HETA 92-165-2251
AUGUST 1992
VERMONT DEPARTMENT OF AGRICULTURE
MONTPELIER, VERMONT

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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 Vermont Department of Agriculture, due to the prevalence of respiratory and irritative symptoms among employees there following renovations in their building. One worker was advised to leave work due to respiratory illness.

On March 5, 1992, NIOSH investigators interviewed workers and collected air samples for 4-phenylcyclohexene (4-PC) and other volatile organic chemicals (VOCs). Air samples were collected in renovated rooms on the first floor, carpeted and uncarpeted rooms on the second floor, and outside. First floor space was converted from laboratories to offices in August of 1991, and included painting, plastering, varnishing, and carpeting. Some second floor areas were carpeted and painted following the first floor work.

Medical interviews revealed that five of the 10 workers were currently experiencing symptoms which included, headache (5 employees), excessive fatigue (3), eye irritation (2), throat irritation (2), and nasal congestion (1). The symptomatic workers reported that their symptoms had begun after their move to the first floor. Many employees reported excessive heat and a lack of ventilation in the warmer months of the year.

Air sampling for 4-PC did not detect this compound (minimum detectable concentration [MDC] ≈0.04 ppb). There were from 26 to 33 compounds identified by the qualitative analyses in remarkably low abundance. Limonene, toluene, benzene, and 1,1,1-trichloroethane were chosen for quantitative analyses, but none of these analytes, or any others, were detected on the quantitative samples (the MDC was ≈60 $\mu g/m^3$ with a 70 liter sample for toluene and benzene, ≈45 $\mu g/m^3$ for limonene, and ≈100 $\mu g/m^3$ for 1,1,1-trichloroethane).

Based on the medical interviews, there appeared to be a temporal relationship between the renovation activities and the appearance of employee symptoms. Environmental measurements indicated that there were no remarkable pollutant concentrations remaining in the areas of concern. Conditions which would create elevated indoor temperatures existed. Recommendations are made to increase ventilation, decrease the solar heat load, and use low emitting building materials and furnishings in future remodeling.

Key Words: SIC 9641 (Regulation of agricultural marketing and commodities), carpet ventilation, VOC, 4-phenylcyclohexene

II. INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH) received a request on January 8, 1992, for a health hazard evaluation of the Vermont Department of Agriculture headquarters building from United States Senator Patrick J. Leahy's office in Montpelier, Vermont. The evaluation was requested because of one employee who was forced to cease work in the building in October 1991 due to respiratory illness. Several weeks after moving to the newly renovated first floor office space, this employee began experiencing respiratory and irritative symptoms. These symptoms increased in severity through the following weeks to the point where she had to leave employment on the advice of her physician. It was desired that NIOSH evaluate the first floor environment to help determine what may have caused this employee's illness.

Investigators from NIOSH conducted an evaluation of the indoor environment on the first and second floors of the Vermont Department of Agriculture (VDA) building on March 5, 1992.

III. BACKGROUND

The Vermont Department of Agriculture is housed in a four story building constructed in 1891. The Dutch Renaissance or Gothic edifice is of Longmeadow (MA) brownstone, a superior quality sandstone, and Vermont brick. The State of Vermont purchased the building in 1921 from the National Life Insurance Company. The building houses about 50 employees, is heated by radiators, and has no mechanical ventilation or air-conditioning systems. On the upper floors ventilation is accomplished by opening double-sashed windows. On the first floor some windows open to provide ventilation. A small exhaust fan was installed in an office on the first floor because of excessive temperatures (reportedly as high as 95°F) during August and September 1991.

In 1990, the VDA laboratories moved to new facilities in Waterbury, VT, from the first floor of the headquarters building. First floor renovations to office accommodations were completed in August 1991. The conversion to office space included moving walls, removing air-conditioning units, painting, plastering, varnishing, and installing carpeting and modular workstations. Following this renovation, some similar work was done on the mezzanine and second floors, but to a lesser extent, including carpeting, painting and plaster repair.

IV. EVALUATION METHODS

The NIOSH evaluation began with an opening meeting attended by VDA administration, a representative or the Vermont Department of State Buildings, and a field representative of the Vermont State Employees Association, which was followed by a walk-through tour of the headquarters building on March 5, 1992. Following the walk-through, interviews with workers and environmental monitoring were conducted.

MEDICAL EVALUATION METHODS

The medical officer interviewed nine of the ten employees present on that day. The 10th employee was interviewed over the telephone the following week. The employee who was advised to leave work at the building was also interviewed by phone.

ENVIRONMENTAL MONITORING METHODS

The proposed protocol for this evaluation included monitoring for carbon dioxide, total volatile organic chemicals (TVOC), and individual VOC species, including 4-phenylcyclohexene (4-PC). The instrument which measured carbon dioxide malfunctioned, so that part of the protocol was abandoned.

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 nanogram (ng) per tube was obtained for this system. This yields a minimum detectable concentration of 0.04 parts per billion (0.25 micrograms per cubic meter) for a four 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 in attempting 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, benzene, 1,1,1-trichloroethane, 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 LOD was 4 µg/sample for toluene and benzene, 3 µg/sample for limonene, and 7 µg/sample for 1,1,1-trichloroethane.

