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MONTPELIER HIGH SCHOOL
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I. SUMMARY

On January 8, 1992, the National Institute for Occupational Safety and Health (NIOSH), received a request for a hazard evaluation from Senator Patrick Leahy's office in Montpelier, Vermont. The request was for NIOSH to evaluate the indoor environmental quality at the Montpelier High School, particularly with regard to new carpets installed there.

On March 4, 1992, NIOSH investigators interviewed teachers and collected air samples for 4-phenylcyclohexene (4-PC) and other volatile organic chemicals (VOCs). Air samples were collected in classrooms and administrative offices which were carpeted. Other yearly remodeling activities, such as painting classrooms and applying a sealant to the gymnasium floor, had been done at the same time the carpet was installed. Energy-saving and fire code modifications to the school over time had altered the effectiveness of the designed ventilation system.

Medical interviews discovered that four of six teachers reported experiencing symptoms during September 1991, when in newly carpeted and painted classrooms. Reported symptoms included headache (4 employees), throat irritation (3), and eye irritation (2). All reported that they were no longer experiencing symptoms, except for one teacher who was still experiencing an increased frequency of headache. One teacher occupying a room carpeted in 1990 reported still experiencing frequent headache, eye irritation, and fatigue.

Air samples detected 4-PC, in trace quantities (≈0.08 parts per billion), in only one classroom. Other VOCs measured qualitatively in higher abundance (toluene, p-dichlorobenzene, limonene, and siloxane compounds), were found in trace concentrations or at the minimum quantifiable concentration (≈100 micrograms per cubic meter or less) in some of the samples. Air concentrations of these and possibly other compounds were likely higher immediately following the remodeling activities conducted just prior to the beginning of the school session. The concentrations of air contaminants associated with remodeling activities typically decrease with the aging of materials (from a few weeks to a months) and ventilation.

Based on the medical interviews and environmental information, it appeared that there was a temporal relationship between the yearly remodeling of the school and the symptoms reported by the teachers. Ventilation system improvements and the use of low emitting building materials and furnishings are recommended.

Key Words: SIC 8211 (Educational facilities, elementary and secondary), carpet, ventilation, VOC, 4-phenylcyclohexene

II. INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH) received a request on January 8, 1992, from United States Senator Patrick J. Leahy's office in Montpelier, Vermont, to perform a health hazard evaluation at Montpelier High School. The evaluation was requested because of symptoms (primarily headache and eye and throat irritation) experienced during the fall school season (1991) by students and teachers in the Montpelier High School who occupied rooms where new carpet had been installed during the previous summer. Their symptoms reportedly improved when classes were moved to other rooms in the building. When classes resumed in the newly carpeted rooms, after they had been ventilated for about a month (using open windows and exhaust ventilation), symptoms were reportedly much improved. There was additional concern about two students who had experienced exacerbations of pre-existing illnesses when they returned to the school in the fall of 1991 and attended classes in the newly carpeted rooms. The symptoms of these students were reported to have improved when (upon the advice of their physicians) they ceased attending classes in the building.

Investigators from NIOSH conducted an evaluation of the indoor environment in the carpeted classrooms at the Montpelier High School on March 4, 1992.

III. BACKGROUND

The Montpelier High School (MHS) was commissioned in 1952. It is a two-story structure constructed of steel I-beams and cinderblock, with an exterior veneer of brick. It is an L-shaped building with classrooms along the exterior walls and a central hallway between these rooms. There are ten classrooms, administration offices, faculty rooms, nurses office, restrooms, cafeteria, theater, and a gymnasium with locker rooms on the first floor, and 18 classrooms, science office, restrooms, and storage rooms on the second floor. The original design had openable windows along the length of the outside wall of each room. The school has two centrally powered exhaust systems, one for each wing of the L shape. The systems are ducted to all rooms in the school except the cafeteria, locker rooms, gymnasium, theater, and restrooms, which are on different systems. Ventilation of the building was designed to be provided by outdoor air infiltration through perimeter windows, open doors, and any other opening in the building envelope, due to the negative pressure created by the exhaust system. Louvers in classroom doors allowed air to flow into the rooms from the hallway.

