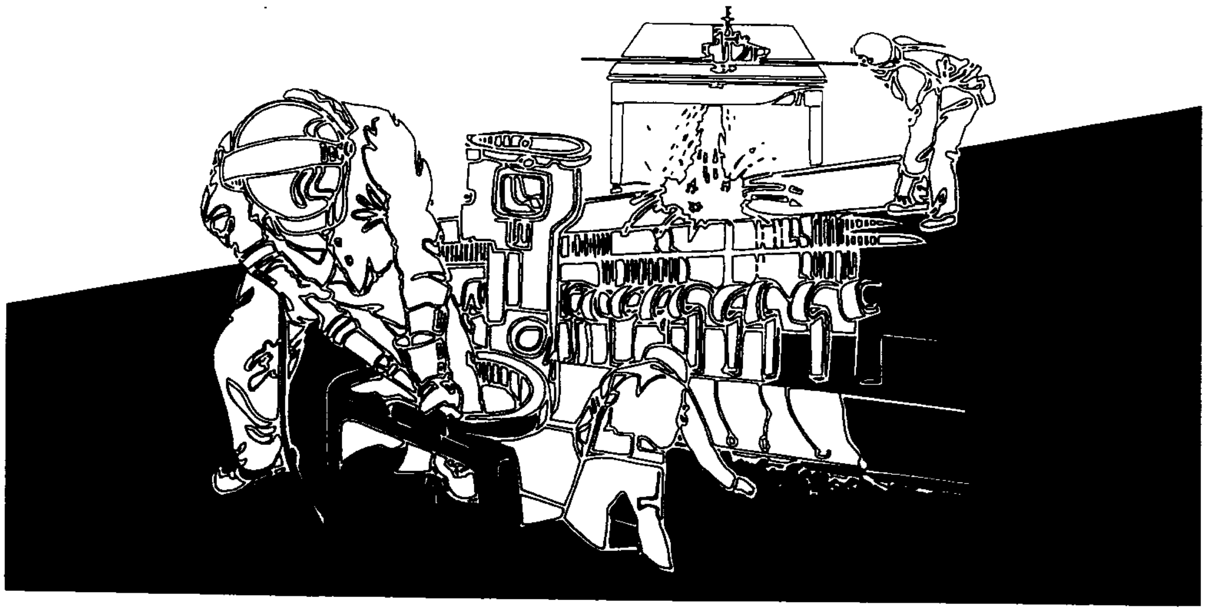
NIOSH

# HEALTH HAZARD EVALUATION REPORT

## HETA 92-107-2227
## WESTERN PRIMARY SCHOOL
## RUSSIAVILLE, INDIANA



U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Public Health Service
Centers for Disease Control
National Institute for Occupational Safety and Health

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# PREFACE

The Hazard Evaluations and Technical Assistance Branch of NIOSH conducts field investigations of possible health hazards in the workplace. These investigations are conducted under the authority of Section 20(a)(6) of the Occupational Safety and Health Act of 1970, 29 U.S.C. 669(a)(6) which authorizes the Secretary of Health and Human Services, following a written request from any employer and authorized representative of employees, to determine whether any substance normally found in the place of employment has potentially toxic effects in such concentrations as used or found.

The Hazard Evaluations and Technical Assistance Branch also provides, upon request, medical, nursing, and industrial hygiene technical and consultative assistance (TA) to federal, state, and local agencies; labor; industry; and other groups or individuals to control occupational health hazards and to prevent related trauma and disease.

HETA 92-107-2227
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WESTERN PRIMARY SCHOOL
RUSSIAVILLE, INDIANA

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## I. SUMMARY

On February 4-6, 1992, an indoor air quality (IAQ) follow-up evaluation was performed at Western Primary School, Russiaville, Indiana. The initial NIOSH IAQ evaluation (HETA 91-143) of this building occurred in May and June of 1991 following a request by the Indiana State Teachers Association concerning recurring headaches, nausea, respiratory, eye, and skin irritation reported by teachers and students. The follow-up request was submitted by the IAQ task force established by the Western Primary School corporation and requested that NIOSH evaluate the modifications that have been completed (and proposed), as well as to repeat the air monitoring conducted during the initial health hazard evaluation (HHE).

