HETA 90-0202-2116
MAY 1991
SHAMOKIN ELEMENTARY
SHAMOKIN, PENNSYLVANIA

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I. SUMMARY

On March 22 and 23, 1990, NIOSH conducted a health hazard evaluation (HHE) survey at the Shamokin Elementary School, Shamokin, Pennsylvania. The survey was conducted in response to health and comfort complaints which included tiredness, irritated eyes, dry throat, etc. The study included industrial hygiene and ventilation measurements, and a medical evaluation.

Real-time carbon dioxide (CO_2), respirable particulate, temperature, and relative humidity measurements were made in a selection of rooms throughout the day of the survey. Air flows from the slot diffusers were measured in all of the classrooms. Symptom questionnaires were distributed to all of the teachers, and follow-up interviews were conducted. An inspection was made of the air handling units supplying the classrooms.

Supply air flow rates for the classrooms were found to vary widely and differed significantly from the values given in a test and balance report conducted prior to the 1989-90 school year. Average CO_2 levels ranged from about 800 parts per million (ppm) to over 900 during the survey. Individual room values ranged from morning readings of 475 to 1100 ppm to afternoon readings of 725 to 1125 ppm. Outdoor CO_2 levels averaged 400 ppm. Average respirable particulate levels were 0.03 milligrams (mg)/m^3 compared to outdoor levels of 0.02 mg/m^3. Average temperatures were 73 °F in the morning rising to 76 °F in the afternoon while outdoor temperatures rose from 54 to 68 °F. Classroom temperatures ranged from 72 to 75 °F in the morning and 75 to 78 °F in the afternoon. Average relative humidities began at 22% in the morning and rose to 27% in the afternoon. Outdoor humidities were 48% in the morning and 26% in the afternoon. The medical questionnaire found that 38 of 51 teachers frequently experienced two or more building related health complaints. Six teachers reported frequently experiencing one such complaint.

Based on the results of questionnaires and measurements, the problems at Shamokin Elementary appear to be related primarily to thermal comfort. No obvious health hazards were identified. Measurements also showed that air flows into the classrooms were unbalanced according to design values, and that the building control systems for the air handlers were identified. The imbalanced air and faulty control systems appear to have caused overheating of some areas which can lead to thermal comfort problems. Low humidity levels are also believed to have exacerbated these problems. Recommendations are given in Section VIII for solving the problems for the mechanical systems and for relieving occupant symptoms.

Keywords: Sic Code 8211 (Educational Facilities, Elementary and Secondary), Indoor Air Quality, Schools, Carbon Dioxide, Relative Humidity, Particulates.

II. INTRODUCTION

On March 22 and 23, 1990, NIOSH conducted a health hazard survey at the Shamokin Elementary School, Shamokin, Pennsylvania. The survey which was requested by management of the school system, was conducted in response to health and comfort complaints which included tiredness, irritated eyes, and dry throat. The study included industrial hygiene and ventilation measurements and a medical evaluation. Results of the survey were communicated to school administration and board personnel by phone. No other reports or letters were sent.

III. BACKGROUND

A. Building Construction.

Shamokin Elementary is a two-story building constructed primarily of concrete, block, and steel. One story is above ground while the other is primarily below ground. The building is shaped like an "H" with the open ends of the H facing north and south. The two legs of the H are divided into classrooms via concrete block walls, although some classrooms have moveable partitions. The center part of the H contains the gymnasium and offices on the ground floor and the mechanical rooms and cafeteria on the lower floor. Driveways and parking areas are located at the south end of the building and a truck unloading area is located in front of the lower floor at the north end of the building. All classroom areas are carpeted and have windows which do not open.

B. Description of the Ventilation System.

This description of the ventilation system covers only the systems for the classroom areas. Air Handling Units (AHU) 1 and 2, located on the roof over the classrooms supply air to the classrooms and corridors via ducted supply systems. AHU-1 supplies air to the east side classrooms and AHU-2 supplies air the west side classrooms. A schematic of the supply duct system is shown in Figure 1.

AHUs 1 and 2 were formerly variable air volume (VAV) systems, but were converted to constant volume systems. This is further detailed in the section, "Past HVAC Activities." Both units have heating and cooling capability.