In the late 1970's (no specific year was provided), energy conservation modifications were made to the building. The windows along the perimeter were removed and replaced by insulated walls and smaller openable windows. In addition to saving energy due to heat loss through the windows, this allowed for less infiltration of outdoor air. Also, in the mid-1970's, the louvers in the classroom doors were covered in order to comply with the local fire code, drastically decreasing the amount of airflow allowed to pass into the rooms from the hallway. These modifications decreased the ability of outside air to infiltrate the building and made the ventilation system work against a greater pressure drop than it was designed for, making it less effective.

Over the past three school years ('89-'90, '90-'91, and '91-'92), several rooms per year have been carpeted. The carpet was glued over tiled floors. There was some painting of classrooms and an application of a sealant to the gymnasium floor in the summer between the school years. During the school summer break in 1991, the gym floor sealing was not completed until late in August. This delayed the use of the gym until a few weeks after the school year had begun. The combination of low ventilation rates and emissions from the numerous wet sources (paint, carpet adhesive, and floor sealant) possibly increased the airborne concentrations of volatile organic chemicals (VOCs) in the school environment for a period of time following the start of classes.

Private environmental consultants were hired to evaluate the air quality at the school in October 1991. They reported that their measurements for formaldehyde, VOC, and 4-phenylcyclohexene (4-PC) were low and within "normal" ranges for the indoor environment. These measurements were made after the new materials in the building had aged for at least two months. Emission rates for new building materials are usually higher immediately following installation or application and then continually decay for up to three months before reaching a point of equilibrium. The rate of ventilation will determine how quickly compounds emitted from remodeling materials are removed from the building. Exhaust system airflow measurements made at MHS by the consultants revealed that they were not providing prescribed amounts of outdoor air for dilution in their current configurations.

IV. EVALUATION METHODS

The NIOSH evaluation began with an opening meeting attended by school administrators and a teacher representative. This was followed by a walk-through tour of the high school on March 4, 1992. A listing of the rooms which had been carpeted over the last three years aided in a decision to do comparative air monitoring among rooms with the different ages of carpet.

There were three different colors of carpet (gray, beige, and rose) among the rooms to be monitored. Interviews with teachers and environmental monitoring were conducted, following the walk-through.

ENVIRONMENTAL MONITORING METHODS

The proposed protocol for this evaluation included monitoring for carbon dioxide, total VOC (TVOC), and individual VOC species, including 4-PC. The instrument which measures carbon dioxide malfunctioned and no measurements were made.

Two sampling and analytical methods were used for VOCs, TVOC, and 4-PC. A thermal desorption method was chosen for quantitative analysis of 4-PC and qualitative identification of other VOCs present because it is able to detect contaminants at very low concentrations. This method utilizes stainless steel tubes containing three beds of different sorbent materials, a front layer of Carbotrap C (≈350 milligrams [mg]), a middle layer of Carbotrap (≈175 mg), and a back layer of Carboxen 569 (≈150 mg). Battery-powered vacuum pumps, calibrated to sample the air at a rate of 20 milliliters per minute (ml/min), were used for sample collection. The collected samples were then analyzed using a Perkin-Elmer ATD 400 thermal desorption system interfaced directly with a Hewlett Packard HP5890A gas chromatograph and an HP5790 mass selective detector (TD-GC-MSD). A limit of detection (LOD) for 4-PC of one (1) nanogram (ng) per tube was obtained for this system. This yields a minimum detectable concentration of 0.08 parts per billion (0.5 micrograms per cubic meter) for a two liter air sample. The TD-GC-MSD system provided a chromatogram which also identified other VOC species present in the school environment.

A second sampling and analytical method was used to quantify the primary VOCs identified by the TD-GC-MSD method. Glass tubes containing two layers of activated coconut shell charcoal (100 mg front layer, 50 mg back layer) were used for this method. Battery-powered vacuum pumps, calibrated to sample at 200 ml/min, were used for sample collection. Samples were analyzed for toluene, limonene, siloxanes, *p*-dichlorobenzene, and total other hydrocarbons (using undecane as the standard), by GC and a flame ionization detector (based upon NIOSH methods 1003, 1500, and 1501).[1] The LODs and limits of quantitation (LOQs) for these compounds are presented with the results in Table 1.

