HHS Public Access
Author manuscript
J Occup Environ Hyg. Author manuscript; available in PMC 2022 June 01.

Published in final edited form as:
J Occup Environ Hyg. 2021 June ; 18(6): 276–287. doi:10.1080/15459624.2021.1910280.

Assessment of home care aides' respiratory exposure to total volatile organic compounds and chlorine during simulated bathroom cleaning: An experimental design with conventional and "green" products

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Abstract

Home care (HC) aide visits to clients' homes often involve cleaning and disinfecting (C&D) bathrooms. Some ingredients in C&D household products are associated with respiratory illness, including sodium hypochlorite (bleach) and quaternary ammonium compounds (quats). "Green" products may be safer for the environment, however there are limited quantitative evaluations of their respiratory risks. This study assessed airborne concentrations and time profiles of total volatile organic compounds (TVOC) and chlorine generated during typical bathroom cleaning performed by aides using conventional and green products. Aides performed cleaning tasks in a simulated residential bathroom constructed in an environmental air sampling laboratory. A balanced experimental design involved each aide coming to the lab for four visits during which she performed two 20-min cleaning sessions using one of three C&D products (bleach-based, 1–5% sodium hypochlorite by weight; quats-based, 0.1–1% by weight quaternary ammonium compounds; and "green," 0.05% by weight thymol, a component of botanical thyme oil) or distilled water as a control. TVOC and chlorine direct reading instruments were attached to aides with sample inlets located in the breathing zone. Ten-second averages of TVOC and chlorine gas concentrations and instantaneous peak concentrations were recorded for the sessions' duration.

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Disclosure statement The authors have declared no conflicts of interest.

Ethics approval
All study protocols and materials were approved by the University of Massachusetts Lowell Institutional Review Board. Written informed consent was obtained from all volunteers before their participation in the study.

TVOC concentrations by methods of C&D application (spraying, streaming, wiping) also were evaluated. The study completed 169 air sampling sessions with 22 aides. The quats-based product generated more than twice the average TVOC concentrations (mean = 1,210ppb) than the bleach-based (mean = 593 ppb) or green (mean = 498 ppb) products. Each product generated TVOC concentrations that rose rapidly within the first few minutes of application. Spraying produced the highest TVOC exposures, wiping the lowest. Thirteen aides (65%) experienced peak chlorine exposures above the OSHA PEL ceiling limit (1 ppm) when using the bleach-based product. HC aides may experience respiratory hazards from use of conventional or green C&D products formulated with bleach or other respiratory irritants and sprayed in small, poorly ventilated spaces typical of bathrooms. Spraying should be avoided.

Keywords

Bleach; disinfection; home healthcare; occupational health; TVOC

Introduction

Home care aides assist people in private homes with health and personal care services including mobilization, bathing, dressing, and toileting, and with household tasks including food preparation and cleaning. Aides are hired by businesses, called agencies, or hired directly by the person receiving care, referred to as “clients” in this paper. Numerous occupational titles are used for aides working in homes, including home health aide, home care aide, and personal care aide. In this paper, the term “home care (HC) aide” refers to the full range of occupational titles because there is overlap in job duties, particularly in regard to cleaning, the focus of this study. The great majority of HC clients are adults aged 65 years or older as well as people of all ages with illness or physical or cognitive disabilities. Home care clients may live in single-family houses, apartment buildings, or other multi-unit housing.

Aides may conduct multiple visits to clients’ homes per day (Quinn et al. 2016). Increasingly, these visits involve cleaning tasks for the purposes of infection control and prevention (Goodyear et al. 2018; Markkanen et al. 2014, 2017). A previous survey found that 80% of nearly 3,500 HC aide visits to clients’ homes in Massachusetts USA, involved cleaning and disinfecting bathrooms and kitchens. Bleach was the most commonly used disinfectant; products with ammonia and other strong chemicals also were used (Quinn et al. 2016). Infection prevention practice usually recommends that cleaning, the removal of visible soil, and disinfecting, the elimination of pathogens, be performed sequentially. However, commercial products for home use are increasingly formulated with multiple chemical ingredients that perform cleaning and disinfecting (C&D) in one step. In HC, the most intensive C&D tasks typically involve bathroom fixtures (tub/shower, toilet, sink), using ready-to-use spray products provided by the client. Residential bathrooms in all types of housing are usually small spaces with low or no ventilation.

Many common C&D products available in retail stores contain ingredients that are known respiratory irritants or sensitizers and are associated with adverse respiratory health effects such as asthma (Archangelidi et al. 2020; Quinn et al. 2015). In the United States, the two most common disinfecting ingredients in household C&D products are sodium hypochlorite (bleach) and quaternary ammonium compounds (quats), both associated with symptoms of respiratory illness (LaKind and Goodman 2019; Rosenman et al. 2020). Additional C&D product ingredients of respiratory concern include hydrogen peroxide, alcohols, peracetic acid, and volatile organic compounds such as ketones, terpenes, aldehydes, and fragrances (Blackley et al. 2019; Carder et al. 2019; Dumas et al. 2020; Henneberger et al. 2020; Walters et al. 2019; Weinmann et al. 2019).

Products advertised as safer for the environment, sometimes called environmentally preferable or “green” C&D products, are now also widely available in retail stores. Many of these are certified by third parties attesting to lower environmental impacts, such as reduced biopersistence. However, there are limited quantitative evaluations of respiratory health risks related to green C&D products. Due to the spray application of all types of C&D products in small, poorly ventilated spaces, there is concern that some airborne chemical exposures may be sufficient to increase respiratory health risks for HC aides, especially if they clean multiple bathrooms and kitchens a day.

The research reported here is part of a larger initiative on respiratory health and C&D in HC, called the Safe Home Care Cleaning and Disinfecting Study. The objective of the research presented here was to assess quantitatively airborne concentrations and time profiles of total volatile organic compounds (TVOC) and chlorine generated during typical HC cleaning tasks performed by aides using two conventional household C&D products and one green C&D product.