Environmental measurements for temperature, relative humidity (RH), carbon dioxide ($CO_2$), airborne fibers, formaldehyde, and volatile organic compounds (VOCs) were collected. Sixteen employee interviews were conducted to characterize any reported symptoms and compare the responses to those previously obtained in May 1991. The design and performance of the heating, ventilating, and air conditioning (HVAC) system was also evaluated, including an assessment of the modifications.

During the initial NIOSH visit, the HVAC system was not operating due to concern regarding possible chloroprene off-gassing from the coating on the fibrous glass 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 of mechanical systems. During summer recess, NIOSH returned to the school to continue the evaluation when the HVAC system was operating. Because the building was unoccupied, $CO_2$ monitoring was not performed since the source of $CO_2$ is expired breath. The follow-up evaluation occurred in the winter with the building fully occupied and the HVAC system operating in the heating mode. (During the 1990-91 school year, the symptoms were reported to be more frequent and more severe in the winter months.) The levels of $CO_2$ measured during the follow-up survey ranged from 400 parts per million (ppm) prior to occupancy up to 525-675 ppm by mid morning, and remained relatively constant throughout the remainder of the day which suggests that the outside air supply rate was adequate.

Air monitoring conducted during the initial and follow-up evaluations were consistent in that air contaminants were detected in the ranges expected in non-industrial environments. Air samples for fibers collected during the follow-up ranged from 0.01 fibers per cubic centimeter (f/cc) to 0.04 f/cc. VOCs, which were detected in the

school air in extremely low concentrations, include ethanol, limonene, toluene, and branched alkanes. Formaldehyde was detected in only one of seven samples in very low concentrations (0.018 ppm). Chloroprene was not detected in any of the samples with a limit of detection of 0.007 ppm.

Employee interviews of the teachers were conducted during the initial and follow-up evaluations. In general, the interviews have suggested a substantial reduction in the frequency of symptoms reported by the building occupants. Some complaints still existed, especially those relating to temperature control, particularly in interior rooms of the building. In two alternative classrooms in adjacent school buildings, which were arranged for those students who were markedly symptomatic the previous year, health complaints have decreased.

During the initial visit, 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 were among the recommendations provided after the initial evaluation.

The school corporation has implemented a number of modifications and has plans to continue installing engineering changes in the next summer recess. Four auxiliary HVAC units have been installed, malfunctioning variable air volume (VAV) boxes were replaced, and fibrous glass insulation lining the interior of HVAC ducting was removed. Building modifications scheduled for the 1992 summer recess include relocating the boilers and hot water heaters to a separate mechanical room, replacing the pneumatic thermostat/VAV controls with digital controls, installing additional auxiliary HVAC units, relocating the outside air intake, and replacing the cooling tower with a condensing unit.

No health hazards were specifically identified during this evaluation. Employee interviews indicated that the frequency of symptoms attributed to being in the building had decreased from the previous school year. Modifications to the HVAC systems that have been implemented (and proposed) have been reviewed and recommendations presented in Section VIII of this report include improving accessibility to HVAC units for maintenance, increasing air filtration efficiency, ensuring proper installation of HVAC insulation, as well as performing scheduled preventive maintenance, cleaning, and calibrations of control systems.

Keywords: SIC 8211 (elementary school), indoor air quality, follow-up, ventilation, carbon dioxide, thermal comfort, volatile organic compounds, chloroprene, formaldehyde, fibrous glass insulation.

## II. INTRODUCTION

On November 26, 1991, the National Institute for Occupational Safety and Health (NIOSH) received a request for a follow-up Health Hazard Evaluation (HHE) of Western Primary School, located in Russiaville, Indiana. The Indiana State Teachers Association submitted the initial request for an indoor air quality (IAQ) investigation as a result of various health complaints being attributed by teachers and students to the environment of the school building. The initial NIOSH evaluation was conducted in May and June 1991. The follow-up HHE request was submitted by the IAQ task force established by the Western school corporation and sought a continued evaluation of the school with particular attention to the modifications which were completed and proposed.

On February 4-6, 1992, NIOSH conducted a follow-up visit in which teacher interviews were conducted, environmental samples were obtained, and the heating, ventilating, and air conditioning (HVAC) systems were evaluated. The preliminary findings and recommendations were discussed with the school corporation management and teacher representative during the closing conference on February 6, 1992.

## 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 the May 1991 visit 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 years 1990 and 1991, 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 fibrous glass 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.

