not operating properly or leaks were being repaired, the status of the machine was designated as midintervention rather than pre- or postintervention. A summary of the resulting total study design is presented in Table II.

We expected seasonal variation in exposures (for various reasons, such as more garments are cleaned during winter months), and to compensate, the analysis was performed for Shops A and C using only observations that were made approximately within the month before the intervention installation and within the month after the intervention installation was completed and the problems were corrected. Using this reduced data set, the duration of the studies at Shops A and C were about 3.5 months each. The full study at Shop B took about three months, so this data set was not reduced.

Statistical Analysis

Data were examined to see if the usual assumptions for parametric analyses were met. The personal breathing zone TWA (PBZ-TWA) and the next-day breath PCE had fairly symmetrical

TABLE II
Number of weeks workers were sampled before and after engineering intervention installation for each shop

Intervention status[A]	Job category	Shop A refrigerated condenser (weeks)	Shop B charcoal adsorber (weeks)	Shop C refrigerated condenser (weeks)
Preintervention	Operator	5	5	17
	Presser	3	4	NA
Midintervention	Operator	2	0	5
	Presser	2	0	NA
Postintervention	Operator	4	3	3
	Presser	1	3	NA

NA = no employee available in designated job.
[A] Shop A, Pre: water cooled condenser, single-pass carbon adsorber; Post: refrigerated condenser. Shop B, Pre: refrigerated condenser; Post: refrigerated condenser, closed-loop carbon adsorber. Shop C, Pre: water cooled condenser, azeotropic recovery device; Post: Refrigerated condenser.

distributions. The peak breath PCE concentrations (change during a door-opening event) had a skewed distribution, however. PCE concentration was higher after the door had been opened in all cases except one, when change was −4.8. This value was retained and 5.0 was added to all of the peak PCE data. Then the natural log was taken. The distribution of this new variable was fairly symmetrical, and thus parametric statistical tests were used. Analyses were performed using SAS procedures.[21] Least squares means, which are means adjusted for other variables in the model, are presented. (For peak exposure, instead of the arithmetic mean, 5.0 was added to each preintervention value, the geometric mean was calculated, and 5.0 was subtracted from it.) All testing was performed with the probability of a Type I error set at 0.05.

Three potentially confounding covariates could affect the results: ventilation (i.e., whether the shop door was open or not), number of loads per day, and length of time the employee worked that day. Because the sample sizes were small, the number of covariates was reduced in the manner described in the appendix.

RESULTS

Overall, including data not used in the analysis, the full-shift PBZ-TWA air samples ranged between 94 ppm PCE (operator, Shop C) to 0.54 ppm PCE (presser, Shop B). Consequently, no values exceeded the OSHA PEL of 100 ppm, although 44 percent of all samples exceeded the ACGIH TLV of 25 ppm. All samples exceeding the TLV were in Shops A or C; after the interventions were fully operational, only two samples (both relatively low values: 25.2 ppm and 26.8 ppm) exceeded the TLV. The next-day breath values ranged between 10.7 (operator, Shop C) to 0.18 ppm (presser, Shop B); 16 values (14 before the intervention) exceeded the BEI of 5 ppm.

For Shop A, ventilation (whether or not the shop door was open) was a significant covariate for peak breath. However, ventilation was confounded with intervention, in that the shop door was always open before the intervention, and always closed during and after the intervention. Thus, the analysis was performed without adjusting for ventilation, with the understanding that a true reduction in peak PCE due to the intervention could be masked by an effect of ventilation. The intervention did not have a statistically significant effect on PCE exposure as measured by PBZ-TWA concentration or next-day breath PCE concentration (Table III), although the observed least squares means after the intervention were lower than those before the intervention for both variables. The intervention did have a statistically significant effect on peak breath PCE concentration. The preintervention mean was significantly higher than the midintervention mean, and higher ($p = 0.0636$) than the postintervention mean.

For Shop B, ventilation was a significant covariate for PBZ-TWA, week was a covariate for peak PCE, and next-day breath had no significant covariates (Table IV). The intervention did not have a statistically significant effect on PCE exposure as measured by the PBZ-TWA concentration or peak breath value, although the observed least squares mean after the intervention was lower than that before the intervention. For next-day breath PCE level, the subject-by-intervention-status interaction was statistically significant, indicating that the effect of the intervention was different for the two subjects. For the operator, the mean preintervention breath PCE concentration was higher than the postintervention breath PCE concentration ($p < 0.01$). For the presser, the difference between pre- and postintervention breath PCE level was not statistically significant, and, in fact, the postintervention value was slightly larger.