Methods

Ethics approval

All study protocols and materials were approved by the University of Massachusetts Lowell Institutional Review Board. Written informed consent was obtained from all volunteers before their participation in the study.

Study design

The air sampling data for this study were collected during July 2016 through April 2017. Due to HC client privacy concerns and difficulty reaching aides during their remote work, the exposure assessment was conducted with aides performing their typical cleaning tasks in a simulated residential bathroom constructed in an environmental air sampling laboratory. A balanced experimental study design involved each HC aide coming to the lab for a total of four visits, scheduled at least 1 week apart. During each visit, two 20-min cleaning sessions were performed by the aide using one of three C&D products or distilled water as a control. Each visit involved cleaning with the same product. The products were randomly assigned across the aide’s four visits. The two sessions performed within each visit were separated by a 20-min break away from the exposure area, similar to the work schedule of aides who perform two consecutive visits to clients’ homes in multi-unit housing. This paper reports on the methods and materials for the exposure assessment for TVOC and chlorine using direct reading instruments.

Exposure setting

Cleaning tasks were performed in a simulated residential bathroom 38 ft^2 (3.5 m^2) constructed in an environmental air sampling lab 550 ft^2 (51 m^2) (Figure 1). The simulated bathroom was constructed according to typical building plans for elder housing, with dimensions W = 61 in (159 cm), L = 89 in (226 cm), H = 99 in (251 cm), and V = 311 ft^3 (8.8 m^3). The bathroom had a vinyl tile floor, was framed using 2 × 4 pine lumber, and was lined with 4 mil (0.004 in, 0.01 cm) plastic sheeting to create an enclosed volume with an opening (no door) for access/egress, that is, simulating a bathroom with the door open. Plastic composite wallboard was installed around the tub/shower and to a height of 48 in (122 cm) on all interior walls to allow easy removal of cleaning product over-spray. The bathroom was equipped with a porcelain toilet, a one-piece gel-coated fiberglass tub/shower and a small vanity cabinet with one-piece molded composite sink-top. The vanity cabinet was freestanding and made of enamel-coated particleboard. The tub/shower was equipped with an-overflow drain cover and a floor drain insert. The sink-top was equipped with a faucet and drain insert. None of the fixtures were connected to water supply or sanitary drains (building plumbing); instead, rinse water was dispensed with a one-gallon tank sprayer and removable basins were inserted below the fixture drains to collect wastewater. The tub/shower was equipped with a shower curtain, two wall-mounted storage racks, two grab-bars, and a shower stool. Neither the bathroom nor the lab had mechanical ventilation. Portable fans were used to provide dilution ventilation between cleaning sessions according to the protocol described in the cleaning procedure. The lab area was significantly larger than the bathroom and could be opened to a hallway allowing sufficient air volume exchange for effective dilution ventilation of the bathroom between cleaning sessions.

Selection of cleaning products and application method

The C&D products and application methods selected for this study were informed by the results of focus groups of aides to characterize HC work (Markkanen et al. 2014); a microbiology laboratory comparative evaluation of conventional vs. green C&D products to remove soil and eliminate pathogens (Goodyear et al. 2015), and a microbiology field study for the effectiveness of conventional and green C&D products to eliminate pathogens in elder housing (Goodyear et al. 2018). For this study, three ready-to-use spray C&D products were selected from brands available at local stores. Two were reported in aide focus groups to be among the most commonly used conventional products, while the third was a widely available green C&D product. The active disinfecting ingredient in the first conventional product was 1–5% sodium hypochlorite by weight according to the product's safety data sheet (the "bleach-based product"). The second conventional product contained 0.1–1% by weight quaternary ammonium compounds (the "quats-based" product). The active disinfecting ingredient in the green product was 0.05% by weight thymol, a mono-terpene and component of botanical thyme oil. Bottled distilled water was used as a control.

Population recruitment

HC aides were recruited from HC agencies in Massachusetts. An administrator at each agency distributed the recruitment materials to eligible employees and interested volunteers returned a response form to the study team. Selected participants were at least 18 years old, did cleaning as part of their job in HC, and could commit to four 3-hr visits to the lab over a 4–6-week period. In addition to a small monetary incentive for participation, aides were paid their regular hourly rate for their time in the lab study.

Air sampling

Each aide's visit to the lab was comprised of two 20-min bathroom cleaning sessions during which direct reading monitoring was used to characterize the realtime air concentration variability of TVOC and chlorine in aides' breathing zones.

Direct reading instruments

Total volatile organic compounds (TVOC)—Real-time TVOC measurements were obtained with a ppbRAE 3000 photoionization detector (PID) (RAE Systems/Honeywell, San Jose CA) and associated ProRAE Studio II, v.1.11.0 software. The PID was worn by the study participant in a vest with the probe secured in the breathing zone. The instrument was battery powered, equipped with a 10.6 eV lamp, a flow rate of 500 cm^3/min, a measurement range of 1 ppb to 10,000 ppm with 1 ppb resolution and a T90 response of three seconds. It was calibrated with zero-grade air and 10 ppm isobutylene in air at least weekly, typically on the day of each participant lab visit. Sample averaging time was set to 10 sec with continuous data logging of maximum, minimum, and average TVOC concentrations in isobutylene equivalents for each 10-sec interval. In order to allow the instrument to be carried in a backpack by the participant to obtain breathing zone measurements, the inlet probe was extended with a 30-cm piece of Viton tubing (ID 3/8 in, 0.95 cm). An RAE external filter cartridge (part no. 002–3022-010) was added to the Viton tubing inlet to protect the instrument from entraining liquid aerosol produced by the pump spray atomizers on the C&D product bottles.