During the summer recess of 1991, a number of modifications were implemented to address the IAQ problem. Four auxiliary HVAC units were installed, malfunctioning VAV boxes were replaced, and fibrous glass insulation lining the interior of HVAC ducting was removed. Additional engineering changes are planned for the 1992 summer recess. Furthermore, children who had been markedly symptomatic while in the building during the 1990-91 school year were placed in "alternative classrooms" in nearby buildings at the Western school district campus and did not enter the primary school building.

## IV. MEDICAL EVALUATION

On February 5-6, 1992, teacher interviews were conducted regarding the symptoms both they and their students had experienced during the school year. Teachers also completed a brief questionnaire which focused on their own symptoms and classroom thermal comfort during the preceding two weeks. Daily logs of symptoms reported by the teachers and students were also reviewed by the NIOSH medical officer.

During meetings on February 5th with teacher representatives, the school principal, and the school nurse, it was agreed that teacher and student reports of building related symptoms (e.g., headache, fatigue, eye irritation, abdominal discomfort, facial redness) had markedly diminished during the current school year as compared to the previous year. Two kindergarten, seven 1st grade and seven 2nd grade teachers were interviewed. The kindergarten teachers reported that neither they nor their students had experienced significant problems during the school year. Table 1 shows the number of first and second grade teachers that reported frequently experiencing the stated symptoms while in the school during the current school year.

Two 1st grade teachers reported having experienced great difficulty maintaining a comfortable schoolroom temperature during the current school year. Two 1st grade and one 2nd grade teacher reported that they tried to keep their classroom windows open throughout the year in order to provide fresh air to the room. Most of the teachers reported that the building-related symptoms of both the teachers and the students had markedly decreased this school year. Both teachers of the alternative 1st and 2nd grade classrooms reported that the health of their students appeared to be much improved and that their students were doing well in their alternative classroom sites.

While the overall situation in the Western Primary School building had markedly improved, several teachers mentioned that they, as well as some students, were still occasionally experiencing symptoms. Several teachers reported that they had experienced an increased frequency of symptoms, especially fatigue and eye irritation, while in the building during the two weeks prior to the interview.

The questionnaires completed by fourteen teachers asked about symptoms experienced while present in the building during the previous two weeks. Four teachers occasionally (1-3 days) had headaches in the previous two weeks, six had unusual fatigue, four had dizziness or lightheadedness, two had nasal congestion, seven had eye irritation, and eight had difficulty maintaining a comfortable thermal environment in their classrooms.

Review of the symptom reporting logs maintained by each classroom teacher in the primary school building revealed that the average number of student reports of symptoms (primarily headaches and stomach discomfort) rose from 25 per week during November and December 1991, to 36 per week during January 1992. For comparison, the weekly average number of student reports of symptoms was 60 during mid-April 1991, a time when the ventilation system was operating.

Reports of teacher symptoms on the daily logs also rose during the same period, from approximately 10 per week in November/December 1991, to 25 per week in January 1992. These symptom logs also revealed that some specialty teachers who teach in interior classrooms (without windows) were frequently experiencing symptoms while in the building. Questionnaires returned by administrative staff also indicated that personnel in interior offices were frequently experiencing symptoms.

It appears that during the 1991-92 school year, health symptoms among teachers and students are less frequent than the previous year. However, there are still people (especially teachers and administrative personnel in interior rooms) experiencing symptoms while at the school.

## V. INDUSTRIAL HYGIENE EVALUATION

Air samples were collected at Western Primary School on February 5, 1992, when the HVAC system was operating in the heating mode. Measurements of carbon dioxide ($CO_2$), temperature, and relative humidity (RH) were also obtained with direct reading instrumentation.

The focus of the sample locations was the southwest corner of the building, although locations in another section of the building and outside were also selected for comparison. The specific sampling locations include rooms 4, 6, 17, staff lounge, and an outside location on the south side of the building. Possible air contaminants sampled for included fibrous glass, formaldehyde, and volatile organic compounds (VOCs) including chloroprene. The findings are presented below under their respective heading.

Fibers

A total of five air samples were collected for fibers during the follow-up survey because of concern regarding skin irritation and facial flushing. 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) for the air sample set were 0.003 fibers/cubic centimeter (f/cc).