TABLE III
Effects of engineering controls in shop A—Reduced data

		Least square mean of concentration in ppm (SE of LSMean)[B]			
Evaluation method	Covariates[A]	Pre	Mid	Post	Statistical significance
PBZ-TWA	Subject Day	n = 6 21.57 (4.38)	n = 4 20.55 (5.22)	n = 5 16.94 (4.99)	No
Exhaled air—next morning	Subject	n = 6 4.66 (0.53)	n = 4 5.15 (0.63)	n = 5 4.29 (0.60)	No
Exhaled air peak due to door opening	None	n = 11 5.07 (1.07)	n = 4 1.98 (1.13)	n = 8 3.11 (1.09)	Yes[C] (pre > mid)

n = number of samples.
[A]Ventilation was significant for all measurements but was confounded with the intervention.
[B]Standard error of least square mean.
[C]($p < 0.05$).

For Shop C, the only significant covariate for next-day breath PCE concentration was ventilation (Table V). The effect of the intervention was not statistically significant, although for PBZ-TWA concentration, it approached statistical significance ($p = 0.0510$). The observed least squares means after the intervention were consistently lower than those before the intervention for all measures.

DISCUSSION

The overall trends of this demonstration project suggest that worker exposures to fugitive PCE emissions during door opening events were reduced by the engineering controls employed. Solvent concentrations were consistently lower after the engineering controls were successfully implemented in all shops. One presser showed an increase (not statistically significant) in

TABLE IV
Effects of engineering controls in shop B—All data

		Least squares mean of concentration in ppm (SE of LSMean)[A]		
Evaluation method	Covariates	Pre	Post	Statistical significance
PBZ-TWA	Subject Ventilation	n = 8 3.46 (0.50)	n = 6 2.74 (0.54)	No
Exhaled—next morning (operator)	None	n = 5 3.32 (0.37)	n = 3 1.04 (0.47)	Yes[B] (pre > post)
Exhaled air—next morning (presser)	None	n = 4 0.72 (0.41)	n = 3 1.53 (0.47)	No
Exhaled air peak due to door opening	Day	n = 13 2.22 (1.10)	n = 5 0.20 (1.7)	No

n = number of samples.
[A]Standard error of least square mean.
[B]($p < 0.01$).

TABLE V
Effects of engineering controls in shop C—Reduced data

Evaluation method	Covariates	Least squares mean of concentration in ppm[A] (SE of LSMean)[B] Pre	Mid	Post	Statistical significance
PBZ-TWA	None	n = 5 47.54 (7.33)	n = 4 25.13 (8.20)	n=2 16.13 (11.59)	No
Exhaled air—next morning	Ventilation	n = 5 5.15 (0.79)	n = 4 4.48 (0.82)	n = 3 3.35 (0.64)	No
Exhaled air peak due to door opening	None	n = 9 10.19 (1.36)	n = 11 5.62 (1.32)	n = 12 6.62 (1.31)	No

n = number of samples.
[A]Differences between pre and mid indicate effect of fixing leaks; differences between mid and post indicate the effect of the intervention.
[B]Standard error of least square mean.

next-day breath concentration, but this subject had minimal PCE exposure both pre- and postintervention.

Despite the trends, statistical significance was not consistently achieved. There were three shops and three dependent variables; of the nine tests (based on 3 to 3.5 months of data), two were significant, and seven of the nine differences indicated exposure was reduced after the intervention. One possible reason for the lack of significance is that, with the small sample sizes available, this study would detect only relatively large differences, a reasonable assumption based on the literature, which suggested a reduction of up to 70 percent, but measured reductions were less than expected.[16]

It is not valid to increase power by grouping or comparing these shops because of the many differences among them. The types of engineering controls that could be installed on the various existing machines were dissimilar. Ages of the dry-cleaning machines ranged from 2 to over 20 years, and gasket leaking became a problem with the oldest machine. Physical layouts of the shops were dissimilar. Whether the shop door was open, a covariate that proved to be significant in some cases, was dependent on layout and the season of year. Finally, work habits and production levels varied among shops. Considering these conditions, it is not surprising that the range of exposures among shops was wide: Shop B had a mean preintervention PCE TWA of about 3 ppm, while, at the other extreme, Shop C had TWAs of over 50 ppm.

