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WESTERN PRIMARY SCHOOL
RUSSIAVILLE, INDIANA

NIOSH INVESTIGATORS:
Kevin W. Hanley, MSPH, CIH
Thomas Wilcox, MD
Matthew Klein, PE

I. SUMMARY

On May 28-29, and June 10-11, 1991, an indoor air quality evaluation was performed at Western Primary School, in Russiaville, Indiana. The evaluation was requested by the Indiana State Teachers Association as a result of recurring headaches, nausea, respiratory, eye, and skin irritation reported by teachers and students. Environmental measurements for temperature, relative humidity (RH), carbon dioxide (CO_2), airborne fibers, formaldehyde, and volatile organic compounds (VOCs) were collected. Thirteen employee interviews were conducted to characterize the reported symptoms. The design and performance of the heating, ventilating, and air conditioning (HVAC) system was also evaluated.

During the initial NIOSH visit, the HVAC system was not operating due to concern regarding chloroprene off-gassing from the coating on the fiberglass insulation lining the interior of the ventilation system. Ordinary cooling fans, open doors, and windows provided the ventilation for the building. Under these conditions, CO_2 is not an effective indicator of the outside air ventilation rate. Since the air was not tempered, temperature and RH were similar to ambient.

During summer recess, NIOSH returned to the school to complete the evaluation when the HVAC system was operating. Air and surface contamination samples for fibers were below, or detected at, the limit of detection (0.005 fibers per cubic centimeter(f/cc)). VOCs including formaldehyde were detected in the school air in extremely low concentrations. The levels were consistent with those expected in a non-industrial environment. Chloroprene was not detected in any of the samples.

Bulk samples of the fiberglass were heated to 60°C (140°F) and a head space analyses were performed. Chloroprene was not detected in these analyses. Trace levels of some VOCs were detected.

Although no health hazards were specifically identified, employee interviews revealed that the majority have experienced symptoms consistent with those commonly referred to as "sick building syndrome". An evaluation of the design and performance of the HVAC system identified a number of concerns. Increasing the outside air ventilation rate, repairing the malfunctioning outside air damper system, calibrating the room control systems, relocating the outside air intake, and balancing the ventilation system are among the recommendations provided in Section VIII of this report.

Keywords: SIC 8211 (elementary school), indoor air quality, ventilation, volatile organic compounds, chloroprene, formaldehyde, fiberglass insulation.

II. INTRODUCTION

On March 12, 1991, the National Institute for Occupational Safety and Health (NIOSH) received a request for a Health Hazard Evaluation (HHE) of Western Primary School, located in Russiaville, Indiana. The Indiana State Teachers Association submitted the request for an indoor air quality investigation as a result of various health complaints being attributed by teachers and students to the environment of the school building.

On May 28-29, 1991, NIOSH conducted an initial visit in which teacher interviews were conducted and environmental samples were obtained. However, due to concern regarding chemical contamination from the fiberglass duct insulation, the heating, ventilating, and air conditioning (HVAC) system was not operating during the initial visit. Therefore, a follow-up site visit was made on June 10-11, 1991, (after the school year had ended) to conduct further environmental sampling while the system was operating, and to evaluate the operation of the HVAC system. A letter containing the preliminary findings from this evaluation was sent to the requester and school administration on July 30, 1991.

III. BACKGROUND

Western Primary School, built in 1979, is one of four schools in a complex located in an agricultural area. The building is a single story structure with a concrete slab foundation. The floor plan is a triangular design with 22 classrooms positioned on the peripheral walls. The interior spaces are occupied by administrative offices, activity/lunch room, media room, staff lounge, rest rooms, and special purpose classrooms.

The school employees 23 teachers and educates approximately 500 students in kindergarten through second grade. During initial meetings with teacher representatives, the school principal, and the school nurse, it was reported that some teachers had experienced headache and fatigue since the building was first occupied. In 1989 it was noted that more teachers were experiencing similar symptoms. During the last two years, some teachers and students were experiencing intermittent facial redness, primarily on the cheeks. (This facial flushing occurred intermittently and could disappear in a matter of minutes.) Although the symptoms occurred throughout the building, the southwest corner appeared to be the focal point.

Prior to NIOSH involvement, two different consultants had visited the site to conduct evaluations of indoor air quality, and a HVAC contractor hired by the school tested and balanced the ventilation system. A number of changes were made as a result of the first consultant's recommendations, including but not limited to, removing the carpet, relocating the outside air intake, discontinuing the use of the garbage incinerator, and raising boiler stacks. One of the consultants suggested that the symptoms could be caused by a chemical (chloroprene) off-gassing from the fiberglass insulation lining the interior of the ducts, reheat, and variable air volume (VAV) boxes in the HVAC system. Because of this concern, the ventilation system was reportedly turned off on April 29, 1991, and remained so until the end of the school year.