The fiber concentrations detected inside of the school ranged from 0.01 to 0.04 f/cc compared to 0.006 f/cc observed outside of the building. The highest concentration was detected in Room 17. Although these fiber concentrations are very low, they are an order of magnitude greater than the airborne fiber concentrations collected during the initial HHE. (All of the airborne fiber samples collected in the spring of 1991, except one, were below the LOD.) Presumably the higher concentrations are the result of the increased activity of an occupied building (i.e. clothing and paper fibers) and possibly from the fibrous glass insulation which was removed from within the ducting or from the unsealed edges of fibrous glass insulation within the heat exchanger units.

NIOSH method 7400 cannot distinguish between fibrous glass, cellulose, asbestos, or any other fibrous material. However, during the initial HHE, 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 these fibers to be of cellulose or glass fiber origin.

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

Formaldehyde

Six air samples were collected for formaldehyde due to reports of nasal and eye irritation. Five of those samples were obtained inside the building 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 limit of quantitation (LOQ) for the samples was 0.016 parts per million (ppm) and 0.047 ppm, respectively. Formaldehyde was not detected in the classrooms on this day. The only sample which detected formaldehyde was obtained inside of a storage cabinet constructed of particle board, but the concentration (0.018 ppm) was below the LOQ. Hence, the precision of this sample result may be reduced. The formaldehyde concentration detected from this same location (inside of the supply cabinet) was 0.11 ppm in May 1991. The formaldehyde samples collected during this survey represent a significant reduction from those collected for the initial HHE.

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 and (non-detectable) 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 five sample locations were selected for collecting volatile organic compound (VOCs) air samples because of reports of odors and the suspicion of chemical emissions. 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 quantify specific air contaminants supplemental air samples were collected on charcoal tubes, and were analyzed using a GC with a flame ionization detector following the GC/MS identification.

As expected, the MS analyses identified a 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 commonly reveals similar compounds at these extremely low concentrations. This is especially true of newly constructed or renovated structures. The organic compounds that were identified substantially above blank levels include limonene, toluene, ethanol, and branched alkanes. Other compounds which were detected (although not as appreciably above blank levels) include acetaldehyde, acetone, isopropanol, xylenes, and $C_9$ aromatic hydrocarbons. The number of different compounds detected in the VOC air samples from the follow-up HHE was less than the number identified in the initial evaluation.

Some of the compounds identified with the MS methods, including toluene, ethanol, limonene, and total aromatic hydrocarbons were further analyzed with a GC and flame ionization detector, a quantitative method. Toluene was not detected using this methodology with a limit of detection of 0.009 ppm. Ethanol, limonene, and total aromatic hydrocarbons were detected in these samples with LODs of 0.012, 0.004, and 0.007 ppm,[1] respectively. The staff lunch room had the highest relative concentrations of these air contaminants. However, all of the concentrations except one were below the LOQs of 0.041, 0.015, and 0.024 ppm (respectively for ethanol, limonene and total aromatics.) Therefore, these samples cannot be precisely quantified. The only compound which was detected above the LOQ was ethanol, at a concentration of 0.08 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 material lining the ventilation duct insulation. Additional analytical tests were conducted to specifically identify the level of chloroprene (if any) present in the air samples. Chloroprene was not detected in any of the samples from the initial evaluation with a LOD of 0.007 ppm. The follow-up evaluation failed to detect chloroprene in any of the samples including the thermal desorption tubes analyzed via MS, and the charcoal tubes analyzed with the GC/FID method. Head space analysis of heated bulk samples of insulation was performed during the initial HHE. Chloroprene was not detected in any of the head space analyses conducted at a temperature of 60°C (140°F) or at an extreme temperature of 300°C.

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.

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[1]Trimethyl benzene was used as reference compound for determining total aromatic hydrocarbon quantities.

Carbon Dioxide

During the follow-up site visit on February 5, 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 outside 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 a cause of indoor air quality symptoms. Rather, 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 or sparsely populated.

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 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 unoccupied classrooms prior to the start of the school day were observed to range from 400-450 ppm. After the building was occupied, the $CO_2$ concentrations rose to 525-675 ppm. The $CO_2$ concentrations remained relatively stable throughout the remainder of the day. Rooms which were occupied with a full class of students typically had $CO_2$ concentrations which ranged from 500-600 ppm. This information suggests that the outside air delivered to this school building is sufficient for the level of occupancy. (It is important to note that one of the previous consultant reports recorded $CO_2$ levels in excess of 1000 ppm, which suggests the outside air supplied was inadequate at that time.)