ENVIRONMENTAL SAMPLE LOCATIONS

The equipment used to collect the air samples (two samples in each room) was positioned on a desk, table, or filing cabinet in the chosen room. Classrooms 3, 5, 21, 22, 24, 28, and 34 were selected, as were the Main Office, a Guidance Counselor Office, and the conference room neighboring the Principal's Office. Rooms 5, 21, 28, and the Main Office were the most recently carpeted. Rooms 3, 22, and 24 were carpeted during the summer break before the '90-'91 school year. The Guidance Counselor Office and conference room were carpeted the year before that. Room 34 has no carpet.

V. EVALUATION CRITERIA

NIOSH investigators have completed over 1100 investigations of the occupational indoor environment in a wide variety of non-industrial settings. The majority of these investigations have been conducted since 1979.

The symptoms and health complaints reported to NIOSH by building occupants have been diverse and usually not suggestive of any particular medical diagnosis or readily associated with a causative agent. A typical spectrum of symptoms has included headaches, unusual fatigue, varying degrees of itching or burning eyes, irritations of the skin, nasal congestion, dry or irritated throats and other respiratory irritations. Typically, the workplace environment has been implicated because workers report that their symptoms lessen or resolve when they leave the building.

A number of published studies have reported high prevalences of symptoms among occupants of office buildings.[2-6] Scientists investigating indoor environmental problems believe that there are multiple factors contributing to building-related occupant complaints.[7,8] Among these factors are imprecisely defined characteristics of heating, ventilating, and air-conditioning (HVAC) systems, cumulative effects of exposure to low concentrations of multiple chemical pollutants, odors, elevated concentrations of particulate matter, microbiological contamination, and physical factors such as thermal comfort, lighting, and noise.[9-14] Indoor environmental pollutants can arise from either outdoor sources or indoor sources.

There are also reports describing results which show that occupant perceptions of the indoor environment are more closely related than any measured indoor contaminant or condition to the occurrence of symptoms.[15-17] Some studies have shown relationships between psychological, social, and organizational factors in the workplace and the occurrence of symptoms and comfort complaints.[17-20]

Less often, an illness may be found to be specifically related to something in the building environment. Some examples of potentially building-related illnesses are allergic rhinitis, allergic asthma, hypersensitivity pneumonitis, Legionnaires' disease, Pontiac fever, carbon monoxide poisoning, and reaction to boiler corrosion inhibitors. The first three conditions can be caused by various microorganisms or other organic material. Legionnaires' disease and Pontiac fever are caused by Legionella bacteria. Sources of carbon monoxide include vehicle exhaust and inadequately ventilated kerosene heaters or other fuel-burning appliances. Exposure to boiler additives can occur if boiler steam is used for humidification or is released by accident.

Problems NIOSH investigators have found in the non-industrial indoor environment have included poor air quality due to ventilation system deficiencies, overcrowding, volatile organic chemicals from furnishings, machines, structural components of the building and contents, tobacco smoke, microbiological contamination, and outside air pollutants; comfort problems due to improper temperature and relative humidity conditions, poor lighting, and unacceptable noise levels; adverse ergonomic conditions; and job-related psychosocial stressors. In most cases, however, these problems could not be directly linked to the reported health effects.

Standards specifically for the non-industrial indoor environment do not exist. NIOSH, the Occupational Safety and Health Administration (OSHA) and the American Conference of Governmental Industrial Hygienists (ACGIH) have published regulatory standards or recommended limits for occupational exposures.[21-23] With few exceptions, pollutant concentrations observed in non-industrial indoor environments fall well below these published occupational standards or recommended exposure limits. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) has published recommended building ventilation design criteria and thermal comfort guidelines.[24,25] The ACGIH has also developed a manual of guidelines for approaching investigations of building-related complaints that might be caused by airborne living organisms or their effluents.[26]

Measurement of indoor environmental contaminants has rarely proved to be helpful in determining the cause of symptoms and complaints except where there are strong or unusual sources, or a proven relationship between contaminants and specific building-related illnesses. The low-level concentrations of particles and variable mixtures of organic materials usually found are difficult to interpret and usually impossible to causally link to observed and reported health symptoms. However, measuring ventilation and comfort indicators such as carbon dioxide (CO_2), temperature and relative humidity, has proven useful in the early stages of an investigation in providing information relative to the proper functioning and control of HVAC systems.

