CLEARING THE AIR: A MODEL FOR INVESTIGATING INDOOR AIR QUALITY IN TEXAS SCHOOLS

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ABSTRACT
This pilot project focused on indoor air quality (IAQ) assessment at a local school, utilizing the U.S. Environmental Protection Agency's *Indoor Air Quality Tools for Schools* program, a low-cost, minimal involvement, primarily educational approach. We compared findings from this approach with an air-sampling program to determine if use of *Tools for Schools* was sufficient to identify conditions related to adverse health effects. Data were gathered for formaldehyde and other volatile organic compounds (VOCs), ozone, particulate matter (PM_{10}), mold, relative humidity, and temperature. Levels of ozone and PM_{10} and all VOC levels except formaldehyde were found to be within federal standards, American Conference of Governmental Industrial Hygienists recommendations, and Texas Natural Resource Conservation Commission's effects screening levels. Mold, however, was widespread, including those associated with allergy and asthma, e.g., *Aspergillus* and *Alternaria*. In general, *Tools for Schools* provides a solid foundation for a school IAQ program.

INDEX TERMS
Indoor air quality, Environmental assessment, School health, VOCs

INTRODUCTION
This pilot project focused on indoor air quality (IAQ) assessment at a local high school in Galveston, Texas, utilizing methods similar to those used in a series of California schools (Speilman, 2000), and guidelines from the U.S. Environmental Protection Agency's (US EPA) *Indoor Air Quality Tools for Schools* program (US EPA, 1995). The *Tools for Schools* program, utilizes a low-cost, minimal involvement approach, based primarily upon education of students, staff, and faculty. We used this approach, combined with an air-sampling program, to determine if use of *Tools for Schools* guidelines was sufficient to identify conditions in the school with the potential for causing adverse health effects.

The study's primary objectives were to: 1) establish an IAQ committee to implement *Tools for Schools* assessments and management strategies; 2) collect air quality data in high-risk areas identified by the committee; 3) collect outdoor air quality data at or in close proximity to the school; and 4) develop methods and instruments to assess environmental risks associated with daily school attendance. Data were gathered for levels of: formaldehyde and other volatile organic compounds (VOCs), ozone, particulate matter (PM_{10}), mold, relative humidity, and temperature. Data values for each sampled pollutant were compared with

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federal standards, recommended values of the American Conference of Governmental Industrial Hygienists (ACGIH) for non-industrial populations, and effects screening levels (ESLs) developed by the Texas Natural Resource Conservation Commission (TNRCC). ESLs are those exposure levels below which no adverse health effects are to be expected.

METHODS

This study involved five components: 1) forming an IAQ committee and educating its members regarding IAQ, 2) conducting a school survey to identify areas of environmental concern, 3) visually inspecting those sites, 4) measuring levels of pollutants in sites identified as potentially problematic, and 5) reporting results to the administration. The two basic departures from *Tools for Schools* guidelines included: 1) developing survey instruments to be distributed with checklists, and 2) air quality sampling in sites identified by the committee.

Indoor Air Quality Committee: The IAQ Committee included administrative staff, teachers, the school health officer, the facility operator responsible for the ventilation system and maintenance, students, an epidemiologist, a physician, and an industrial hygienist. One student was selected to assist with coordinating activities, based upon characteristics identifying her as a potential change agent, i.e., one able to influence the diffusion of new ideas/practices into the school environment (Rogers, 1983). IAQ action packets related to particular job duties were distributed to teachers, administrative staff, food service personnel, maintenance and waste management employees, the school health officer, and the contractor responsible for maintenance of the school's heating, ventilating and air conditioning (HVAC) (US EPA, 1995). Each packet included a risk checklist, but because *Tools for Schools* checklists are lengthy and not specifically designed to collect data, we developed streamlined surveys. Care was taken to ensure content validity, clarity, word choice, and readability of survey instruments (Petronella, Thomas, Stone, Goldblum, & Brooks, submitted).

Sampling Methods: HVAC systems were set for normal cycles during a typical school day. Windows and doors were closed. The building consists of an old and a new section; older classrooms utilize individual unit ventilators, and the newer section utilizes central air. Because we hypothesized that teachers with rooms in the older sections would report more IAQ problems than those in the new section, independent sample t-tests were run to assess if mean scores per subscale were different for the two groups. Outdoor samples were also collected, including formaldehyde and other VOCs, mold, ozone, temperature, and humidity.

Summa canisters were used for VOC sampling, obtained from and analyzed by A & B Laboratory (Houston, Texas), utilizing gas chromatography/mass spectrometry in accordance with US EPA Method T0-14A (US EPA, 1999). These canisters capture 36 organic compounds, and up to five additional organic compounds per summa canister were identifiable by comparison with a data library. The collection media for formaldehyde was 3M™ formaldehyde diffusion monitors (St. Paul, MN; Model 3721). Area monitoring was carried out in four locations, and four individuals (student members of the IAQ Committee) each wore passive badge monitors near his/her breathing zone. All samples were collected over an 8-hour period. Formaldehyde samples were submitted to HIH Laboratory (Houston, TX) and analyzed by high-pressure liquid chromatography (HPLC) in accordance with National Institute for Occupational Safety and Health (NIOSH) Method 2016 (NIOSH, 1998).