ENVIRONMENTAL SAMPLE LOCATIONS

The equipment used to collect the air samples (two samples in each room) was positioned on desks, tables, or filing cabinets in the areas or interest. Samples were collected in renovated areas of the first floor, in refinished areas of the second floor for comparison, and in one case outdoors. Two locations were monitored on the first floor, the office where the absent employee worked (northwest corner office) and the open plan area with modular workstations. Two locations were also monitored on the second floor: the Commissioner's office and an uncarpeted office on the southeast corner.

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 in 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. Laboratory studies 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. 4-PC, the cause of "new carpet smell," has been anecdotally linked to adverse effects in humans, such as mucous membrane irritation, eye irritation, skin rashes, and respiratory symptoms. While 4-PC emission rates from some carpets may be high initially (0.04-0.15 mg/m^2*hr), they tend to diminish quickly over time and are very dependent on carpet type.[29] The half-life of 4-PC was calculated to be three days in one study of eight carpets 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 a possibly significant toxicant until recently and has not been fully studied. One study has reported that while the onset of eye and respiratory irritation has 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 to have a low acute oral lethality (Sprague-Dawley rats) in another study.[32]

VI. RESULTS

ENVIRONMENTAL RESULTS

Air sampling for 4-PC did not detect this compound (minimum detectable concentration [MDC] ≈0.04 ppb). There were from 26 to 33 compounds identified by the qualitative analyses. It was difficult to choose the predominant species, since all were present in remarkably low abundance. Limonene, toluene, benzene, and 1,1,1-trichloroethane were chosen for quantitative analyses, but none of these analytes, or any others, were detected on the quantitative samples (the MDC was ≈60 $\mu g/m^3$ with a 70 liter sample for toluene and benzene, ≈45 $\mu g/m^3$ for limonene, and ≈100 $\mu g/m^3$ for 1,1,1-trichloroethane). These relatively high MDCs are a shortcoming of the method used for quantifying VOCs at VDA. However, even if these compounds would have been detected at their MDCs, the interpretation of the results would have remained that the concentrations of VOCs in this building were very low.

MEDICAL RESULTS

The interviews with the current first floor employees revealed that five of the 10 workers were currently experiencing symptoms while in the building that subsided upon leaving. The symptomatic workers reported that their symptoms had begun after their move to the first floor. The symptoms reported were as follows: headache (5 employees); excessive fatigue (3); eye irritation (2); throat irritation (2); and nasal congestion (1). One additional employee reported experiencing building-associated headache and throat irritation for several months following the move to the first floor but was asymptomatic at the time of this evaluation.

Many employees reported that in warmer weather when windows can be opened, it was difficult to get sufficient ventilation on the 1st floor and summer temperatures there could become quite high. Despite the large surface area of windows on the 1st floor, only a few would open and three of these could only be opened a few inches because they were blocked by modular furniture or supports for vertical venetian blinds.

VII. DISCUSSION AND CONCLUSIONS

The environmental sampling revealed low levels of many organic compounds that are commonly found in indoor environments. However, no specific exposure was found that would help explain either the illness in the employee who had to leave work or the symptoms of current employees. Illnesses similar to that which forced this employee to cease working in the Vermont Agriculture Building have been reported from many parts of the country. Some of these illnesses have occurred following some change in the work environment such as renovation or the installation of carpet or other furnishings. However, these illnesses have not been scientifically associated with specific exposures, and the physiologic mechanism that causes these illnesses is not understood at present. The most effective therapy has been avoidance of environments in which the symptoms are experienced. An episode of similar illness associated with the installation of new carpet in the EPA headquarters in Washington D.C., forced about 20 employees to work in alternative work sites because they could no longer function in the headquarters building.

Office building renovation has also been associated with the onset of symptoms in building occupants. The interviews with the 1st floor employees revealed that about 50% were still experiencing symptoms of the type that are commonly reported by employees working in office buildings. It has been estimated by the World Health Organization that up to 30% of office workers in the developed world may experience similar symptoms. The cause is not understood but it has been hypothesized that organic mixtures of the compounds that emanate from many of materials used in modern furnishings (e.g., particle board, synthetic fabrics and rugs) may play some role in the symptomatology. The workers all stated that they had not experienced such symptoms prior to their move to the 1st floor and that the symptoms began after the onset of colder weather when ventilation that was available from open windows ceased because the windows had to be closed to maintain heat.

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. Building ventilation is particularly important following remodeling activities.

VIII. RECOMMENDATIONS

It would be advisable to increase the capability to bring fresh air into the 1st floor, both to better remove the indoor contaminants and to allow better control of the high temperatures that reportedly occur in the 1st floor offices during the summer. The venetian blind supports in the office in the south east corner should be moved so that they do not prevent the adequate opening of the large windows in that room, and consideration should be given to installing an air conditioner if modifying the windows does not provide a comfortable temperature in that room. (This Room has large windows and a southern exposure that allows the capture of much solar heat.) Perhaps awnings or reflective glass would be appropriate. Windows in the large central 1st floor office also need to be made readily openable, and the modular furniture that blocks one window needs to be modified. If these measures are not sufficient in providing better comfort, serious consideration should be given to the installation of a mechanical ventilation system. To avoid entraining vehicle exhaust fumes, such a system should not draw air in from the side of the building nearest to the bus station.

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

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