The installation of the refrigerated condensers in Shops A and C resulted in those shops having the same type of engineering control as Shop B had preintervention, since Shop B originally had a factory-installed refrigerated condenser. Postintervention PBZ-TWA PCE concentrations were about 16 ppm for Shops A and C, while the preintervention PBZ-TWA PCE concentration was about 3 ppm for Shop B. However, it should not be concluded that add-on refrigerated condensers are not as effective as factory-installed condensers. Too many other variables could influence these comparisons among shops. In addition to the physical differences among the shops, the operators at Shops A and C, but not B, were observed occasionally truncating the dry cycle to improve productivity, a work practice that could greatly contribute to PCE exposures.

During this study, variability was controlled both physically (for instance, by restricting the data used in the comparisons to 3.5 or fewer months, or by repairing leaks prior to the intervention) and, to the extent possible, statistically (by including measured variables as covariates). A larger study including more shops would be required to more fully resolve issues of variability. Also, because an open shop door was often a significant covariate, further studies should include detailed information on ventilation patterns that might provide information regarding accessory ventilation devices to reduce worker exposures.

Additional insight into exposures in dry-cleaning shops results from measurements related to the machine leaks in Shop C. A net improvement of about 9 ppm can be attributed to the engineering controls by comparing the midintervention (after the leaks were repaired) and the postintervention status (Table V). Repairing leaks resulted in a net improvement of over 22 ppm (comparing pre- and midintervention status). Clearly, leaking machines cannot be ignored in terms of workers' exposures—machine maintenance can be important in dry-cleaning shops.

CONCLUSIONS

Even with the small scale of this project, a consistent reduction in the PBZ-TWA PCE concentration resulted from installing engineering interventions in all shops. The results support the hypothesis that installing relatively low-cost engineering controls on existing dry-cleaning machines (especially by replacing water-cooled condensers with refrigerated condensers) can reduce the machine operators' exposures to PCE. However, work practices, especially maintenance procedures, were also important in reducing exposures; for example, repairing a leaking dry-cleaning machine (Shop C) was shown to have a greater impact on one worker's overall PCE exposures than the retrofit engineering control. Further, dry cleaners contemplating retrofitting their machines should consider that we encountered technical difficulties during the installation of the retrofit vapor-recovery devices.

Several recommendations can be made. Manufacturers should facilitate the installation of retrofits by providing technical assistance. They should place cycle-dependent interlocks on the doors to discourage operators from opening them until the cool-down and dry cycles have been completed. Dry-cleaning shop owners should retrofit existing dry-cleaning machines with engineering controls (refrigerated condensers and/or carbon adsorbers) only if the machines are otherwise in good working order and after consultation with their machine's manufacturer. Employers should be educated so they understand the health hazards of PCE exposure and are aware of appropriate work practices to minimize exposures, being especially diligent to keep machines well maintained so they do not leak. They should not tolerate machines that are releasing PCE odors detectable to the human nose, and should routinely monitor PCE levels within their shops by participating in quantitative sampling programs, some of which are offered by PCE solvent manufacturers or trade groups. Employees should be educated so that they understand the routes of exposure for PCE and should be given specific instructions not to circumvent safety features on dry-cleaning machines.

ACKNOWLEDGMENTS

This study would not have been possible without the patient participation of dry cleaners at Shops A, B, and C, and the assistance of Larry Wetzel, Clint Morley, Chris Newman, Nathan Sweet, Ed Burroughs, Richard Bullard, Donald Booher, and Machinex, Inc.

DISCLAIMER

Mention of company names or products does not constitute endorsement by the National Institute for Occupational Safety and Health.

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APPENDIX

Statistical analysis of the models was performed in the following manner. For Shops A and B, an effect of subject was forced to remain in the models for PBZ-TWA concentration and next-day breath PCE concentration because these shops had two participants, whereas Shop C had a single participant. For each of the three shops, a model was fit that included the forced variable (for Shops A and B) and the potentially confounding covariates. The covariate with the largest p-value was then excluded if that p-value was greater than 0.05. This was repeated until only covariates with p-values less than or equal to 0.05 and the subject effect, when appropriate, remained. These covariates were used to adjust the test for intervention status (pre, mid, post) in the linear model for final analysis.

For Shops A and B, the final model included the following covariates: subject when appropriate, any confounding covariates, intervention status, and a week effect (differences from week to week) nested within intervention status effect. For Shop C, only the confounding covariates and intervention status were included (because week was the only error term). Before fitting the above model for PBZ-TWA concentrations and next-day breath PCE concentrations in Shops A and B, however, an interaction effect between subject and intervention status was added and checked for significance. If not significant, it was removed from the model and the above main effects model was fit to test for the effect of intervention status. If the interaction was significant, models containing the covariates and intervention status were fit separately for each subject to test for the effect of intervention status. The effect of week was removed if it was not significant. If it was significant, its mean square was used as the denominator for testing intervention status.