IV. MEDICAL EVALUATION

During the initial visit on May 28-29, 13 out of 23 teachers were interviewed (seven 1st grade and six 2nd grade teachers). Table 1 shows the number of teachers that reported experiencing the stated symptoms. In addition, one 1st grade and one 2nd grade teacher reported having experienced great difficulty maintaining a comfortable school room temperature, and one 2nd grade teacher and two 1st grade teachers reported the frequent presence of strong odors in their classrooms. Four 1st grade and one 2nd grade teacher reported that they kept their classroom windows open throughout the year in order to provide fresh air to the room and help keep their students alert.

A review of the symptom reporting logs maintained by each classroom teacher revealed that the average number of students experiencing symptoms (primarily headaches and stomach discomfort) fell from 60 during mid-April, 1991, (before the ventilation system was turned off) to 26 during the last week in May of this school year.

The symptoms reported by the teachers during private interviews and those recorded on the student symptom logs are typical of those usually reported by the occupants in the many buildings that NIOSH has been asked to evaluate. The occurrence of these symptoms in building occupants is commonly referred to as "sick building syndrome," and despite intensive research both in this country and abroad, the etiology of these symptoms is not well understood. However, most researchers in the field feel that the condition is probably multifactorial in origin, with factors such as outside air, ventilation effectiveness, interior concentration of organic chemical contaminants, microbial agents, and stress possibly playing a role.

In recent months, faculty and parental concern has increased because of reports of concentrations of volatile organic compounds (VOCs) such as toluene, 1,1,1-trichloroethane, benzene, etc., being found in the blood of a few students that exceeded the "average level" as reported by the laboratory that performed the analysis. The parents had received opinions from some pediatricians that no such chemicals should be found in children's blood. A review of anonymous copies of the blood analysis reports revealed that most concentrations were around or below the laboratory's limit of detection. (A few were somewhat above the limit of detection.) It is normal for even the blood of people without industrial chemical exposure to have very low blood levels (such as the levels found in the students' blood) of VOCs because of the exposures that we all encounter during our normal activities. Such compounds are ubiquitous in our houses and offices due to the organic chemicals present in furniture, building materials, commercial products such as cleaning supplies, office supplies, and arts & crafts materials, as well as the amount of gasoline and other chemicals used in a modern society.

V. INDUSTRIAL HYGIENE EVALUATION

Air samples were collected at Western Primary School on May 29, 1991, when the HVAC system was not operating, and on June 10, 1991, when the HVAC unit was operating (without the air conditioner). Because the symptoms were reported to be more numerous and more severe during the winter, an effort was made to have the HVAC system mimic its operating parameters associated with cold weather. The air conditioner was turned off, the boilers were fired, (the heating mode was activated), and the branch line air pressure regulating the outside air damper was set to (reportedly) correspond to the minimum opening position of 40 percent. Visual observation, however, confirmed that this air pressure actually could not open the outside air damper beyond its totally closed position. Furthermore, since the classroom temperatures quickly exceeded the maximum thermostat settings (85°F), the heating system could not be continually run.

The focus of the sample locations was the southwest corner of the building, although locations in other sections of the building and outside were also selected for comparison. The specific sampling locations include rooms 4, 5, 6, 12, 17, C, staff lounge, and an outside location on the south side of the playground. Samples obtained in room 6 and the staff lounge were either collected inside the ventilation duct or at the air diffuser opening. Possible air contaminants sampled for included fiberglass, formaldehyde, and volatile organic compounds (VOCs) including chloroprene. Bulk samples of the fiberglass insulation from inside the ventilation system were also collected and submitted to the analytical laboratory for a head space analysis. (These samples were heated inside a close vessel to the desired temperature, and the air space above the bulk material was monitored for aldehydes and VOCs including chloroprene.) Direct reading instrumentation was also used to monitor carbon dioxide (CO_2), temperature, and relative humidity. The findings are presented below under their respective heading:

Fibers

A total of four air samples were collected for fibers during the initial survey, and eight air samples were collected during the follow-up survey because of concern regarding skin irritation and flushing. Seven surface vacuum samples were also collected to assess the degree of settled fiber contamination present on horizontal surfaces such as a cabinet top, window ledge, and the inside of a vent diffuser. These samples were collected on mixed cellulose ester filters and were analyzed in accordance with the NIOSH 7400 method which utilizes phase contrast microscopy at a magnification of 400X. The limit of detection (LOD) and the limit of quantitation (LOQ) for the air sample set were 0.003 fibers/cubic centimeter (f/cc) and 0.05 f/cc, respectively.

All of the air samples collected except one were below the limit of detection. The one sample which exceeded the LOD was only slightly above the detection limit. (The lab reported this sample concentration as 0.005 f/cc, but since it is below the LOQ it is only semi-quantitative.) The surface vacuum samples presented a similar pattern. Four out of seven samples were non-detectable, while the remainder were only marginally above the LOD and well below the LOQ. A few of the samples were also analyzed with a transmission electron microscope (TEM) at 10,500X magnification to confirm the identity of the fiber. TEM analyses confirmed the fibers to be of cellulose or glass fiber origin.