Air typically enters the classrooms through two-sided linear slot diffusers. Three diffusers are normally located along the centerline of the room parallel to the inside walls. A few rooms have different arrangements of the diffusers, but there are still typically three diffusers in all rooms. Corridors in each wing normally have a diffuser located in the north and south ends of the corridors on each floor.

The supply air duct to each room typically has a hot water heating coil in the former VAV terminal. A thermostat in the each room controls the hot water valve to the reheat coil for the room.

Air is returned to the air handling units via a ceiling plenum (the space between the suspended ceiling and the roof). Classroom air enters the ceiling plenum through slots similar in construction to the linear diffusers. Typically, return slots are located above each window and at another non-specific location in each room.

All bathrooms and some utility closets in the classroom areas of the building are connected to exhaust systems. Air is also exhausted from the building through exhaust dampers on the air handlers and relief vents in the roof.

Outside air is supplied to the classrooms through AHUs 1 and 2. Building personnel reported that the controls for the outside air dampers at the time of the survey were set so that the dampers began to open from the minimum position at 35 °F and were fully open at about 40 °F.

Discussions with school administrative and board personnel indicated that problems were worse during the coldest times of this past year, particularly when the outside air temperature dropped below about 30 °F. To counter these problems, school personnel set the controls on the AHUs so that the maximum outside air could be pulled into the building at the lowest feasible outside air temperature(40 °F).

C. Past HVAC Activities.

A report by Basil Greene, Inc. (Philadelphia, PA), dated November 17, 1982, detailed problems with the original heating, ventilating and air conditioning (HVAC) system design. The main conclusion of this report was that the original HVAC system design could not adequately heat the building. Recommendations from the report included: introduce the required amount of ventilation air when the building is occupied and, concurrently, increase the heating capabilities of all of the air handling units; modify the air duct systems so that interior rooms are on one system and exterior rooms are on another; increase the water storage capacity of the hot water mechanical system to account for expansion; and arrange the control system to accommodate changes. The ventilation rates apparently recommended for the school by Basil Greene were included in parts of a publication attached to the report, titled "Recommended Design Criteria for School Facilities" (Published by the Pennsylvania Department of Education, Bureau of Educational Administrative and Management Support Services--no other publication information available). The publication recommended a ventilation rate for classrooms of 7.5 cubic feet per minute (cfm)/pupil and not less than 6 total air changes/hour. The publication also recommended a design temperature of 70 °F in the classrooms.

In 1987, the building maintenance personnel changed AHUs 1 and 2 from VAV (variable air volume) systems to constant volume systems. The change resulted in the classrooms receiving a constant flow of air instead of an air flow which varied with the room temperature. In addition, the thermostats in the classrooms, which originally controlled the air flow dampers and the hot water valves in the VAV terminals, were changed to control only the hot water valves. Presumably, the change should have relieved complaints of stale air, draftiness, too hot or too cold temperatures which can occur if parts of the VAV system malfunction, are not calibrated or set correctly, or have design air flows which are too high or too low. The change also allowed the teachers some control over the environmental conditions in their classrooms since they could adjust the temperature using the thermostat.

Because of continued complaints, over $1.5 million was spent on modifications to the school, including the HVAC systems in the summer prior to the 1989-90 school year. The HVAC modifications that affected the classroom parts of the building were the following: adding two new boilers (to increase the heating capacity of the system), new heating and cooling coils to AHUs 1 and 2, unit heaters inside AHUs 1 and 2 for freeze protection of the coils (when the units are not operating); and changing the control systems for the AHUs including adding an energy management system (EMS). After the changes were completed, the air supply systems for the building were tested and balanced. All changes were completed by October 1989.

D. Past Environmental Monitoring Activities.

NIOSH had previously visited the school in June, 1987 (HETA 87-323). During this survey, carbon dioxide (CO_2), carbon monoxide (CO), formaldehyde, temperature and relative humidity levels were measured using Draeger detector tubes. Measurement results were as summarized: carbon monoxide and formaldehyde were not detected; CO_2 ranged between 500 and 1200 ppm in the classrooms during the first afternoon compared to an outside reading of 200 ppm; CO_2 increased from 800 to 1250 ppm in two select classrooms (several classes had been combined because of low attendance) during the second day compared to an outside reading of 300 to 400 ppm; temperature and relative humidity levels were within the comfort zone of ASHRAE Standard 55-1981. The major recommendations from this first survey concerned increased maintenance and housekeeping of the air handling units, the school interior, and the roof.