Temperature and Relative Humidity

Temperature and RH measurements were conducted in the school during the follow-up 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] Assuming slow air movement and 50% RH, the operative temperatures recommended by ASHRAE 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 RH be maintained between 30 and 60%.[3] Excessive humidities can support the growth of microorganisms, some of which may be pathogenic or allergenic.

Real-time temperature and RH 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 RH ranging from -4 to 140°F, and 0 to 100%, respectively. The temperatures observed in the classrooms ranged between 71 and 76.6°F, while the RH ranged from 12.6 to 18.3%. Some of these values exceed the thermal comfort guidelines for winter (68 to 74°F), as published by ASHRAE. The humidities were consistently below the range recommended by ASHRAE. Although low RH is not uncommon in a heated building, low RH may possibly cause the eyes and upper respiratory tract to dry which could result in irritation.

Microbial Agents

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 during the initial HHE revealed significant concerns. Refer to Appendix A for the description of the HVAC system and observed deficiencies as noted in the initial HHE conducted in May and June 1991 (HETA 91-143). During this follow-up evaluation, the current design and operation of the HVAC system was reviewed. Air flow measurements were repeated in the same classrooms included in the initial survey. In addition, a calibration check was made on the classroom thermostats and the operation of the outside air damper was observed. Table 2 lists the data obtained from the physical findings of the initial and follow-up evaluations. An inspection of the mechanical systems and discussions with the school representatives indicated that the following changes were completed since the initial HHE:

1. The pressure regulator for the outside air flow was adjusted so full main line pressure was applied to the outside air damper. No changes were made in the position or operation of the damper motor. The readjustment of the pressure allows the outside air damper motor to completely stroke, but the readjustment affected the operation of the damper on the damper rod, as noted in the findings and observations section.

2. The insulation on the interior of the main air handling unit was removed, and insulation was applied to the exterior of the unit from the coil section to the supply duct.

3. Four new heat exchanging units were installed above the suspended ceiling to supply additional outside air to 1st and 2nd grade classrooms. Each unit was designed to supply 375 cfm of air to each of four classrooms. The air was supplied to the classrooms through 2′ x 2′ diffusers located near the hall walls of the classrooms. A heat exchanger in these units exchanged sensible heat between air removed from the ceiling plenum and outside air. Two of the units had their own intakes and exhausts, while the other two shared a common inlet and outlet. The intakes and exhausts for the new units were located on the roof of the school.

4. A controls contractor was reportedly hired to check and adjust the control systems.

Findings and Observations

The details pertaining to the HVAC evaluation are organized in the following categories - damper system, accessibility, filtration, drains, air flow distribution, controls systems, preventive maintenance, and outside air intake. The observations and physical findings in regards to problem areas in these categories are presented as follows:

1. **Damper system** - As the outside air damper motor rod extends with an increase in line pressure, the damper shaft travels in an elliptical path as the motor rotates it, instead of rotating about its axis. The bolts which clamp the damper shaft onto the damper were loosened, apparently, to allow the shaft to rotate without jamming the damper linkage. While this did allow the damper system to operate, the loosened bolts allowed the damper to be moved by hand. The effect on the outside air flow was not measured, but this condition may impair the performance of the damper system, especially if the bolts were to loosen further.

2. **Accessibility** - When the insulation was installed to the outside of the main air handling unit, the access panel to the downstream side of the coil was covered. To gain access into this section of the HVAC unit, the insulation will have to be partially removed. Access to the interior of HVAC units is critical for performing routine preventive maintenance.

   There were a number of other conditions which would impede accessibility into the heat exchanging units. Access to all of the auxiliary units was difficult because of their location in the ceiling plenum. For two of the units, some access doors had to be reached by leaning across pipe lines. The access doors on all of the units had hazardous sharp sheet metal edges which are a safety concern for anyone removing the access doors.

   The filters could not be fully removed from two of the auxiliary units. (A pipe blocked the removal of the filter in one, while a duct installed with the heat exchange unit, blocked the removal of the other one.) Routine filter changes are critical for proper air filtration.

   Furthermore, all of the auxiliary units had direct-drive exhaust and supply fans. The fan motor was typically mounted inside the fan housing opposite the access door to the fan. To service the motor, removal of the entire fan assembly appeared necessary.