Chlorine (Cl_2)—Real-time measurements of chlorine gas were obtained with a Dräger Pac 7000 passive diffusion sampler and associated Dräger CC-Vision Basic, v.7.1.0 software (Dräger Safety, Lübeck, Germany). The instrument was clip-on type, battery powered, equipped with a chlorine electrochemical sensor, passive diffusion membrane, a measurement range of 1–20 ppm with a 0.05 ppm resolution and a T90 response of 30 sec. The instrument was calibrated with zero air and 5 ppm chlorine in nitrogen at least weekly. Sample averaging time was set to 10 sec with continuous data logging of average concentrations for each 10-sec interval and the maximum concentration measured during the total data logging session.

Other measurements

Temperature, pressure, and relative humidity—During each cleaning session ambient conditions were recorded in the lab where the exposure measurements were made using a digital weather station (AcuRite, Lake Geneva, WI).

Event timing—In order to control for the duration of each task comprising a cleaning session, four battery-powered digital timers were activated simultaneously at the start of each session. The four timers were pre-set to alarm at 10 min, 15 min, 18 min, and 20 min. The series of alarms were used to move the participant through the timed tasks.

Amount of cleaning product dispensed—Each study participant was instructed to spray the C&D product on the bathroom surfaces as she would during a typical home visit; the amount of product a participant could use was not restricted. During each cleaning session the amount of C&D product dispensed by the participant was calculated as the change in weight of the spray bottle. All measurements were made using a digital balance (AND/A&D, Japan).

Equipment preparation—The direct reading instruments were started approximately 45 min prior to each visit. Direct reading instrument data logs were cleared, internal clocks were set to NIST time, battery power status was checked, and instrument calibration was verified.

Cleaning product preparation—Each C&D product and the distilled water were assigned a number (1–4) and the manufacturers' labels were replaced with the number to disguise the product. Products were dispensed in their original manufacturer spray bottles. Spray nozzles were tested for proper function and bottles were weighed immediately prior to use. Paper towels were provided for cleaning.

Preparation of the simulated bathroom—Fixture surfaces were marked with washable crayons to simulate a soiled surface. The marked surfaces included: (1) walls, floor, and exterior front face of the tub/shower; (2) all surfaces of the toilet including tank, lid (top and bottom), seat (top and bottom), bowl (interior and exterior), and exterior of the base; (3) the sink basin top, bowl, and faucet; and (4) the top of the shower stool. The surface markings provided a visual reference to identify which surfaces to clean. The bathroom was ventilated for 15 min by placing a rolling stand with two box fans in the doorway such that dilution air was directed inward at a flow rate of approximately 5,000 cfm (141.6 m^3/min).

Outfitting the participants—Study participants wore an impermeable disposable lab coat and nitrile gloves. They were also offered the option of wearing hospital scrub pants to protect their clothing. Participants were fitted with a vest that held the direct reading instruments.

Cleaning session tasks—On their initial visit, study participants watched a brief training video instructing them on the cleaning tasks and techniques, based on typical cleaning practices identified in HC aides focus groups (Markkanen et al. 2014). Participants were asked to spray the C&D product onto the soiled surfaces, using the same amount of product they would typically use during a client home visit. The C&D product and soil were then wiped off with paper towels which were placed in a plastic pail during the cleaning, then removed from the lab and disposed at the end of each session. The sequence of tasks and times that comprised each 20-min cleaning session included 10 min for the tub/shower (shower stool, left-end wall, center wall, right-end wall, tub interior, tub exterior); 5 min cleaning the toilet (no specific sequence instructions); 3 min cleaning the sink top, bowl, and faucet; and 2 min remaining in the bathroom after the cleaning tasks stopped in order to measure the first minutes of exposure decline after the cleaning tasks stopped and to simulate the time aides used to gather materials before exiting the bathroom.

Evaluation of C&D product application method and TVOC exposure—Additional TVOC air sampling of bathroom cleaning was conducted to evaluate how the method of C&D product application could impact exposures. Only the quats-based product was used for this evaluation because it produced the highest PID response, thus generating a set of concentration-time profiles that made it easiest to compare application methods. Spraying was compared to “streaming,” a more focused, concentrated column of C&D product liquid produced by a different setting on the product bottle nozzle, and “wiping” conducted by first applying the C&D product directly to a sponge, and then wiping it across the bathroom surfaces. Spraying, streaming, and wiping were conducted using the same protocols as in all previous experiments except that an industrial hygienist member of the research team conducted the C&D product applications. Additionally, the order of the bathroom cleaning tasks was reversed, and the time spent in the tub/shower was shortened by approximately 3 min.

Between-cleaning session preparations—Following completion of the first cleaning session, the direct reading instruments were removed from the participant who was then escorted to an office while the lab was prepared for the second cleaning. The bathroom fixtures were thoroughly sprayed with tap water, which was collected in drain basins and removed for disposal. Fixtures were dried with a squeegee and towels. The dilution ventilation fan cart was then placed in the bathroom doorway for a minimum of 15 min to assure surface drying and purge the room air of remaining C&D product emissions. The direct reading instruments were used to determine when the bathroom TVOC and chlorine exposures had returned to background before the next cleaning session began. After the dilution ventilation was completed, fixture surfaces were re-soiled with a similar number of washable crayons.

Post-cleaning activity—At the end of the second cleaning session, data log files for the direct reading instruments were downloaded to a secure server.

Data analysis

Time-weighted averages (TWA) of TVOC and chlorine air concentrations by C&D product were calculated. Smoothed airborne concentration-time profiles generated by each C&D product were then computed by combining the direct reading monitoring data across all cleaning sessions using a particular C&D product. This smoothing was performed using a nonparametric smoothing technique, Locally Weighted Regression Scatterplot Smoothing (LOWESS or LOESS) (Cleveland and Devlin 1988).

In order to evaluate the relationship between the amount of C&D product sprayed and airborne concentrations generated in the bathroom, mixed regression models with random person intercepts were used. These models accounted for within-person effects as the same aide performed two sessions within each visit. For each of the three C&D products, a model was constructed using the amount of product sprayed and the TWA TVOC concentration; a fourth model was constructed using the amount of bleach-based product sprayed and the TWA airborne chlorine concentration. All statistical calculations were performed using SAS 9.4 (SAS Institute Inc., Cary, NC).