Between 1987 and the time of the survey, several contractors and school personnel performed sampling for various substances at the school. Between July 24 and 28, 1987, samples for radon gas were collected at the school by Radon Detection Services, Inc. (Allentown, PA) using the charcoal absorption technique. In addition, two long-term alpha-track samples were collected from September 29, 1987 to February 18, 1988. These samples were not found to exceed any standards.

On January 14 and 21, 1988, Lancaster Laboratories, Inc. measured the CO and CO_2 levels, using Mine Safety Appliance detector tubes, and relative humidity levels in seven and eight locations on consecutive days. Lancaster Laboratories also sampled the air for aerobic mold and yeast and took wipe samples from the diffusers to be analyzed for mold and yeast in the same locations where the CO, CO_2, and relative humidity levels were measured. Samples for CO were less than 5.0 parts per million (ppm) and CO_2 levels averaged about 800 ppm (range 500 to 1000 ppm. Samples for mold and bacteria were unremarkable.

Since October 1989, both school and contractor personnel have performed air sampling at the school. School personnel measured CO_2 levels using detector tubes and temperatures at various times during the days between October 9, 1989 and March 14, 1990. Measurements were made in both the morning and the afternoon, and in various classrooms. The average indoor CO_2 level from these samples, excluding unusual events, such as mechanical problems, was less than 750 ppm. However, the CO_2 samples did show that the average CO_2 levels were above 700 ppm even in the morning. Temperature measurements averaged about 72 °F.

On January 9, 1990, six grab air samples were collected by Texas Research Institute, Inc. (Austin, TX) and analyzed for oxygen, CO, methane, total gaseous hydrocarbons, CO_2, sulfur dioxide, nitrogen dioxide, and halogenated solvents. The results were either well below standards or within "normal" limits when compared to the contractor's standard compressed gas used for breathing apparatus. However, the CO_2 samples did show that the average CO_2 levels were above 700 ppm.

IV. EVALUATION DESIGN

A. Industrial Hygiene Evaluation.

Temperatures, and CO_2 and respirable particulate levels were measured in selected classrooms during three different time periods on March 22, 1990. The time periods were approximately: 8:00 to 9:45 a.m.; 10:45 to 11:45 a.m.; and 1:20 to 2:30 p.m. Classrooms selected for the measurements were dispersed among Kindergarten to Fifth Grades and Special Education. Attempts were made to make measurements in all of the selected classrooms at least once during the day. Some measurements were made in some of the selected classrooms more than once to check the trends of the measurements.

1. Temperature and Relative Humidity Measurements.

Real-time temperature and relative humidity measurements were conducted using a Vista Scientific, Model 784, battery-operated psychrometer. Dry and wet bulb temperature readings were monitored and the corresponding relative humidity determined using the manufacturer-supplied curve.

2. Carbon Dioxide Measurements.

Real-time CO_2 levels were measured using a Gastech, Model RI-411A, CO_2 meter. This portable, battery-operated instrument monitors CO_2 (range 0-4975 ppm) via non-dispersive infrared absorption with a sensitivity of 25 ppm. Instrument zeroing and calibration were performed prior to use with zero CO_2 concentration air and a known CO_2 concentration span gas (800 ppm).

3. Respirable Particulate Measurements.

Real-time respirable particulate concentrations were measured using a GCA Environmental Instruments, Model RAM-1, monitor. This portable-battery operated instrument assesses changes in particle concentrations via an infrared detector, centered on a wavelength of 940 nanometers. Indoor air at 2 liters per minute (lpm) first passes through a cyclone preselector. Because of the characteristics of the cyclone preselector, all particles with sizes less than about 2.5 micrometers (µm) pass through the collector, while the number of particles passing through the cyclone exponentially decreases for particle with sizes between 2.5 and 9 µm. Particles which are larger than 9µm do not pass through the cyclone. After passing through the cyclone, the air then passes through the detection cell. Operating on the 0-2 milligram per cubic meter (mg/m^3) range with a 32 second time constant yields a resolution of 0.001 mg/m^3.