3. **Filtration** - The same filtration system used during the initial HHE survey was still being used inside the main air handling unit. This is a low efficiency filtration system (less than 20% efficient according to the ASHRAE dust spot test).[15]

   The new heat exchange units had 1/2" panel filters, constructed of a washable media. These filters also have a low efficiency rating of less than 20% according to the ASHRAE dust spot test. Filter systems which were checked, showed signs of bypassing around the filter because notable dust accumulation on the heat exchanger and insulation had occurred, despite the units being in place for only six months. Cleaning the inside of the units will be a maintenance problem because access to some parts of the units would only be possible by disassembling the units. Therefore, it is essential to use effective filtration to minimize the dust accumulation. Dust accumulation would also decrease the efficiency of these heat exchanging units because of the insulant properties of the dust.

4. **Insulation installation** - The insulation inside the heat exchanger units was fastened with pins and adhesive. None of the edges of the insulation were sealed, leaving the edges exposed to the air flow. In one unit, a pin on the access

panel was missing, and the insulation in that area was loose. Because glue holding the insulation to the panel only bonded with a few layers on the face of the insulation, exposed insulation could eventually be torn loose by the airstream.

5. **Drains** - The condensate drain lines on all of the heat exchanger units were tilted down from the unit. However, on one unit the drain line passed under another pipe, causing the end of the condensate drain connected with a sanitary line to run uphill which could adversely affect proper drainage. For another drain line, the sanitary line ran uphill from the connection between the condensate drain line and the sanitary line. Drain lines typically had traps in the lines. Drain lines which were connected directly to sanitary lines had vertical vent pipes located near the traps.

6. **Air flow distribution** - Considerable improvement was noted in the uniformity of maximum air flows between rooms. However, most rooms had maximum supply air flows which were notably less than design. Minimum air flows varied widely, indicating improper setting of the minimum air flow. Based on the existing design specifications, the volume of outside air provided by the main HVAC unit and the newly installed (and proposed) heat exchanger units should exceed the outside air criterion recommended by ASHRAE for the current level of occupancy.

7. **Control systems** - The settings for the thermostat set points ranged between 70 and 74°F, indicating that adjustments had been made; this range is less than the 65 to 76°F range found during the initial HHE. Minimum throttling settings ranged from 64 to 68°F during this survey compared to 70 to 83°F for the initial survey. Maximum throttling settings ranged between 69 and 76°F during this survey compared to 78°F to "off scale" for the 1991 survey. These shifts in the minimum and maximum throttling point settings is a definite improvement for making the VAV system more responsive to meet thermal comfort requirements in the rooms. The throttling range for each of the thermostats varied widely, however. (Throttling ranges were from 2 to 9 degrees.) Normally, throttling ranges are set from 2 to 4 degrees to make the VAV system quickly respond to changing thermal conditions. Many of the classrooms were observed to have opened windows which implies the occupants were dissatisfied with the room temperature.

8. **Preventive maintenance** - Accumulations of dust in the thermostats was moderately improved over the last visit. Overall, the parts of the thermostats were correctly in place. The exceptions were in a thermostat where the induction tube was not over the induction port and where the induction tube was placed on the branch line pressure port instead of the

induction port. A piece of insulation on the screen in front of the upstream side of the cooling coil was still there.

9. **Outside air intake** - No changes were made in the outside air intake or the treatment system. As previously noted, the main HVAC outside air intake is in a poor location due to its close proximity to the air conditioning water cooling tower as well as the school bus staging area.

## VII. CONCLUSIONS

1. Interviews conducted with the teachers revealed that during the 1991-92 school year, some have experienced symptoms temporally related to their presence in the building. The frequency of these symptoms was generally less during the 1991-92 school year than during the previous year.

2. Volatile organic compounds 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 fibers were detected within the classrooms in very low concentrations.

5. The outside air damper in the main HVAC system, which was not functioning properly during the initial HHE, was repaired by applying greater branch line (air) pressure. However, the mechanical restriction of the actuator rod and damper linkage was still potentially present and the bolts on the damper shaft were loose (presumably to lessened the possibility of jamming). Hence, the continued performance of the outside air damper system of the main HVAC unit is uncertain.

6. The original 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 outside air supply flowrate was not measured. However, according to the existing design specifications, the combined amount of outside air that is provided to each classroom by the heat exchanger units and the main HVAC unit, should be sufficient to meet the current ASHRAE outside air criterion (15 cfm/person).

7. The maximum supply air rates, which includes both recirculated and outside air, provided to the classrooms through the slot diffusers was measured to be below design.