Results

Study participants and data collection

Overall, 22 HC aides participated in the study, contributing a total of 169 air sampling sessions. This number is slightly lower than the maximum possible (22 aides x 4 visits/aide x 2 sessions/visit = 176 sessions), due to inability of all aides to participate in all sessions and to instrument data storage malfunctions when recording some session data. The total numbers of visits and sessions by C&D product were: 20 visits (40 sessions) using the bleach-based product; 20 visits (40 sessions) using the quats-based product; 22 visits (43 sessions) using the green product; and 22 visits (46 sessions) using distilled water.

Air sampling

TVOC exposure by C&D product—Aide bathroom cleaning visits using the quats-based product generated more than twice the average TVOC breathing zone concentrations (mean = 1,210 ppb) than aides' visits using the bleach-based product (mean = 593 ppb) or the green product (mean = 498 ppb) (Table 1). A sample set of TVOC concentration-time profiles generated by the same aide as she performed a cleaning session using each product illustrates the higher TVOC concentration with more frequent, distinct peaks generated when spraying the quats-based product as compared to the other two products (Figure 2). Because the mixture of substances comprising the TVOC generated during the use of different C&D products varies, the TVOC concentrations are presented in isobutylene equivalents and can be compared across products. While the concentrations and peaks differ, the patterns of exposure over the 20-min sessions are fairly similar, as the use of each product generates TVOC concentrations that rise steeply within the first few minutes when spraying begins (Figure 2).

These product patterns of exposure persisted when the data for all aides' TVOC concentration-time profiles were combined across sessions by product using the LOESS smoothing technique (Figure 3). No occupational exposure limits (OELs) for TVOC exist so a reference value of 500 mg/m^3 (218 ppb in isobutylene equivalents) recommended by the Leadership in Energy and Environmental Design (LEED) is provided in Figures 2 and 3 (AIHAV® Construction and Toxicology Committees and Green Building Working Group 2017). Both figures show that the LEED guideline for TVOC is exceeded rapidly during the use of all three C&D products.

Chlorine (Cl_2) exposure—Chlorine gas was detected only during use of the bleach-based product. A typical airborne concentration-time profile is shown in Figure 4 generated by the same HC aide for whom the TVOC concentration-time profiles were shown (Figure 2). The OSHA Permissible Exposure Limit (PEL) ceiling of 1 ppm for chlorine exposure (NIOSH

2020) is shown for comparison (Figure 4). The OSHA PEL ceiling limit was exceeded after approximately 5.5 min of tub/shower cleaning and again during toilet cleaning. The NIOSH REL, 0.5 ppm averaged over 15 min, (NIOSH 2020) and ACGIHV® STEL, 0.4 ppm averaged over 15 min (ACGIH 2019) are also presented for visual reference in Figure 4.

For evaluation of the study population's chlorine exposure data, the peak airborne chlorine concentrations generated during each aide's lab visit using the bleach-based product were compared to the OSHA PEL ceiling limit (Figure 5). Thirteen of the 20 visits (65%) involving cleaning with the bleach-based product resulted in peak exposures above the OSHA PEL ceiling limit of 1 ppm.

Amount of cleaning product applied—While the sequence and the time permitted cleaning task (tub/shower, toilet, sink) was fixed across all study participants, the amount of spray product that an aide was permitted to use was not restricted; instead, aides were asked to apply the products in the same way they would for bathroom cleaning during an actual HC visit. The amount (in grams) of C&D product and of distilled water sprayed by the aides varied approximately four-fold, however the median amount of product sprayed was nearly the same for all three products and for distilled water (Table 2). That is, there was variation among aides in the amount of product they used, but, on average, they used the same amount of product and of distilled water to accomplish the cleaning tasks. Despite this person-to-person variation, the amount of product used did not affect the TVOC concentration when using either the bleach-based or the green product, according to the mixed regression models (Table 2). In contrast, greater amounts of quats-based product were associated with higher TVOC concentrations ($\beta = 2.0$ ppb/g, $p = 0.01$, Table 2). The analogous model measuring the association between the airborne chlorine concentration and the amount of bleach-based product used showed no association ($\beta = 0.0008$ ppm/g, $p = 0.21$).

Evaluation of C&D product application method and TVOC exposure—Spraying produced the highest TVOC exposures compared to the other application methods (Figure 6). For all application methods, TVOC exposures were still detectable several minutes after cessation of cleaning, even after using dilution ventilation fans in the bathroom. The wiping application produced considerably lower TVOC exposures than the spraying and streaming applications and was more rapidly cleared from the bathroom.

Discussion

This study followed an experimental design to evaluate the concentrations of TVOC and airborne chlorine generated during bathroom cleaning by HC aides using three common household C&D products. Construction of the bathroom in an environmental lab enabled precise control of potential exposure determinants and extensive air sampling that would have been intrusive to perform in private homes. The airborne exposures generated by the C&D products, two conventional and one green product, were compared to distilled water, all randomly assigned to aides as they came to the environmental lab for four cleaning visits, that contributed a total of 169 twenty-min cleaning sessions with direct reading monitoring. The 20-min sessions approximated the work organization of aides who may be assigned consecutive client visits in multi-unit housing, each involving bathroom cleaning.

The concentrations of TVOC and chlorine approached maximums well before the end of the 20-min cleaning sessions. In the case of the quats-based product, the TVOC concentrations rose rapidly within 2 min of the start of the session, approaching the maximum concentration in approximately 5 min and generating higher TVOC concentrations than the other two products overall (Figure 3). Sessions with the bleach-based and green products showed a more gradual rise in the TVOC concentrations, each approaching the maximum 7–10 min after the start of the spray cleaning tasks (Figure 3). The regression models evaluating the association between the amount of product used and TVOC concentrations (Table 2) show that when the bleach-based and green products were used, there was no relationship between the amount of product and airborne concentrations of either TVOC or chlorine generated.