Two means of ozone sampling were employed. One collection media for ozone was treated glass fiber filters in 37 mm plastic cassettes, using a portable battery-operated sampling pump. Samples were collected over a 6-hour period and submitted to HIH Laboratory (Houston, TX) where they were analyzed by HPLC in accordance with Occupational Safety and Health Administration (OSHA) standard ID-214 (OSHA, 1995). Additional samples were collected using a direct-read Ecosensor® ozone monitor (Santa Fe, NM; model C-30ZX), equipped with a Stowaway® data logger (Onset Computer Corp., Pocasset, MA; model DL2).

Both indoor and outdoor air samples for total spore content were collected with Zefon® Air-O-Cell cassettes (St. Petersburg, FL), using an electrically powered air sampling pump. Total spore air samples were submitted to MSI Laboratory (Houston, TX) to be analyzed via polarized light microscopy, using a microscope equipped with a Vernier stage and X-Y coordinate movement, using the protocol published by Zefon® Analytical Accessories (Zefon, 1998). This method identifies and quantifies spores by genera.

Each laboratory is accredited by the American Industrial Hygiene Association, the National Voluntary Laboratory Accreditation Program, and the Texas Department of Health. We compared values and ranges for each sampled pollutant with federal standards, ACGIH-recommended values for non-industrial populations, and TNRCC ESLs. Temperature and relative humidity were assessed with a Mannix Model SAM990DW Digital Sling Psychrometer/ThermoHygrometer.

RESULTS

Department chairs distributed surveys during faculty meetings. Of 165 surveys distributed, 116 were completed and returned within two weeks. A second copy of the survey was then sent to non-respondents, yielding an additional 23 responses, for an overall 84.2% response rate (139 of 165). The building contains 235 separate air conditioning systems. The facilities operator randomly selected 40 units for inspection; all 40 HVAC surveys were returned. Reliability of the teacher questionnaire was tested by measuring the amount of inter-item correlation among subscale items for the Teacher Questionnaire, with coefficient alpha ranging from 0.76 to 0.90, indicating acceptable reliability. Coefficient alpha was not calculated for one subscale due to sparse response and was found to be poor for two additional subscales (0.5 and 0.6), which have been revised accordingly.

Survey responses yielded 156 items for visual inspection by the IAQ committee, including 36 rooms with evidence of water leaks, 42 with possible ventilation problems, 39 with cleaning problems, 28 with pest control problems, and 11 with exhaust fan problems. Independent t-tests to assess differences in mean scores per subscale for the old and new sections revealed a statistically significant difference in perceived thermal comfort ($p=0.03$), and approached statistical significance for adequacy of ventilation (0.06), indicating that teachers perceived both thermal comfort and ventilation as insufficient in the old sections of the building.

The committee conducted an inspection of each site. Active or recurring leaks were identified for 24 of 36 rooms. Visible mold growth was observed in water fountains, locker room showers, ceiling tiles, and in and adjacent to vents and light fixtures. One ceiling tile was removed and samples assessed by a mycologist, who identified the growth as a pure culture of *Stachybotrys spp*. We recommended that all leaks be repaired and ceiling tiles replaced to discourage mold growth. Each site was recommended for follow-up inspection. Quantitative pollutant measurements were taken in 27 indoor sites; outdoor samples were taken simultaneously. Samples taken included ozone (8), PM_{10} (11), mold (15), and VOCs (7).

Ozone sampling results were similar for both methods, all below 0.02 ppm, i.e., well below the 0.12 ppm National Ambient Air Quality Standards (NAAQS) level. An independent samples t-test revealed no statistical differences between indoor and outdoor samples. Spore content revealed *Stachybotrys* to be limited to the room containing the contaminated ceiling tile; however, allergenic genera, including *Aspergillus* and *Alternaria,* were identified throughout the school. PM_{10} values were well below recommended levels, though formaldehyde was elevated beyond $1/10^{th}$ of the ACGIH-recommended level for industry and the NIOSH guideline in virtually every sample. All VOCs detected except formaldehyde were within recommended levels. Of the standard compounds, only bromochloromethane and 1,4-difluorobenze were detected; those identified by data library matching are depicted in Table 1.

Table 1. VOCs Identified by Matching with Data Library

Acetic acid, butyl ester	1,1-Dichloro-1-fluoroethane	Isopropyl alcohol
Acetone	Ethanol	2-methyl pentane
Butane	Ethanol 2,2,2-trifluoro	Nonane
Butane, 2-methyl	Heptane	Pentane
Cyclohexane, methyl	Hexane, 3-methyl	Undecane
Dichlorodifluoromethane/Freon	Hexanol	
1,2-Dichloroethane	Isobutane	

Current American Society of Heating, Ventilating and Air Conditioning Engineers (ASHRAE) guidelines recommend 15 CFM per occupant for a typical classroom. Of 19 rooms assessed by maintenance staff, only 3 met guidelines.