8. Some of 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 remains in an extremely poor location. The proximity of this intake to the air conditioner water cooling tower increases the potential for distribution of bioaerosols. Vehicle exhaust may also enter the air intake when school buses (or other vehicles) are idling on the south side of the building.

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

11. Accessibility to the main and heat exchanger units presents a significant problem for performing effective routine preventive maintenance.

## VIII. RECOMMENDATIONS

School officials reported that a number of changes are planned for the mechanical systems in the next summer recess. Some of the proposed changes were reviewed. Recommendations are presented based on the existing equipment and proposed design, as follows:

1. The installation and construction of the new heat exchanger units should be reviewed with plans to improve the filtration of the units. Current filtration is not adequate to prevent dust accumulations on the heat exchanger and insulation of the unit. Dust accumulations on the heat exchanger can severely hinder the energy exchange efficiency of these units. Dust accumulations could be a health problem for hypersensitive individuals. Filters with an ASHRAE dust spot test efficiency rating of 35 to 60%, should be used as recommended by ASHRAE.

2. Access to the HVAC units should also be improved. Maintenance to mechanical systems generally suffers when access is difficult and/or hazardous. Currently, some parts of the units are inaccessible, while others are accessible with great difficulty.

3. The insulation on all of the units should be inspected to assure that it is adequately glued and pinned according to the Sheet Metal and Air Conditioning Contractors' National Association (SMACNA) recommendations.[8] All exposed edges of the insulation should also be sealed to prevent exposure to the air and possible fraying.

4. Future plans call for replacement of the current slot diffusers with three 2' x 2' diffusers. The heat exchanger units are planned to supply air to a fourth 2' x 2' diffuser in each room. Replacement of the slot diffusers with the 2' x 2' diffusers should be reviewed if the VAV system is continued. Slot diffusers have fewer performance problems with varying air flow than 2' x 2'

diffusers. Regardless of the air distribution system that is used, the air flow from the heat exchanger units should be blended with the supply air before being distributed to the room. The proposed system could cause hot or cold spots in the room because of the lack of temperature control of the air from the heat exchanger units.

5. Whether the current thermostat control systems will be replaced when other changes in the mechanical systems are made is uncertain. If the current system is not replaced, the thermostats should be cleaned thoroughly and have their throttling ranges readjusted to 2-4 degrees. All future control system components should be placed on a preventive maintenance and calibrations schedule. This schedule can be derived through consultation with the manufacturers. Records should be kept for all maintenance performed on the HVAC systems.

6. Insulation on the main air handling unit should be modified so access panels can be removed. Moreover, the coils and condensate pans should be placed on a routine cleaning schedule.

7. The problems noted with the main HVAC outside air damper motor and linkages should be corrected so that the motor can open the damper without loose bolts on the damper shaft. The outside air flow for the building should be maintained based on the occupancy of the building and the ASHRAE outside air criterion of 15 cfm/person for educational institutions. The minimum outside air flow for the building should be set based on actual measured air flow in the main and auxiliary units' outside air ducts or by other established methods. This minimum outside air flow should be set at the minimum flow setting of the supply fan.

8. The outside air intake of the main HVAC unit should be relocated so that contaminants from the cooling tower, waste treatment plant, building exhausts, vehicle exhausts, or other contaminant sources are less likely to enter the outside air intake. Relocation of contaminant sources away from the outside air intake is an alternative to relocating the outside air intake. School buses (or any other motor vehicles) that are staged and allowed to idle, should not be in close proximity of an outside air intake.

9. The entire HVAC system should be re-tested and balanced by a competent engineering firm upon completion of the installation of heat exchanger HVAC units and blend boxes. The person performing the testing and balancing should be NEBB (National Environmental Balancing Bureau) certified or otherwise have equivalent certification.

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

## 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.

2. ACGIH (1990). Threshold limit values and biological exposure indices for 1990-1991. Cincinnati, OH: American Conference of Governmental Industrial Hygienists.

3. ASHRAE (1989). Ventilation for acceptable indoor air quality. Atlanta, GA: American Society of Heating, Refrigerating and Air Conditioning Engineers. ANSI/ASHRAE Standard 62-1989.

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.

5. ASHRAE (1992). HVAC Systems and Equipment. ASHRAE Handbook. Atlanta, GA: American Society of Heating, Refrigerating and Air Conditioning Engineers.

6. SMACNA (1975). Duct Liner Application Standard. Second edition. Vienna, VA: Sheet Metal and Air Conditioning Contractors' National Association, Inc. SMACNA Standard 15D.