B. Ventilation Evaluation.

1. Air Flow Measurements.

Air flow measurements were made in all of the classrooms after school hours with a Shortridge Flow Hood (MN 86 BP). This instrument compensates measurements for temperature of the supply air, local atmospheric pressure, and backpressure of the instrument and thus measures real-time actual flow rate as opposed to standard flow rate. Per the manufacturer's recommendations, a 5-1/4" x 48" skirt and flow straightening grid were used and the backpressure compensation flaps were kept in the closed position during measurements.

2. Room Pressure Assessment.

Smoke tubes were used at all of the classroom doors to determine whether the rooms were under positive or negative pressure (shown by whether the smoke blows out of or into the room, respectively). This assessment provides information on the possibility of contaminants from other areas entering the rooms.

3. Ventilation System Inspection.

The filters, coils, condensate pans, fans, and plenum interiors of AHUs 1 and 2 were inspected for potential air contaminant sources and general condition. As part of the inspection, a pocket level was used to determine the tilt of the condensate pans relative to their drains. In addition, the pressure in the lines to the outside air damper motors was measured to see if the dampers were fully open.

C. Medical Evaluation.

A health and comfort symptom questionnaire was distributed to approximately 65 teachers, 16 Intermediate Unit (IU) staff and seven administration staff. Responses were received from 51 teachers, 16 IU staff and seven administration staff. Questionnaires were evaluated for symptoms normally attributed to complaints due to building-related illness or comfort.

D. Analysis.

The data from Shamokin Elementary were analyzed for trends. The peak CO_2 and number of occupants data, the maximum temperature, the minimum relative humidity, and the total air flow per room data were entered in a spreadsheet with the corresponding room numbers. The peak CO_2/occupant and flow/occupant were calculated. Data were separated according to the east and west classrooms. Data were then sorted successively, with the east and west data being sorted separately, and compared to summary data from the medical evaluation which indicated severity of symptoms (by one of four levels of severity). Occupants who did not return their questionnaires were assumed to have no symptoms in the analysis.

V. EVALUATION CRITERIA

Standards for air contaminant levels in buildings do not exist. NIOSH, the Occupational Safety and Health Administration (OSHA), and the American Conference of Governmental Industrial Hygienist (ACGIH) have published regulatory standards and recommended limits for occupational exposures.[1-3] With few exceptions, pollutant concentrations observed in office work environments fall well below these published standards or recommended exposure limits. The American Society of Heating Refrigerating and Air Conditioning Engineers (ASHRAE) has published recommended building design criteria for ventilation and thermal comfort.[4,5] The basis for monitoring individual environmental parameters are presented below.

A. Temperature and Relative Humidity.

The perception of comfort is related to one's metabolic heat production, the transfer of heat energy to or from the environment, physiological adaptation, and body temperature. Heat transfer between the body and the environment is influenced by such factors as air temperature, humidity and movement, the temperature and heat radiating properties of the body and surrounding surfaces, and the insulative properties of clothing. The American National Standards Institute (ANSI)/ASHRAE Standard 55-1981, Thermal Environmental Conditions for Human Occupancy, specifies conditions in which 80% or more of the occupants would be expected to find the environment thermally comfortable.[4]

The conditions for thermal comfort are shown in a chart in (ANSI)/ASHRAE Standard 55-1981 (Figure 2, ASHRAE Thermal Comfort Chart, in the standard). This chart is for "persons clothed in 'typical' summer or winter clothing, at light, mainly sedentary, activity." The temperature on the abscissa of the chart is operative temperature. Operative temperature is not the same as normal room temperature unless there is little radiated heat from, or to, the occupant. Other parameters, such as air velocity around the person's body, change in temperature relative to time, and other factors influence feelings of comfort. Therefore, several factors must be considered when assessing thermal comfort.

B. Carbon Dioxide Concentrations.

Carbon dioxide is a normal constituent of exhaled breath. Monitoring the CO_2 levels can be a useful tool to judge whether adequate outside air is being introduced into an occupied space. Indoor CO_2 concentrations (or levels) are normally higher than outdoor CO_2 concentrations which normally range between 200 and 400 ppm. When indoor CO_2 levels are elevated (above 2 to 3 times outdoor levels depending on the outdoor levels) in areas where the only known source is exhaled breath, inadequate ventilation is suspected. Elevated CO_2 levels can mean that other indoor contaminant concentrations are also elevated. However, using CO_2 measurements to judge whether a building is adequately ventilated or to make conclusions about other contaminants requires professional interpretation because other factors, such as occupant density, building volume and interior partitioning, and other interfering sources, can significantly affect the usefulness of the CO_2 data.