Cleaning with the quats-based product generated more than twice the TVOC exposure than the other two products (Figure 3, Table 1) even though the median amount of product sprayed was similar (Table 2). Additionally, the amount of quats-based product sprayed was associated with the TVOC concentration (Table 2). Quaternary ammonium compounds per se are not volatile and thus not likely to contribute to this TVOC exposure. However, the quats-based product does contain volatile ingredients. Figures 2 and 6 show how important the spray action of the quats-based product was in contributing to the increase in airborne concentration, while for the other products, spraying produced a more gradual increase in the concentration that accumulated over the session. Additional exposure assessment using time-integrated measurements of specific quaternary ammonium compounds is needed in future studies of quats-based products. For all products however, the volume of the bathroom was so small and the ventilation so low that initial spray applications rapidly increased the TVOC (Figures 2 and 3) and chlorine concentrations (Figure 4) and these air contaminants remained throughout the cleaning session and for minutes after the cessation of product use (Figure 6). Also noteworthy is that aides accomplished the cleaning tasks with about the same amount of distilled water, on average, as cleaning products (Table 2).

Chlorine is a strong eye and respiratory irritant associated with asthma and other adverse respiratory symptoms (NIOSH 2020; Sastre et al. 2011). In this study, 65% of aides generated an airborne chlorine exposure above the OSHA ceiling limit, that is, the concentration not to be exceeded at any time (Figure 5). Like TVOC, the chlorine concentration built up rapidly in the small, unventilated air volume of the bathroom (Figure 4). This exposure scenario poses a l. risk to aide respiratory health, especially those who perform bathroom cleaning multiple times a day within a multi-day work week.

Volatile organic compounds generated from many materials, including C&D products, can cause eye, nose, and respiratory irritation (LeBouf et al. 2014; Su eta 2018) and although there are no OELs, TVOC limits are used to assess healthy indoor air quality (AIHA Construction and Toxicology Committees and Green Building Working Group 2017). All the C&D products used in this study generated mean TVOC concentrations well above the LEED criterion: the quats-based C&D product generated more than five times the LEED criterion; the bleach-based, nearly three times; and the green product more than two times.

In this study, the green product produced some favorable characteristics compared to the two conventional products: (1) it generated lower TVOC concentrations and no chlorine; and (2) it took more time to reach a maximum TVOC concentration, that is, the TVOC built up more slowly over time. However, very limited toxicology data are available for thymol, the active disinfecting ingredient, and no epidemiologic evaluations of human respiratory effects were available. Thymol is a common antimicrobial agent in green C&D products and is approved by the U.S. Environmental Protection Agency (EPA) under List N as an active ingredient in disinfectants for SARS-CoV-2 (EPA 2021). Further research is needed to quantify exposures from green products and to identify whether the TVOC mixture generated is of respiratory health concern.

The results of this study inform the practice of occupational hygiene by demonstrating the potential for hazardous respiratory exposures to HC aides when they perform C&D in small rooms with low ventilation, such as bathrooms. Because the airborne exposures persisted for minutes after the C&D product applications stopped, reducing these exposures may also improve home environmental air quality for clients. This could be especially important for clients with respiratory illness. When possible, spraying should be avoided, and C&D products formulated with less hazardous ingredients should be used. Concern for infection prevention during the COVID-19 pandemic has resulted in a substantial increase in the use of C&D products or do-it-yourself (DIY) formulations, especially with bleach. Guidance for environmental surface disinfection should include methods to effectively reduce pathogens *and* to minimize airborne chemical respiratory hazards (CDPH 2020; TURI 2020; UWDEOHS 2020). Work practices to maximize infection prevention effectiveness and minimize airborne C&D chemical exposures should be incorporated into HC aide job training and educational materials for both aides and clients.

Conclusions

HC aides may be exposed to respiratory hazards from use of conventional or green C&D products formulated with bleach or other respiratory irritants and sprayed in small, poorly ventilated spaces typical of bathrooms. Spraying should be avoided, especially when using a bleach-based formulation. Further research is needed to identify specific airborne chemicals of respiratory health concern in the TVOC mixtures produced by common C&D products and whether these airborne exposures are related to adverse respiratory symptoms.

Acknowledgments

The authors are grateful to the home care aides and employers for their participation in this study.

Funding

This publication was supported by Grant Number R01OH008229, funded by the Centers for Disease Control and Prevention (CDC)/National Institute for Occupational Safety and Health (NIOSH). Its contents are solely the responsibility of the authors and do not necessarily represent the official views of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention.