The extremely low fiber concentrations observed would not be expected to produce significant irritative symptoms in the school population.

Formaldehyde

Thirteen air samples were collected for formaldehyde due to reports of nasal and eye irritation. Five of those samples were obtained when the HVAC system was off (with the windows and doors open), seven samples were collected inside the school when the HVAC system was operating (with the windows and doors closed), and one sample was collected outdoors. The samples were collected using the NIOSH 3500 method which entails bubbling the sampled air through a 1% sodium bisulfite solution, and subsequent analysis using an ultraviolet spectrophotometer. This is the most sensitive analytical method for formaldehyde to date.

The LOD and LOQ for the samples collected on May 29 (when the HVAC was off) were 0.008 parts per million (ppm) and 0.032 ppm, respectively. Formaldehyde was detected in the classrooms on this day but the concentration (0.016 ppm) was below the limit of quantitation. Hence, the precision of these sample results may be reduced.

The formaldehyde air samples collected inside of the school on June 10 (when the HVAC was on), ranged from 0.013 to 0.030 ppm. (The LOD and LOQ for this sample set was 0.004 and 0.012 ppm, respectively.) Formaldehyde was also detected outdoors (0.008 ppm), however it was below the LOQ. It is interesting to note that some of the higher concentrations (even though all were very low) were in classrooms which were not in the southwest corner of the building.

One sample was also obtained inside a closed classroom supply cabinet. The formaldehyde concentration detected from this sample was 0.11 ppm. The samples collected inside the ducts measured 0.013 and 0.016 ppm of formaldehyde. These data suggest that the pressboard cabinets are a source of formaldehyde emissions. Materials contained inside the cabinets (fabrics, glues, papers, books, etc.) may also possibly contribute to the off-gassing. This is not to suggest that these cabinets should be removed, since people do not work inside the cabinets, the formaldehyde levels in the occupied spaces are relatively low, and replacement furniture may generate even higher concentrations.

The low level of formaldehyde that was found in the school rooms (0.02-0.03 ppm) is not unusual. Most indoor environments in the United States will have formaldehyde levels similar to the range found in the Western Primary School classrooms. The OSHA Permissible Exposure Limit for formaldehyde is 1.0 ppm averaged over an eight hour day. However, this limit is applicable to an industrial environment, and is not appropriate for evaluating an indoor air quality complaint building such as an office or a school. Generally, 0.1 ppm is the lowest level at which formaldehyde is thought to cause noticeable irritation for those who are sensitive. A few hypersensitive individuals may experience discomfort below this value. However, the very low formaldehyde air concentrations observed in the classrooms cannot account for the number and type of reported complaints.

Because formaldehyde is considered to be a potential occupational carcinogen, the NIOSH Recommended Exposure Limit (REL) for formaldehyde is to control exposure to the lowest feasible concentration. The extremely low formaldehyde concentrations observed in the classrooms were in the range expected in non-industrial environments, and were comparable to the ambient level. Therefore, the classroom formaldehyde concentrations are considered to be at the lowest feasible level.

Volatile Organic Compounds

A total of six sample locations were selected for collecting volatile organic compound (VOCs) air samples during the initial survey because of reports of odors and the suspicion of chemical emissions from the ventilation duct insulation. Two additional locations were added on the follow-up survey when the HVAC system was operating. VOCs is the general term used for a large class of chemical compounds which are organic (i.e. containing carbon) and have a sufficiently high vapor pressure to allow some of the compound to exist in the gaseous state at room temperature. There are literally thousands of unique chemical compounds which are VOCs. VOCs, including formaldehyde and other aldehydes, are emitted in varying concentrations from numerous indoor sources including but not limited to carpeting, fabrics, adhesives, solvents, paints, cleaners, waxes, cigarettes, and combustion sources.

Two different methods were used to collect and analyze the VOC samples. Carbotrap 300 thermal desorption tubes were used for collection and were analyzed using a gas chromatograph and mass spectrophotometer detector (GC/MS). The thermal tubes consist of a three bed sorbent containing Carbotrap C/Carbotrap/Carbosieve S-III materials for trapping organic compounds over a wide range of volatility. Substances such as xylene, toluene, trimethylbenzene, chloroprene, etc. will be captured with this sorbent tube. NIOSH uses this method as an extremely sensitive and a very specific qualitative screening technique; it will identify the VOCs present on the sample in the parts per billion range. To quantitate specific air contaminants supplemental air samples were collected on charcoal tubes, and were analyzed using a GC with a flame ionization detector following the MS identification.