ASHRAE Standard 62-1989, Ventilation for Acceptable Indoor Air Quality, specifies that indoor CO_2 levels be less than 1000 ppm.[5] This level is based mainly on a correlation with odor perception and comfort and is far below the ACGIH threshold limit value (5000 ppm for industrial environments) and the levels at which adverse health effects would be expected. ASHRAE Standard 62-1989 also recommends ventilation rates of 15 and 20 cfm per person of outside air for classrooms and libraries, and offices, respectively, based on a specified number of occupants per 1000 ft^2 of occupied area.[5] By ventilating the building with the proper amount of outside air, ASHRAE believes that CO_2 levels can be kept to less than 1000 ppm and that other contaminants, except for unusual sources, will be kept at acceptable levels. This standard further specifies that the outdoor air meet applicable Environmental Protection Agency (EPA) standards for outdoor air. Applicable EPA standards for outdoor air and applicable standards by other organizations for indoor air for certain contaminants are listed in the ASHRAE 62-1989.

C. Respirable Suspended Particles and Inhalable Particles.

Respirable suspended particles (RSP) smaller than 2.5 micron (µm) normally come from combustion sources. The greatest contributor to indoor RSP is environmental tobacco smoke (ETS), but RSP also come from outdoor sources and other indoor sources. Increased RSP levels in buildings with oil, gas or kerosene heating may be important.

Inhalable particles (those less than 10 µm in size) are a combination of particles from combustion, soil, dust, and mechanical sources. The EPA standard for inhalable particles is 150 $\mu m/m^3$ averaged over 24 hours.

VI. RESULTS AND DISCUSSION

A. Medical Evaluation.

Thirty-eight of the 51 teachers who responded to the questionnaire reported frequently experiencing two or more building related-health complaints (complaints about symptoms which occur only when the person is in the building). Six teachers reported frequently experiencing one building-related health complaint and seven reported experiencing no building-related complaints. The majority of the seven Administration staff members who responded reported frequently experiencing two or more building-related health complaints.

Nine of the 16 Intermediate Unit (IU) staff who responded reported frequently experiencing two or more building-related health complaints. Three reported frequently experiencing one building-related health complaint. Four reported experiencing building-related complaints infrequently or never.

Symptomatic teachers and staff appeared to be located in all wings of the building, with approximately equal density. The most common symptoms reported by the questionnaire respondents were dry mouth, excessive fatigue, headache, sinus congestion, difficulty concentrating and eye discomfort. These are the symptoms most commonly reported by employees in most of the indoor air quality investigations that have been conducted. Many respondents reported that their symptoms were similar to those that they had experienced in previous years at the school, but that the frequency and severity of the symptoms had decreased somewhat this year. However, symptoms were still significant enough to make teaching or performing other work difficult.

B. Air Flow Measurements.

The range of air flow measurements in Table 1 shows a wide variation in the flows. When comparing the air flows from the test and balance report to those from the NIOSH survey, a sizeable difference existed between most of the measurements. This difference is more than expected from instrument and measurement error or from the difference between actual and standard flow rates. The conclusion is that the air flows for both AHU 1 and 2 are not balanced. Balanced means that the air flow into a space has been adjusted to meet the design flow. A possible cause for the imbalance is that the test and balance personnel reportedly did not have their instrument properly equipped, according to the manufacturer's recommendations, to measure airflows from the slot diffusers.

When the flows measured by NIOSH were divided by the maximum number of room occupants, the results showed that all but one of the rooms met the 15 cfm/person criteria in the ASHRAE Standard 62-1989. However, this analysis assumes that 100% of the supply air is outside air (the case when the outside air dampers are fully open). The outside ventilation rate with the dampers in the minimum position is unknown and could not be established during the survey.