NIOSH and the Environmental Protection Agency (EPA) jointly published a manual on building air quality, written to help prevent environmental problems in buildings and solve problems when they occur.[27] This manual suggests that indoor environmental quality (IEQ) is a constantly changing interaction of a complex set of factors. Four of the most important elements involved in the development of IEQ problems are: 1) a source of odors or contaminants; 2) a problem with the design or operation of the HVAC system; 3) a pathway between the contaminant source and the location of the complaint; 4) and the building occupants. A basic understanding of these factors is critical to preventing, investigating, and resolving IEQ problems.

The basis for measurements made during this evaluation are listed below.

VOLATILE ORGANIC CHEMICALS

VOCs, including formaldehyde and other aldehydes, are emitted in varying concentrations from numerous indoor sources (e.g., carpeting, fabrics, adhesives, solvents, paints, cleaners, waxes, cigarettes, kerosene heaters, and other combustion heating products). New building materials, products, and furnishings are known to emit a large number of organic chemicals into indoor air.[28] The length of time over which each material strongly emits VOCs can be highly variable. A compound may have very high emissions but dry rather quickly. Another may have low total emissions and dry slowly. A critical factor affecting the rate of decrease of emissions is the ventilation rate. Health symptoms experienced by building occupants are often blamed on the presence of such chemicals in indoor air, although the health consequences of most VOCs emitted from building materials are not well understood. Some organic species (e.g., formaldehyde and benzene) have been determined to be carcinogenic in animal studies. NIOSH, OSHA, and the ACGIH have established compound-specific Recommended Exposure Limits (RELs), Permissible Exposure Limits (PELs), and Threshold Limit Values (TLVs) for many organic compounds.[21-23] Total indoor VOCs and aldehyde concentrations typically exceed corresponding outdoor levels except in locations immediately impacted by industrial or combustion source emissions. A laboratory study evaluating human responses to controlled exposures to varying VOC mixtures reported test subject health symptoms similar to those reported by workers in large office buildings.[11]

4-PC

4-Phenylcyclohexene is an odorous manufacturing by-product created during the production of styrene-butadiene rubber (SBR) latexes. These are frequently used in carpet manufacturing. While 4-PC emission rates from some carpets may be high initially (0.04-0.15 $mg/m^2 \bullet hr$), they tend to diminish quickly over time and they are very dependent on carpet type.[29] The half-life of 4-PC was calculated to be three days in one study of eight carpet types (ventilation rate of 1.0 air changes per hour [ACH]) and about eight days in another study of seven carpet types (2.0 ACH).[29,30] 4-PC was not considered to be a possibly important toxicant until recently and has not been fully studied. One study has reported that while the onset of eye and respiratory irritation have been reported to coincide with the installation of carpeting, efforts to link these irritative effects to 4-PC vapor in animal studies (Fischer 344 rats) have been negative thus far.[31] 4-PC liquid was found to be slightly irritating to the eyes of rabbits when applied directly into the eye and, in another study, to have a low acute oral lethality (Sprague-Dawley rats).[32]

VI. RESULTS

ENVIRONMENTAL RESULTS

Air sampling results are presented in Table 1. The compounds which were detected, except for a trace quantity of 4-PC in Room 21, were those associated with materials common in the indoor environment (toluene [adhesives and many building materials], p-dichlorobenzene [deodorizers and moth crystals], limonene [paint, adhesives, and detergents], siloxanes [cosmetics and silicone elastomers, such as caulks and adhesives]).[28] All of the compounds listed were qualitatively detected on the thermal desorption tube samples. The most abundant and often detected were siloxane compounds. The one 4-PC value was at the minimum detectable concentration of the analytical method (≈0.08 parts per billion, based on a sample volume of two liters).

MEDICAL RESULTS

The teachers who occupied six of the eight rooms that had been carpeted and painted during the summer of 1991 were interviewed. Four reported experiencing symptoms during September when in the newly carpeted and painted rooms. Reported symptoms included headache (4 employees), throat irritation (3), and eye irritation (2). All reported that they were no longer experiencing symptoms, except for one teacher who was still experiencing an increased frequency of headache. One teacher from a room that had been carpeted one year earlier was also interviewed. That teacher reported still experiencing frequent headache, eye irritation, and fatigue, and insufficient air movement in the room even when the window was open.