DISCUSSION

Research regarding health effects associated with exposure to outdoor air pollution has become increasingly important, particularly in response to the rapid increase in asthma prevalence in the U.S. and worldwide, which seems to be correlated with industrialization (CDC, 1995). Asthma is now the most frequent cause for hospitalization of children, the number one cause of school absenteeism, and accounts for 10 million days of missed work annually for parents of children with asthma (Weiss, Sullivan, & Lyttle, 2000). This increase remains largely unexplained, although links are indicated between asthma and both indoor and outdoor pollutants, including smoke, fine particulates, dust mites, molds, pollens, animal dander, and cockroaches (Pew Environmental Health Commission, 2000). Concern regarding IAQ is a more recent development, dating back to the 1970’s fuel crisis, at which time Americans began constructing and insulating buildings much more tightly than before—and creating environments which facilitated the retention of VOCs, radon, formaldehyde, and the proliferation of mold. The impact of such changes may be amplified by the fact that the majority of Americans spend up to 90% of their time indoors (US EPA, 2001).

The IAQ of schools is especially important for the 55 million children currently enrolled in the nation’s 115,000 public schools (US EPA, 2001). Because children have a faster respiratory rate than adults and tend to be more sensitive to irritating air contaminants, they may be at increased risk for lung function impairment resulting from exposure to indoor air pollutants (US EPA, 1995). Indoor air pollutants in schools arise from science laboratories, machine, auto, and woodworking shops, kitchens and home economics rooms, copy and printing shops, and art studios. In addition, poor IAQ can also be the result of poor design, insufficient or inappropriately placed vents, leaking roofs, windows, walls, and floors, or improper moisture control by HVAC equipment, which encourages growth of mold.

In this study, we examined a single secondary school in some detail. Overall, we found low levels of VOCs. None of thesamples exceeded recommended levels and/or effects screening levels. However, permissible exposure limits are typically based upon occupational studies, and in many cases, no standards exist. Formaldehyde did exceed the NIOSH standard and $1/10^{th}$ the ACGIH recommendation. The health effects of such exposures may include eye, nose, and throat irritation; wheezing and coughing; fatigue; skin rash; and allergic reactions, and high concentrations may trigger exacerbations in people with asthma (OSHA, 1999).

The health effects of exposure to fungi are not well understood for all species. Most severe effects have been reported for heavy occupational or agricultural exposures. Reported immunologic reactions include hypersensitivity pneumonitis and allergic rhinitis, though common symptoms include runny nose, eye irritation, cough, congestion, asthma exacerbation, headache, and fatigue (Levetin, 1995; Husman, 1996; Dales, Zwanenburg, Burnett, & Franklin , 1991; Hodgson et al., 1998; DeKoster & Thorne, 1995). While trace amounts of fungal spores are generally present in most samples, large amounts or presence of fungal fragments (e.g., hyphae and conidiophores) suggests colonization. In this study, several fungal species were identified that are known or suspected to be allergenic, including *Aspergillus, Alternaria, Chaetomium, Cladosporium*, and *Fusarium*, several of which have been linked to both allergic rhinitis and asthma. Indoor measures of several species were lower than outdoor measures, indicating normal or background presence of fungi. Among these are *Curvularia*, *Cladosporidium,* the *Arthrinium/Nigrospora* group, *Chaetomium*, and the *Bipolaris/ Drechslera* group, while *Tetraploa* and *Leptosphaerulina* were only detected outdoors. In contrast, the levels of *Aspergillus, Fusarium, Alternaria*, and *Stachybotrys* were higher indoors than outdoors, suggesting amplification in the indoor environment.

Although IAQ is becoming increasingly important, currently, no legally enforceable standards exist for IAQ similar to the NAAQS. However, ASHRAE Standard 62-1999, *Ventilation for Acceptable Indoor Air Quality,* has been widely adopted in state and local building codes, particularly regarding minimum flow rates of fresh air into buildings for specific occupancy patterns. In Texas, no designated or funded IAQ program exists to encourage use of ASHRAE guidelines or to provide other direct assistance to schools to ensure acceptable IAQ.

In general, *Tools for Schools* provides an excellent starting point for any school in addressing IAQ. As described, we did find it necessary to streamline data collection by developing simple, one-page questionnaires, and we attribute our 84.2% response rate to both ease of collection and the community-based nature of the program. Air sampling did not reveal any recognizable problems with VOCs or particulates. While this would seem to indicate that the *Tools for Schools* guidelines are sufficient for assessing VOCs in the school, it should be noted that organic compounds (e.g., benzene) can be toxic at very low levels that may not readily be detected by odor. In addition, air sampling revealed the presence of molds, including *Aspergillus* and *Alternaria,* in areas where mold was not visible.

CONCLUSIONS

An immediate benefit of the project has been the identification of risk areas in the school with the potential for adverse health effects. Continuation of the program as part of the school's environmental sciences curriculum will have a long-term benefit, since the community-based nature of the program led to active participation by teachers and students. An additional long-term benefit is validation of this method for assessing air quality in schools.

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