Sorting of the data according to air flow showed that complaint rooms (as established by the questionnaire) generally had the highest and lowest flow rates. Complaint rooms having the lowest flow rates would normally be expected because these rooms would not get enough outside air or would not be tempered properly. Complaint rooms having the higher supply air flow rates is the opposite of what might be expected because these rooms should have been receiving more outside air than rooms with lower flow rates. However, rooms with air flow extremes may be the rooms with the temperature extremes. Rooms with too much supply air may be too hot in the heating season and too cold in the cooling season. Rooms with not enough supply air may have the opposite problem. For the latter rooms, though, the reheat coils may be able to compensate for the lack of supply air during the heating season.

Problems due to the imbalanced air flow should occur mostly in the heating season because most of the school year coincides with the heating mode. In addition, people tend to equate hot air more readily with stuffy air than cool air. Moreover, outdoor humidity is generally lower in the winter causing indoor humidity levels also to be lower. The effects of low humidity are enhanced in rooms with elevated temperatures. In fact, many of the symptoms described by the questionnaire respondents, such as drowsiness, sinus pain, and dry throat, might have been due to overheated, dry classrooms.

C. Room Pressure Measurements.

All of the classrooms, except Room 417, were found to be under positive pressure, meaning that the air was being pushed out of the rooms. Three of the four rooms which had moveable dividers and two doors had air flow in one door and out of the other. Reasons for the air flow movement might have been due to one part of the rooms having a return while the other did not, or that the air flow through the corridor created pressure differentials in the rooms. Still, too much air leaving the rooms through the doors may indicate that the return system is not operating properly.

By design, the classrooms should be under a slight positive pressure to prevent drafts from air leaks in the outside walls and infiltration of contaminants into the classrooms from other areas. Likewise, by design, most of the air from the classrooms should be returned to the air handlers through the ceiling plenum to effectively capture the heat generated by the lights and solar load on the roof. Proper operation of the return system in the Shamokin Elementary building is imperative because the temperature of the air in the return air duct is used to control the supply air temperature. If the return air is not collecting the heat load as intended, the control system could receive an incorrect signal about the heat load in the building and cause overheating.

Other problems which may occur with a faulty return system is that it can cause backpressure which, in turn, can affect the supply air flow by impeding air flow into the rooms. In other NIOSH surveys, faulty return systems have contributed in part to stagnated air in rooms. In addition, if too much air moves through the doors instead of the ceiling plenum, the doors can slam shut instead of gently closing or may be hard to open.

D. Carbon Dioxide Measurements.

The results presented in Table 2 show that the average CO_2 levels climbed throughout the day (from 755 to 925 ppm) despite the outside air dampers being fully open most of the time during the survey. Most of the classrooms ended the day with levels of 900 ppm or more. Indications are that the air handlers were not capable of delivering enough outside air. These results may help explain why more complaints occurred when the weather was colder, because the outside air dampers closed to a minimum position when the temperature outside went below 35 °F.

The early morning CO_2 measurements suggest a possible alternate explanation. Average CO_2 levels for the early morning measurements were 663 ppm and 821 ppm for the east and west side classrooms, respectively. The outdoor CO_2 level for this time of the morning was 400 ppm. Ideally, the indoor CO_2 levels should be about the same as the outdoor CO_2 levels when people first occupy the building in the morning. The elevated morning CO_2 levels indicate that the building was not being adequately purged of contaminants overnight. The air handlers reportedly go to their on-off cycle, night setback mode about one hour after classes end. Since the school is cleaned at night when the units are on night setback, the cleaning agents being used, such as ammonia, a known irritant, were probably not being removed from the building.

Ventilation of the building at night might help to lower daytime CO_2 levels and remove other contaminants. Putting the air handling units on a reduced flow setback instead of an on-off cycle setback can accomplish this if the air handling units provide outside air during the reduced flow. Besides purging the building at night, the night setback flow offers the added advantages of additional air filtration. Unpublished research has indicated that reduced flow setback may offer energy savings over cycling setback. Should the school decide to continue using an on-off cycle, ASHRAE 62-1989 provides guidelines on purging time for part-time occupied spaces.

Analysis of the CO_2 data did not show an apparent correlation between CO_2 levels, number of occupants, or flow rates. These results could be due to the air exchange rate of the classrooms and the mixing of the return air from all of the spaces. This resulted in rapid mixing of air with different CO_2 content further resulting in averaging of the CO_2 levels.