Table 1
Air Sampling Results for VOCs and 4-PC
Montpelier High School
Montpelier, Vermont
March 4, 1992
HETA 92-108

	VOC and 4-PC Concentrations (µg/m³)[a]					
Location	Toluene	p-Dichloro-benzene	Limonene	Siloxanes	Total Other VOC	4-PC
'91-'92 School Year[b]						
Room 5	--[c]	--	--	(32)[d]	--	--
Room 21	--	--	--	--	--	(0.45)
Room 28	--	--	(78)	109	--	--
Main Office	--	--	--	--	--	--
'90-'91 School Year						
Room 3	--	--	--	(56)	--	--
Room 22	--	(75)	--	(32)	--	--
Room 24	--	--	(64)	107	--	--
'89-'90 School Year						
Guidance Office	--	--	--	--	--	--
Conference Rm	--	--	--	(54)	--	--
No Carpet						
Room 34	--	(95)	--	(32)	--	--
LOD, µg/sample	4	3	3	3	4	0.001
LOQ, µg/sample	10	10	10	10	10	0.003
MDC[e], µg/m³ (90 ℓ sample)	111	111	111	111	111	
(2 ℓ sample)						0.5

a - micrograms per cubic meter
b - school year room was carpeted
c - value below the limit of detection of the analytical method
d - value between the LOD and LOQ of the analytical method
e - minimum detectable concentration

VII. DISCUSSION

The health symptoms which were prevalent at the beginning of the school year resolved over time. These symptoms were thought by those affected to be a result of emissions from the remodeling materials, especially the new carpets in the school. While this is not an unreasonable inference, no causal link could be determined for this relationship. Neither the environmental results from the consultants nor those from our investigation could support the proposition that the new carpeting in the school alone was responsible. It is possible that the combined emissions from the recently applied paints, adhesives, and floor sealants, and a lack of ventilation, also contributed to the symptoms reported. The classroom where the detectable concentration of 4-PC was measured was reported to be a particularly problematic room. It was reported to be more odorous than other rooms. This room is on the end of the exhaust system farthest away from the fan and had one of the lowest measured exhaust ventilation flowrates.

The following steps can be taken by all who are involved with decisions relating to remodeling activities to minimize the possibility of experiencing similar problems in the future. 1) Become familiar with all aspects of the remodeling project. 2) Review material selections (consider emissions and functionality) and eliminate materials which might emit toxic or irritating chemicals after project completion. 3) Test material emissions if possible. The ideal solution is to substitute high emission products with those with lower or no emissions, including alternative flooring materials. The most effective way to obtain low-emission, or "clean," materials is to place the responsibility of providing data on product emissions on the manufacturer. If there are no alternative products, time and good ventilation are needed to allow for materials to emit the bulk of their VOC contaminants after application or installation. Materials which are important sources of VOCs include carpets, adhesives, caulks, sealants, and paints.

Manufacturers of carpets are keenly aware of IEQ issues. Carpets may require conditioning prior to, or after, installation. Conditioning at the factory is preferable. A conditioning step at the end of manufacturing may involve running the carpet through a well-ventilated, heated chamber. If done after installation, it should be conducted well before occupancy of the carpeted area. Good air movement above the carpet, elevated temperature, and good ventilation are important to accelerate and remove emissions. Conditioning in place may require several days and perhaps as long as a week.

Source control through conditioning or product substitution is very important in the indoor environment, but it is difficult to eliminate product emissions entirely. Modifications made to the MHS building have compromised the ability of the existing ventilation system to work effectively. Measurements made by the private environmental consultant indicated that good ventilation was not being provided to the building. Modern good HVAC engineering practices suggest that a system providing filtered OA, in amounts adequate to control odors and dilute point and distributed sources of contaminants, is preferable to the original design at MHS.

VIII. RECOMMENDATIONS

1. Permanent building modifications have compromised the effectiveness of the existing ventilation system to be effective. A mechanical contractor

experienced with the design of building HVAC systems should be hired to determine whether the current system could be modified to provide sufficient ventilation. The best course of action would be to redesign the system to provide filtered outside air.

2. Low-emission materials should be used in all future remodeling and renovation work.

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