As expected, the MS analyses identified a large number of organics present in the air samples in trace quantities (parts per billion range). This is not unusual. Monitoring for VOCs in non-industrial buildings will reveal similar compounds at these extremely low concentrations in essentially all buildings. This is especially true of newly constructed or renovated structures. Table 2 lists the organic compounds that were identified via MS analysis along with the room number where the sample was obtained. As it can be seen from this table, VOCs were measured throughout the building. Compounds which were present on virtually all of the samples include 1,1,1-trichloroethane, toluene, aliphatic hydrocarbons, benzaldehyde, naphthalene, trichloroethylene, and xylene. The outdoor sample also revealed a number of VOCs such as benzaldehyde, acetic acid, naphthalene, aliphatic hydrocarbons, etc.

Some of the compounds identified with the MS methods, including 1,1,1-trichloroethane, toluene, trichloroethylene, xylene, and benzaldehyde, were further evaluated using the supplemental air samples for VOCs which were analyzed with a GC and flame ionization detector, a quantitative method. The only compounds which were detected in these samples were 1,1,1-trichloroethane, and toluene. The highest concentrations observed for 1,1,1-trichloroethane, and toluene were 0.003 ppm and 0.019 ppm, respectively. Trichloroethylene, xylene, and benzaldehyde were not detected with limits of detection of 0.002, 0.003, and 0.02 ppm. Because benzene was found on all of the thermal desorption tube samples including the blank, analysis for this analyte was repeated using a GC/FID method. Benzene was not detected on these samples with a limit of detection of 0.004 ppm.

Chloroprene was a special concern for this HHE investigation due to suspicion by one of the previous consultants that this substance may be off-gassing from the neoprene lining of the ventilation duct insulation. Additional analytical tests were conducted to specifically identify the level (if any) of chloroprene present in the air samples. Chloroprene was not detected in any of the samples, including the thermal desorption tubes analyzed via MS, and the charcoal tubes analyzed with the GC/FID method. Specific standards were prepared for comparison purposes, and the limit of detection was determined to be
2 micrograms per air sample (or 0.0066 ppm).

Standards for indoor air quality in office buildings do not exist. The Occupational Safety and Health Administration (OSHA) and the American Conference of Governmental Industrial Hygienists (ACGIH) have published regulatory standards and recommended limits for occupational exposures in industrial environments (1,2). With few exceptions, pollutant concentrations observed in the office work environment fall well below these published standards or recommended exposure limits. The regulatory standards and recommended limits for occupational exposures are orders of magnitude higher than the concentrations observed in the classrooms of Western Primary School. Furthermore, the extremely low levels of airborne organic chemicals were well below the concentrations thought to be capable of causing symptoms in normal, healthy people.

Bulk Samples

Bulk samples of the fiberglass insulation were obtained during the initial site visit on May 28-29, 1991. These samples were collected from insulation lining the interior of ventilation ducting. The primary objective for collecting these samples was to assess whether chloroprene can be emitted when this insulation was heated. Three separate samples were submitted to the laboratory for head space analysis. The samples included a dark gray fiberglass with a dark gray coating, a yellow fiberglass with a black mesh coating, and a rose-colored semi-elastic substance (presumably an adhesive) removed from some of the fiberglass.

The head space analysis entails heating the sample within a chamber and monitoring the air space within the chamber for aldehydes using Orbo 23 sorbent tubes, and VOCs using charcoal tubes and mass spectrophotometer identification. This is a qualitative method which can identify the presence or absence of a substance, but only provides a relative quantity. Chloroprene was <u>not</u> detected in any of the head space analyses at a temperature of 60°C (140°F). This temperature should exceed the maximum temperature expected within the HVAC system, including the reheat boxes. Furthermore, since neoprene was the suspected source of the chloroprene, a glove made with this substance was also subjected to this laboratory analysis at an excessively high temperature of 300°C. Chloroprene was detected in this experiment. Exposing the bulk samples to this same extreme temperature (300°C) failed to identify chloroprene in the head space of the heated chamber.

The head space analyses at 60°C did reveal trace quantities of toluene, benzaldehyde, acetaldehyde, formaldehyde, and furfural emissions. Other VOCs which were identified at barely detectable concentrations included 1,1,1-trichloroethane, n-butanol, xylene, styrene, naphthalene, and non-specified aromatics. Trace quantities of benzene were detected in all of the samples including the blank.

Carbon Dioxide

During the initial site visit on May 29, carbon dioxide (CO_2) measurements were obtained. CO_2 is a normal constituent of exhaled breath and, if monitored, can be used as a screening technique to evaluate whether adequate quantities of fresh air are being introduced into an occupied space. The American Society of Heating, Refrigerating, and Air Conditioning Engineers' (ASHRAE) most recently published Ventilation Standard, ASHRAE 62-1989, Ventilation for Acceptable Indoor Air Quality, recommends outdoor air supply rates of 20 cubic feet per minute per person (cfm/person) for office spaces, and 15 cfm/person for reception areas, classrooms, libraries, auditoriums, and corridors (3). Maintaining the recommended ASHRAE outdoor air supply rates when the outdoor air is of good quality, and there are no significant indoor emission sources, should provide for acceptable indoor air quality.