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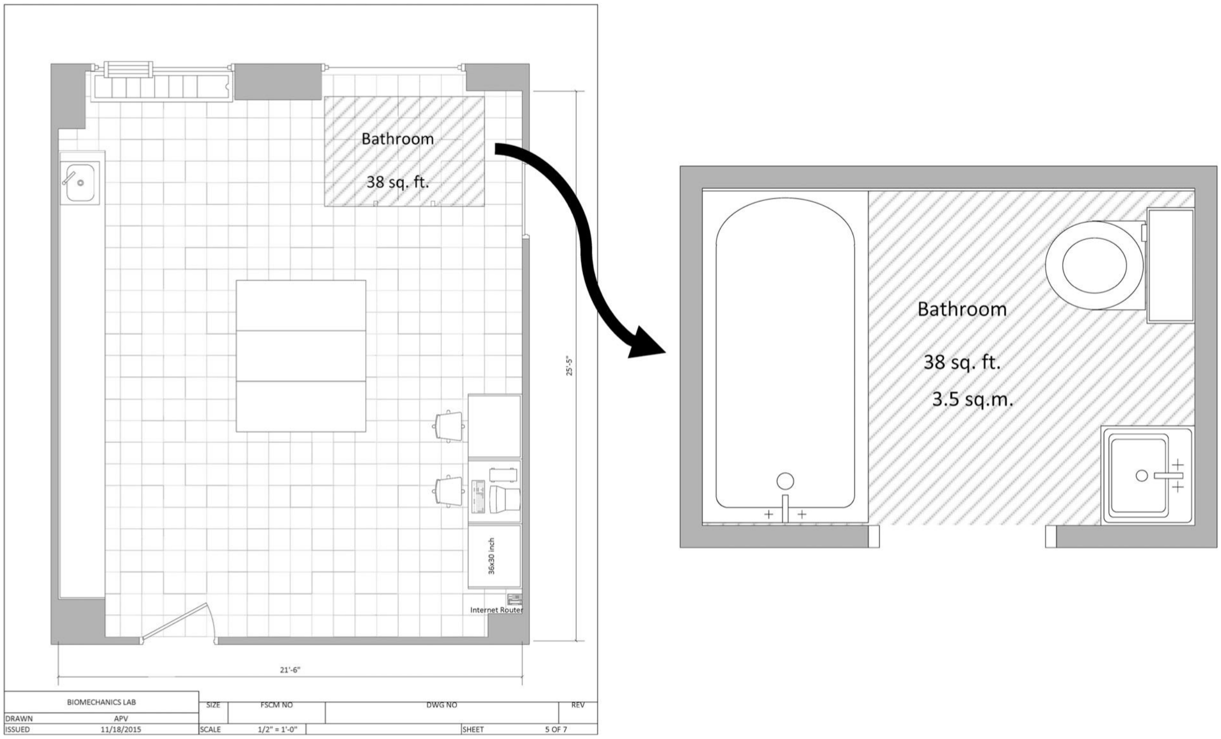

Figure 1.
Environmental air sampling laboratory with simulated residential bathroom for the Safe Home Care Cleaning and Disinfection Study.

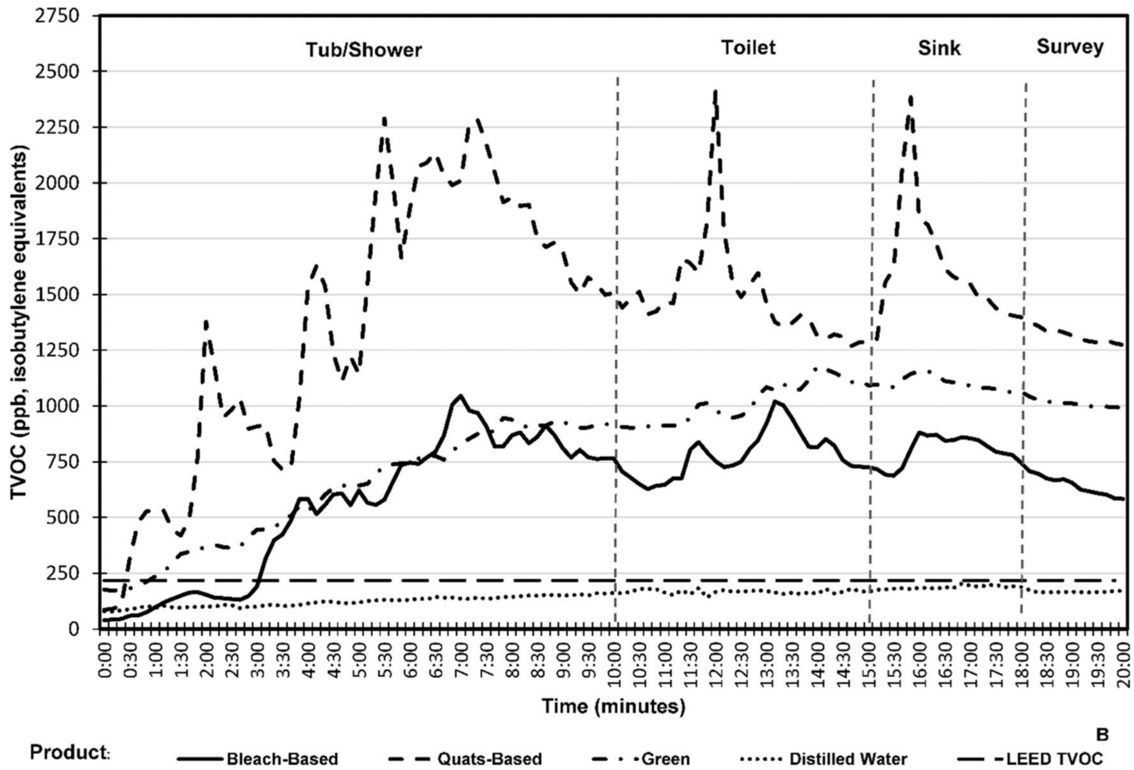

Figure 2.

Total Volatile Organic Compounds (TVOC) concentration-time profiles[A] generated by one study participant performing bathroom cleaning using three products and distilled water. [A]TVOC concentration measurements: 10-sec averages over one 20-min cleaning session, converted to isobutylene equivalents. [B]LEED TVOC = Leadership in Energy and Environmental Design reference value for indoor air TVOC concentration (500 mg/m^3) converted to a volume concentration in isobutylene equivalents (218 ppb). (AIHA Construction and Toxicology Committees and Green Building Working Group 2017).