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6. NIOSH, Cincinnati, Ohio

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**

**BUILDING ASSOCIATED TEACHER SYMPTOMS**
**1991-1992 SCHOOL YEAR**
**HETA 92-107**

| SYMPTOM | SEVEN 1ST GRADE TEACHERS | SEVEN 2ND GRADE TEACHERS |
|---|---|---|
| Headache | 0 | 0 |
| Fatigue | 4 | 1 |
| Dizzy/Lightheaded | 0 | 0 |
| Nausea | 0 | 0 |
| Mucus Membrane Irritation | 2 | 1 |

Table 2
Western Primary School, Ventilation Data
HETA 92-107

| FIRST TRIP DATA | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| ROOM | AS FOUND SETPOINT | AS FOUND 'STAT TEMP | BLP AT AS FOUND TEMP | MINIMUM TEMP | BLP AT MIN TEMP | TOTAL SUPPLY AIR FLOW AT MIN TEMP | MAX TEMP | BLP AT MAX TEMP | TOTAL SUPPLY AIR FLOW AT MAX TEMP | DESIGN AIR FLOW |
| 3 | 76 | 81 | 12.0 | 80 | 14.0 | 660 | >85 | 5.5 | 336 | 860 |
| 4 | 75 | 80 | 13.0 | 81 | 12.5 | 571 | >85 | 3.0 | 353 | 870 |
| 5 | 76 | 80 | 17.5 | 83 | 18.0 | 779 | 85 | 8.0 | 767 | 960 |
| 6 | 72 | 81 | 4.0 | 74 | 17.5 | 427 | 83 | 0.0 | 141 | 910 |
| 9 | 75 | 80 | 2.5 | 74 | 17.0 | 941 | 83 | 0.0 | 417 | 1680 |
| 12 | 75 | 80 | 17.0 | 82 | 17.5 | 309 | 84 | 0.0 | 303 | 910 |
| 17 | 74 | 79 | 12.0 | 76 | 17.5 | 1013 | 84 | 0.0 | 971 | 1020 |
| A | 65 | 80 | 0.0 | 70 | 17.5 | 710 | 78 | 0.0 | 665 | 1080 |
| C | 75 | 79 | 5.0 | 81 | 5.0 | 568 | 85 | 0.0 | 533 | 1070 |
| SECOND TRIP DATA | | | | | | | | | | |
| ROOM | AS FOUND SETPOINT | AS FOUND 'STAT TEMP | BLP AT AS FOUND TEMP | MINIMUM TEMP | BLP AT MIN TEMP | TOTAL SUPPLY AIR FLOW AT MIN TEMP | MAX TEMP | BLP AT MAX TEMP | TOTAL SUPPLY AIR FLOW AT MAX TEMP | DESIGN AIR FLOW |
| 3 | 73 | 73 | 2.0 | 68 | 13.0 | 1010 | 74 | 0.0 | 646 | 1235 |
| 4 | 71 | 72 | 4.0 | 67 | 13.5 | 1061 | 76 | 0.0 | 768 | 1245 |
| 5 | 74 | 75 | 0.0 | 71 | 19.0 | 1149 | 74 | 0.0 | 612 | 1335 |
| 6 | 72 | 75 | 2.0 | 67 | 18.5 | 1100 | 75 | 0.0 | 810 | 1285 |
| 9 | 71 | 74 | 5.5 | 68 | 19.0 | 1303 | 76 | 0.0 | 1336 | 1680 |
| 12 | 70 | 73 | 0.0 | 67 | 19.0 | 1027 | 69 | 0.0 | 651 | 1285 |
| 17 | 71 | 72 | 2.0 | 64 | 19.0 | 1182 | 73 | 0.0 | 698 | 1395 |
| A | 73 | 73 | 8.0 | 68 | 19.0 | 1128 | 76 | 0.0 | 0 | 1080 |
| C | 70 | 73 | 4.0 | 66 | 19.0 | 784 | 76 | 0.0 | 487 | 1070 |

BLP = branch line air pressure

## Appendix A

Description of HVAC System
Western Primary School, Spring 1991
HETA 92-107

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 ¼" 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 set point 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 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 set point 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 set point.

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 cfm. Maximum air flows averaged 664 cfm, but ranged from 309 to 1013 cfm. Design air flows for the classrooms average 1141 cfm and range from 860 to 1680 cfm. 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.