Indoor CO_2 concentrations are normally higher than the generally constant ambient CO_2 concentration (range 300-350 ppm). When indoor CO_2 concentrations exceed 1000 ppm in areas where the only known source is exhaled breath, inadequate ventilation is suspected. Carbon dioxide is not thought to be an etiological agent of indoor air quality symptoms. It is used as an indicator of the adequacy of outside air supplied to occupied areas. Elevated CO_2 concentrations suggest that other indoor contaminants may also be increased. It is important to note that CO_2 is not an effective indicator if the ventilated area is vacated.

Real-time CO_2 levels were determined using Gastech Model RI-411A, Portable CO_2 Indicator. This portable, battery-operated instrument monitors CO_2 via non-dispersive infrared absorption with a range of

0-4975 parts per million (ppm), and a sensitivity of 25 ppm. Instrument zeroing and calibration were performed daily prior to use with zero air and a known concentration of CO_2 span gas (800 ppm). Confirmation of calibration were conducted throughout the instrument use period.

Carbon dioxide measurements taken in occupied classrooms were observed to range from 400-800 ppm. All of the readings except for two were within 400-550 ppm. The two higher readings were collected either near a cluster of children listening to a story, or when windows were closed during the rain. Naturally, this only demonstrates that the outside air supply rate was adequate with the windows and doors open (when the HVAC system was off). On June 10, CO_2 measurements were not made since it was summer recess and the building was essentially vacated. One of the previous consultant reports recorded CO_2 levels in excess of 1000 ppm, which suggests the outside air supplied to this area was inadequate.

Temperature and Relative Humidity

Temperature and relative humidity measurements were conducted in the school during the initial visit because these parameters affect the perception of comfort in an indoor environment. The perception of thermal comfort is related to one's metabolic heat production, the transfer of heat to the environment, physiological adjustments, and body temperatures. Heat transfer from the body to the environment is influenced by factors such as temperature, humidity, air movement, personal activities, and clothing. ANSI/ASHRAE Standard 55-1981 specifies conditions in which 80% or more of the occupants would be expected to find the environment thermally acceptable (4). The temperatures range from 68-74°F in the winter, and from 73-79°F in the summer. The difference between the two is largely due to seasonal clothing selection. In a separate document (ASHRAE standard 62-1989), ASHRAE also recommends that relative humidity be maintained between 30 and 60% (3). Excessive humidities can support the growth of pathogenic and allergenic microorganisms.

Real-time temperature and relative humidity measurements were conducted using a Vaisala, Model HM 34, battery-operated meter. This meter is capable of providing direct readings for dry bulb temperature and relative humidity ranging from -4 to 140°F, and 0 to 100%, respectively. The temperatures observed in the classrooms ranged between 80 and 84°F, while the humidity ranged from 69 to 74%. These values exceed the thermal comfort guidelines for summer (73 to 79°F) and the recommended humidity range, as published by ASHRAE. Certainly it is understood that the temperature and humidity were not being controlled at the time these data were obtained because of the concern regarding the operation of the HVAC system. The above information was provided for future reference.

Microbial Agents

Issues regarding airborne biological contamination are difficult to address. Biological contamination is typically characterized as colony forming units (CFUs) per cubic meter of air, or square inch of surface area. Unfortunately, this type of data is extremely difficult to interpret because of the large variety of methods used to collect, incubate, and cultivate the samples. One of the major problems is that there is not an established scientific data base concerning the "normal" range of microbial concentrations (and species) in indoor environments. A dose-response relationship in humans has not been established, and a criteria for acceptable exposure levels is not available. Furthermore, microbes are ubiquitous in nature; samples collected outdoors may reveal substantial bioaerosol concentrations. Hence, NIOSH generally does not routinely recommend this type of sampling. However, visible microbial growth on interior building surfaces, for example, should serve as clear evidence that there is a potential biological problem. It is not typically necessary, or helpful to try to quantify the contamination.

The guidelines published by the American Conference of Governmental Industrial Hygienists' Committee on Bioaerosols shares this interpretation (5). "One should use air sampling as a last resort...Air sampling rarely provides proof of inappropriate exposure to bioaerosols."

Visible evidence of microbial contamination, standing, or leaking water was not apparent at Western Primary School, and monitoring for airborne microbial contamination was not performed.

VI. VENTILATION EVALUATION

While no chemicals were identified at unexpected concentrations in the classroom environment, the evaluation of the school's HVAC system revealed significant concerns. Prior to addressing the deficiencies, a brief description of the HVAC system and its operation is warranted.

One air handling unit (AHU-1), supplies air to all of the classroom and administration areas at Western Primary School. Two other air handlers supply air to the activities/lunch room and kitchen areas of the building. Air Handling Unit-1 is the unit of concern and is the only unit discussed.