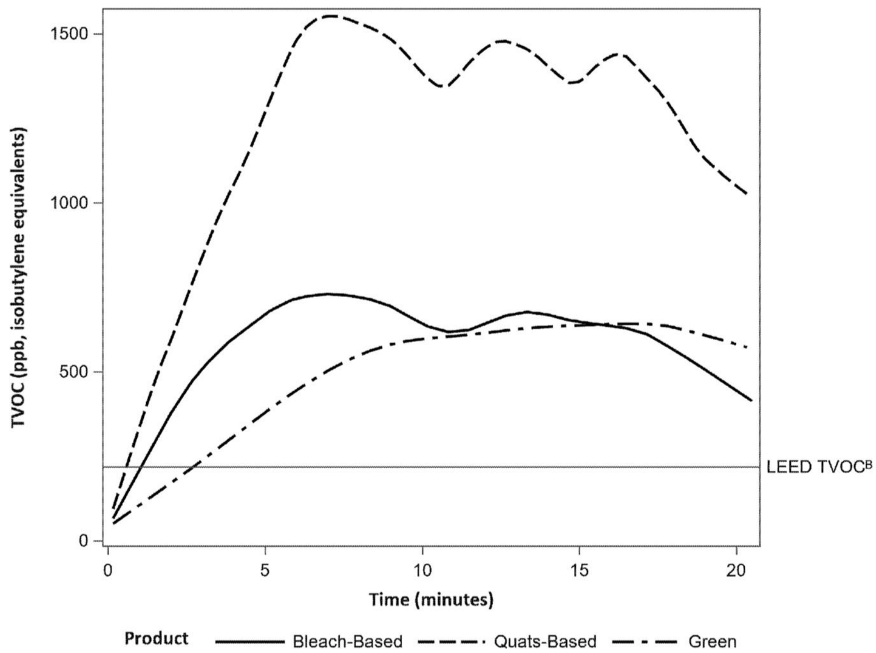

Figure 3.

Total Volatile Organic Compounds (TVOC) concentration-time profiles[A] by product, all study participants' sessions combined using LOESS smoothing. [A]Each curve represents the smoothed TVOC concentration-time profile for all cleaning sessions using a specific product. The LOESS curve for the bleach-based product is based on 40 sessions; for the quats-based product, 40 sessions, and for the green product, 43 sessions (see text). [B]LEED TVOC = Leadership in Energy and Environmental Design criteria for indoor air TVOC concentration (500 mg/m^3) converted to a volume concentration in isobutylene equivalents (218 ppb) for comparison.

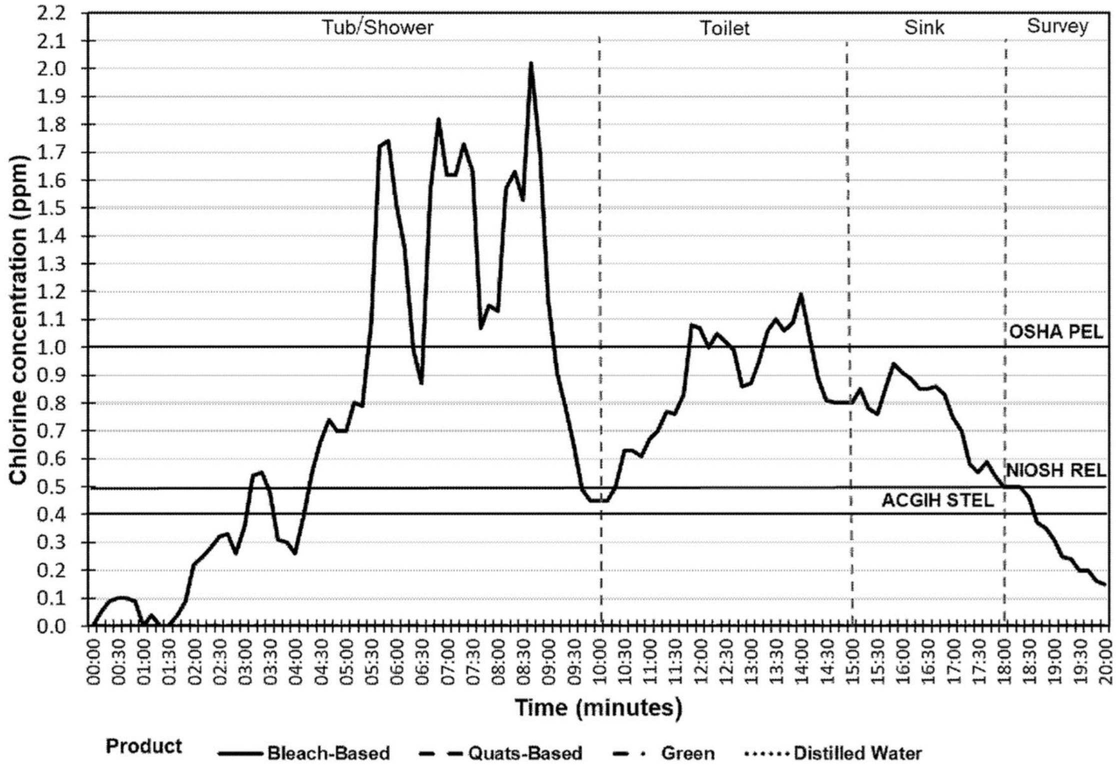

Figure 4.

Chlorine (Cl_2) gas concentration-time profile generated by one study participant performing bathroom cleaning using three products and distilled water. Note: Chlorine gas was monitored during the use of all products and distilled water; it was detected only during use of the bleach-based product. OSHA PEL = US Occupational Safety and Health Administration Permissible Exposure Limit, 1.0 ppm, ceiling. (NIOSH 2020). NIOSH REL = US National Institute for Occupational Safety and Health Recommended Exposure Limit, 0.5 ppm averaged over 15 min. (NIOSH 2020). ACGIH STEL = American Conference of Governmental Industrial Hygienists Short Term Exposure Limit, 0.4 ppm averaged over 15 min (ACGIH 2019).