The system for AHU-1 is a variable air volume (VAV) system. Perimeter areas have hot water, finned-tube convective baseboard heaters in addition to the VAV terminals, while interior rooms have VAV reheat terminals. Virtually every room on the system has its own VAV terminal. The VAV terminals supply air to two or three standard four-foot double-throw slot diffusers located along the centerline of the room. The diffusers are perpendicular to the outside walls of the building and are spread approximately equally-spaced along the centerline.

Pneumatically powered thermostats in each VAV area control the valves in either the convective heaters or the reheat coils. The thermostats also control operation of the VAV damper actuators. Most of the thermostats are the original Barber-Coleman flush mount design; but some of the thermostats have been replaced with Johnson Controls thermostats. The Barber-Coleman design thermostats are induction air types. That is, these thermostats emit a small jet of main pressure line air into a tube on the face of the thermostat. The jet inducts room air across the sensing element of the thermostat and into an opening in the bottom of the tube. Openings and structures on the cover plate for the thermostat allow passage of room air into the thermostat while supposedly preventing recirculation of jet air to the thermostat. The thermostats are located next to the door frame of the doors to the rooms or within about three feet of the doorway.

Air is returned from the rooms through the ceiling plenum. Air from the rooms is supposed to enter the plenum through slots around the luminaries. Some rooms had a plastic egg-crate grille in the ceiling which served as a return. An alternate unintended return path could be through open doors and the hallways.

On June 10 and 11, 1991, an inspection was made of all accessible components of the air handling unit. As part of the inspection, the operation of the minimum outside air damper system was observed.

Air flow measurements using the Shortridge flow hood equipped with the 5 1/4" x 47" skirt were made on the diffusers in the rooms in which samples were collected plus three others (ten rooms total). Measurements with the flow hood were made with the flaps closed and with the use of a flow distribution grille. In addition, the measurements were compensated for supply air temperature and local barometer; therefore, the measurements were made in actual flow as opposed to standard flow. These flows were measured with the VAV set fully opened and closed as judged by the branch line pressure to the VAV actuator.

Along with the air flow measurements, thermostat calibrations were checked. Calibrations were checked by adjusting the setpoint on the thermostats to the temperature measured at the thermostat using a thermocouple. The branch line pressure to the damper actuator was then monitored using a pressure gage.

The evaluation of the HVAC design and performance identified a number of problems. The most significant ones include the location of the outside air intake, the operation of the outside air damper, the balancing of the classroom air supply, the functioning of the room thermostats and control systems, and the outside air supply rate.

Outside Air Intake

The outside air intake is common to all of the air handling units. This intake is located in a southwestern wall over the door to the Mechanical Room. The cooling tower is located next to and south of the intake and is set up off the ground on four foot concrete pillars. The cooling tower fan pulls air horizontally through the tower and discharges the air toward the outside air intake. Total distance between the fan discharge and outside air intake is approximately 20 feet. Furthermore, the cooling tower is located inside a brick wall which shelters the east and south sides of the tower, and could reduce the dispersion of the tower discharge. This arrangement makes the intake of cooling tower discharge into the outside air intake of the school building very possible. In fact, sulfur odors from an algicide added to the tower water reportedly had been smelled by building occupants in the past.

A small waste-treatment plant is located about 300 feet southwest of the outside air intake. This treatment plant treats waste water effluent from the school complex. Open water ponds exist as part of the plant. Under unfavorable conditions contaminated air may be able to travel from the plant to the outside air intake.

Outside Air Damper System

The minimum setting for the outside air damper is set by adjusting a component (possibly an adjustable pneumatic relay) of the damper control system. Control system drawings call for the minimum branch line pressure to the outside air damper to be set at 9 psi. The outside air damper was found to be barely open when the unit was operating. In fact, the damper did not open even when the line pressure to the damper was measured with a pressure gage to be 10 psi. At 10 psi line pressure, the actuator rod moved only 3/8". Stroke at full pressure according to the specification sheets for the actuator is 3 11/16"; therefore, at 10 psi line pressure, the actuator should have stroked to about 1/2". However, full main pressure (17 psi) did cause the actuator to stroke out its full length. Furthermore, when the damper motor was not connected to the damper linkage, the actuator rod stroked to about 1 1/2"at 10 psi, and the outside air damper could easily be opened and closed by hand. The conclusion is that the mechanical resistance of the outside air damper system was too great for the damper actuator to move the damper at a line pressure of 10 psi. Hence, adequate outside air was not supplied under these operating conditions.

Thermostats/VAV Controls

A calibration check on the thermostats showed branch line pressures of 12.0, 13.0, 17.5, 4.0, 17.0, 12.0, 0.0, 5.0, 2.5, and 10.0 psi, when the thermostat setpoint was set to the temperature measured at the thermostat. A local Barber Coleman representative stated that the proper calibration for the type of thermostats at the school is somewhere between 7 and 8 psi. At this pressure, the hot water valve for the baseboard convectors and reheat coils would be fully closed and the VAV damper would be set to a minimum setting. The measured calibration pressures are noticeably different than this setting. The result of the calibration setting would be that (depending on the calibration point or the season), rooms could be either overcooled or overheated unless the thermostat was adjusted to account for the inaccurate setpoint.

Nearly all of the thermostats that were checked had some dust build up along the inside walls of the aspiration tube. In some cases, additional dust was found around the aspiration orifice to the point where the air flow coming from the orifice appeared to be affected. If the aspirator is compromised, the thermostat may not be properly sensing the room temperature which may affect proper room tempering.

In several cases, a structure on the back of the thermostat cover plate which encloses the end of the aspirator tube was missing or the aspirator tube was missing. The enclosing structure and aspiration tube are important because these structures guide the aspiration air out of the thermostat. Without these structures, aspirator jet air could be recirculated back over the sensing element of the thermostat causing the thermostat to sense the wrong temperature.

Air Supply Balancing

Minimum air flows measured in the several classrooms averaged 498 cfm, but ranged from 141 to 971. Maximum air flows averaged 664 cfm, but ranged from 309 to 1013. Design air flows for the classrooms average 1141 cfm and range from 860 to 1680. Air flow measurements clearly show that the rooms are not receiving adequate air flow relative to design.

Outside Air Supply Design

The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) has published recommended building design criteria, regarding ventilation of indoor spaces, which can be used for evaluating HVAC system design and performance. ASHRAE's most recently published Ventilation Standard, ASHRAE 62-1989, Ventilation for Acceptable Indoor Air Quality, recommends outdoor air supply rates of

20 cubic feet per minute per person (cfm/person) for office spaces, and 15 cfm/person for reception areas, classrooms, libraries, auditoriums, and corridors (3).

The HVAC system at Western Primary School was apparently designed to bring in approximately 3000 cubic feet per minute of outside air during severe climate conditions (very hot or very cold). Considering that approximately 500 people could be in the building during the normal school year, it appears the outside air design was based on the ASHRAE criterion that was in effect during 1979 (5 cfm outside air/person). This amount of outside air is grossly insufficient to provide the minimum outside air flow recommended by the current ASHRAE standard. Seventy five hundred cfm of outside air would need to be supplied for the 15 cfm/person criterion to be met for 500 people. With VAV systems, it is generally acknowledged that the outside air flow rate should be established with the system operating at the minimum setting. The written report supplied by the HVAC contractor identified that the outside air measurement was taken with the fan operating at the maximum setting.

When the supply fan was operating at the minimum position (VAV dampers closed to their minimum stops), it was cycling. This makes it impossible for the system to effectively deliver a continuous supply of outside air.

Miscellaneous Problems

The filters were of unknown efficiency, but appeared to be low efficiency filters. ASHRAE recommends using filters with an efficiency rating of 35 to 60% according to the ASHRAE dust spot test (3).

A smoke tube used at the access doors for the various plenums showed that the air from the mechanical room would leak into the unit. Any volatile materials used in the mechanical room could also enter the unit and be distributed throughout the building. Smoke tubes also showed the mechanical room to be under negative pressure relative to the adjacent areas including outside. Therefore, air contaminants could be pulled into the room and into the unit.

VII. CONCLUSIONS

1. Interviews conducted with the teachers revealed that the majority have experienced symptoms consistent with those commonly associated with "sick building syndrome." The teacher interviews also established the symptoms to be temporally related to their presence in the building.

2. Volatile organic compounds including formaldehyde were detected in the school in extremely low concentrations. The levels were consistent with those expected in a non-industrial indoor environment.

3. Chloroprene was not off-gassing from the insulation lining the interior of the ventilation system.

4. Airborne and settled fibers were not detected in essentially all of the samples. (Some of samples had amounts that were marginally above the limit of detection, a very low level.)

5. The outside air damper in the HVAC system was not functioning properly. The damper was closed when the branch line (air) pressure was set at the minimum setting of 9 psi due to mechanical restriction of the actuator rod and damper linkage. Hence, the HVAC system was not supplying adequate outside air according to design.

6. The HVAC system was not balanced. The minimum and maximum air supply rates to the classrooms were below those intended by design.

7. The design of the outside air supply rate was consistent with the ASHRAE criterion of that era (5 cfm/person), which is no longer accepted as adequate. The current ASHRAE outside air supply criterion for classrooms is now 15 cfm/person.

8. The HVAC control systems in the classrooms were either improperly calibrated, dirty, or otherwise malfunctioning, which affected the VAV air supplies and the effective regulation of the classroom temperatures.

9. The outside air intake is in an extremely poor location. The proximity of this intake to the air conditioner water cooling tower increases the potential for distribution of bioaerosols.