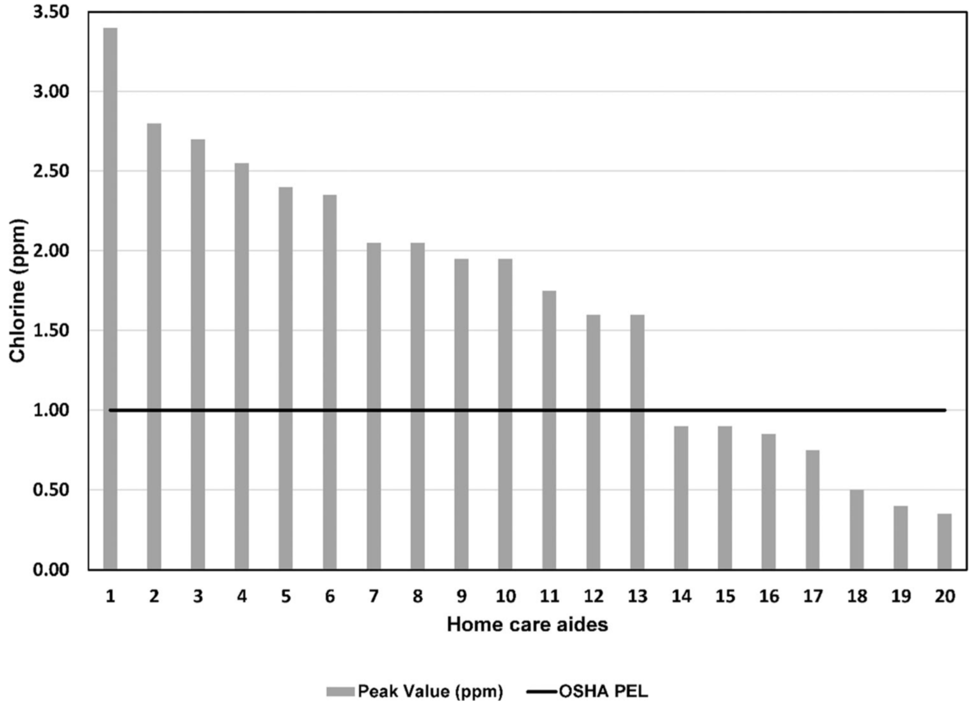

Figure 5.

Peak chlorine (Cl_2) gas concentrations generated by all study participants during bathroom cleaning with the bleach-based product compared to the US Occupational Safety and Health Administration Permissible Exposure Limit ceiling. OSHA PEL = US Occupational Safety and Health Administration Permissible Exposure Limit, 1.0 ppm ceiling limit.

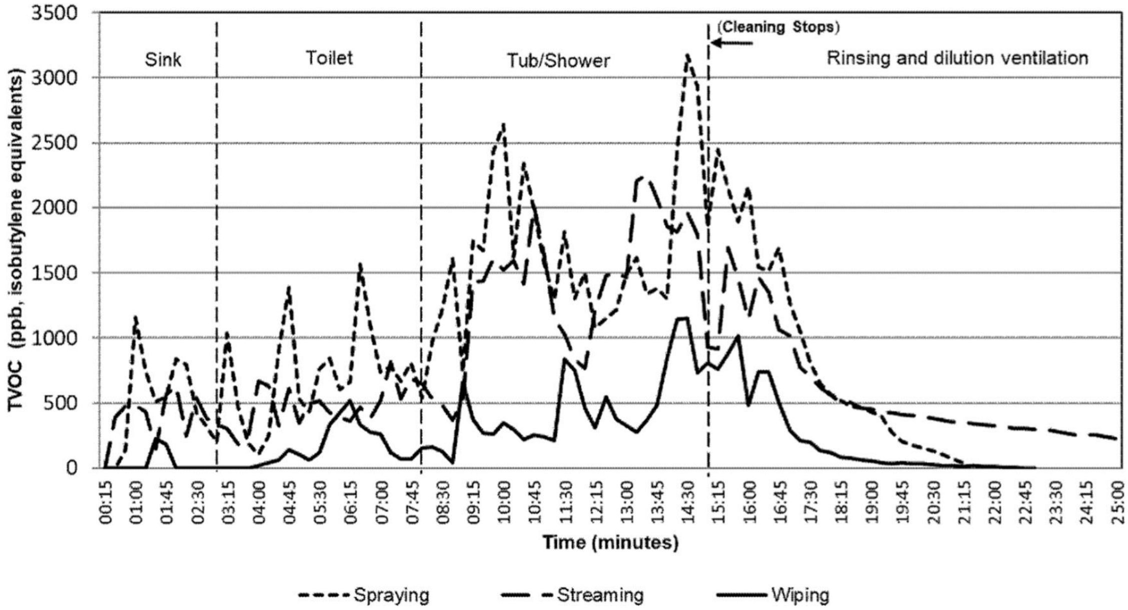

Figure 6.

Total Volatile Organic Compounds (TVOC) concentration-time profiles generated during bathroom cleaning using the quats-based product with different application methods: spraying, streaming, and wiping.

Table 1.

Time-weighted average (TWA) total volatile organic compounds (TVOC) and chlorine breathing zone concentrations summarized over 20 aides' visits,[A] by cleaning and disinfecting product.

Cleaning product	Mean	Median	IQR[B]	Min	Max
TVOC (ppb)					
Bleach-based	593	515	271–759	149	1,245
Quats-based	1,210	1,196	891–1,501	590	2,065
Green	498	480	341–619	186	829
Chlorine (ppm)					
Bleach-based	0.55	0.53	0.30–0.77	0.09	1.24

[A] Data were available on 22 visits for the green product, 20 for all others.

[B] Interquartile range.

Table 2.

Amount of cleaning and disinfecting product used and association with the total volatile organic compounds (TVOC) breathing zone concentration.

	Cleaning session	Amount of product sprayed (g)			Association of amount sprayed with TVOC concentration[A]	
Cleaning product	n[B]	Median	Min	Max	beta[C]	p-value[D]
Bleach-based	35	193	105	389	1.32	0.11
Quats-based	39	206	126	592	2.01	0.01
Green	42	215	121	484	0.08	0.84
Water[E]	45	218	132	446	–	–

[A] Time-weighted average (TWA).

[B] Each cleaning session was 20 min (2 in each visit); the numbers of sessions vary from the total sessions for each product due to missing data on the variables used in the analyses presented here.

[C] Slope from mixed regression model with random person intercepts. Units: ppb/g of product.

[D] From test of the null hypothesis: beta = 0.

[E] Distilled water was used as a control product.