10. Filters used in the HVAC system were of low efficiency.

VIII. RECOMMENDATIONS

1. An engineering firm familiar with Barber-Coleman controls should be hired to completely clean, repair, and calibrate all control systems in the building. A representative from the maintenance staff should participate in the process to learn the operation of the control systems. This school representative should also be formally trained in the operation and maintenance of the controls. School maintenance personnel, under the advisement of the controls company, should establish a routine maintenance and calibration schedule for the controls.

2. The problems noted with the outside air damper system should be corrected. The outside air flow for the building should be established based on the occupancy of the building and the ASHRAE outside air criterion of 15 cfm/person. The minimum outside air flow for the building should be set based on actual measured air flow in AHU-1's outside air duct or by other established methods. This minimum outside air flow should be set at the minimum flow setting of the supply fan.

3. The outside air intake should be relocated so that contaminants from the cooling tower, waste treatment plant, building exhausts, or other contaminant sources are less likely to enter the outside air intake.

4. The entire HVAC system should be re-tested and balanced by a competent engineering firm. The person performing the testing and balancing should be NEBB (National Environmental Balancing Bureau) certified or otherwise have equivalent certification.

5. The maintenance staff should be formally trained on all aspects of proper operation of the mechanical systems.

6. Filters with an efficiency rating of 35 to 60% should be used as recommended by ASHRAE and determined by the ASHRAE dust spot test.

7. Since the school board decided to have the insulation removed from the interior of the ventilation duct system, every effort must be made to assure that no residual fiberglass remains in the ducts that may easily become airborne and be carried into the classrooms and cause occupant irritation.

IX. REFERENCES

1. Code of Federal Regulations (1989). OSHA Table Z-1. 29 CFR 1910.1000. Washington, DC: U.S. Government Printing Office, Federal Register.

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4. ASHRAE (1981). Thermal environmental conditions for human occupancy. Atlanta, GA: American Society of Heating, Refrigerating and Air Conditioning Engineers. ANSI/ASHRAE Standard 55-1981.

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X. AUTHORSHIP AND ACKNOWLEDGEMENTS

Report prepared by:
Kevin W. Hanley, M.S.P.H.,C.I.H.
Industrial Hygienist
Industrial Hygiene Section

Thomas Wilcox, M.D.
Medical Officer
Medical Section

Matthew Klein, P.E.
Mechanical Engineer
Industrial Hygiene Section

Field Assistance by: Leo M. Blade, C.I.H.
Industrial Hygienist
Industrial Hygiene Section

Originating Office: Hazard Evaluations and Technical Assistance Branch
Division of Surveillance, Hazard Evaluations and Field Studies

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For the purpose of informing affected employees, copies of this report shall be posted by the employer in a prominent place accessible to the employees for a period of 30 calendar days.

TABLE 1
SYMPTOMS REPORTED BY TEACHERS
WESTERN PRIMARY SCHOOL
HETA 91-143

Symptom	Seven 1st Grade Teachers	Six 2nd Grade Teachers
Headache	4	2
Fatigue	4	2
Dizzy/Lightheaded	3	1
Nausea	1	0
Mucus Membrane Irritation	4	0

TABLE 2
WESTERN PRIMARY SCHOOL
RUSSIAVILLE, INDIANA
HETA 91-143

Trace Levels of Air Contaminants Identified By Mass Spectrophotometer Analysis

Compound	Room #							
	4	5	6*	12	17	C	SL*	Outside
1,1,1 Trichloroethane	x	x	x	x	x	x	x	
Toluene	x	x	x	x	x	x	x	
Trichloroethylene	x	x		x	x		x	
Xylene	x	x		x	x		x	
Benzaldehyde	x	x	x	x	x		x	x
Hexane	x	x			x		x	
Naphthalene	x		x	x	x		x	x
Acetone		x	x	x			x	x
Pentane		x						
Freon 11®		x	x	x			x	
Methyl ethyl ketone		x					x	
Methyl cyclopentane		x						
Acetic acid	x	x	x	x		x		x
Aliphatic hydrocarbons	x	x	x	x				x
Methyl styrene		x						
Styrene							x	x
Diethyl carbitol	x	x			x	x		x
Glycols/glycol ethers	x							
Aliphatic alcohol				x				
Dimethyl benzyl alcohol		x						
Ethyl hexanol			x	x				x
Phenol								x
Unspecified Furan								x

TABLE 2 (cont.)
WESTERN PRIMARY SCHOOL
RUSSIAVILLE, INDIANA
HETA 91-143

Trace Levels of Air Contaminants Identified by Mass Spectrophotometer Analysis

C_9, H_{12} Aromatic	x	x	x	x
C_8 - C_{13} Alkanes	x		x	
C_7				x

* The samples in the staff lounge were collected inside of the ventilation duct. Room 6 samples were collected at the vent diffuser opening.