E. Respirable Particulates.

Respirable particulates did not appear to correlate with complaint rooms. Table 3 shows that the overall average respirable particulate level remained constant (30 $\mu g/m^3$) throughout the day for both the east and west wings. Some classrooms were slightly higher than others, but not significantly as shown by the range values. Overall average indoor particulate levels were slightly higher, though not significantly higher, than outdoor levels (30 compared to 20 $\mu g/m^3$). EPA's criteria for respirable particulate is 150 $\mu g/m^3$.

The filters in the air handlers were clean and school personnel stated that the filters are changed about three times per year. The school reportedly uses a 40% efficient filter. ASHRAE recommends using a 35 to 60% efficient filter according to the ASHRAE dust spot test[6].

F. Temperature and Relative Humidity Measurements.

Results in Table 4 show that the average dry bulb temperatures in the classroom areas rose during the day (from 73 to 76 °F). Individual room temperatures were within ±2 °F of the overall average. Average relative humidity levels also rose over the day (from 22 to 27%). Individual room humidities were within ±4% of the overall average.

Each room's temperature and relative humidity measurements were plotted on the ASHRAE Comfort Chart. All of the measurements, except one, were outside the comfort zone on the chart mainly due to the low relative humidity levels. That is, the temperature was within the comfort limits, but the humidity levels were not. However, the measured temperature was dry bulb temperature and not "operative" temperature as listed on the chart. The accuracy in assessing thermal comfort conditions using the chart depends on how close the dry bulb temperatures reflect the operative temperatures and the accuracy of the chart. (True operative temperatures are typically not measured and were not measured at Shamokin Elementary because of the difficulty in making the measurements and include such parameters as velocity of the air, clothing insulation properties, radiated heat, etc.) In most cases, the dry bulb temperature offers a reasonable indication of conditions. Overall, the chart should be used with caution because cases of thermal discomfort have occurred despite individuals being exposed to conditions which are within the comfort zone in the chart. Furthermore, the chart was developed using the criteria that 80% of the occupants would be comfortable under conditions within the comfort zone. Still, when people say they are not thermally comfortable, they are not thermally comfortable despite indications from using the chart.

The overall average temperature data in Table 4 further shows an increase of one to two degrees on the day of the survey. On a room to room basis, the increase in temperature was more pronounced than shown by the average. Some rooms' temperatures increased by two to three degrees in just the morning period. Outside temperatures for the day began at 54 °F and rose to 68 °F and the sky was mostly sunny.

Despite the increase in room temperature during the day, the cooling system did not start operating because the cooling cycle is controlled by the outside air temperature. The sensor for the outside air is in the rear portion of the school in a shady location.

In this location, the sensor does not sense the temperature of the air entering the air handling units. The temperature of the air entering the air handler may be several degrees warmer than the temperature sensed by the sensor because air entering the air handlers is warmed by heat radiated from the roof.

Increases in temperatures in the rooms may not only be due to inaccurate sensing of the outdoor air temperature but also to the method used to control the supply air temperatures in the classrooms. Supply air temperature is controlled by the return air temperature. Since the return air may not be taking the designed route back to the air handler, the return air may not be reflecting the actual heat or cooling load of the building. All parts of the building share a common ceiling return. Therefore, abnormal loads on one part of the building may not be sensed properly by the air handler supplying that part of the building because of the averaging effect of mixing in the common return system. Both cases could cause the supply air temperature to be set improperly.

Another situation which may cause an increase in room temperatures occurs when the supply air control limits are set too far apart. A wide temperature band means that the return air temperature has to change too far before the air handling unit responds to the change. Under these conditions, the room temperature will climb before the unit acts to restore the temperature. The control system can be adjusted to correct this problem if the problem exists. However, setting the control limits too close together will cause the system to exhibit a phenomenon called searching where the supply air temperature will oscillate between the control limits trying to find a correct temperature.

Occupants in the classrooms may be thermally comfortable, but may still suffer effects from low humidity. The main reason that the plotted data points fell outside of the comfort zone in the comfort chart was the low relative humidities. However, the low outdoor humidity (26%) on the day of the survey appears to be the cause of the low indoor humidity (about 26%). If this is the norm for the area, on cold days, the heating of the supply air would further decrease the indoor humidity. A situation like this in the Shamokin area could be another reason for complaints being worse on colder days.

To solve problems associated with low humidity, humidification may be tried on a trial basis before expanding to the entire school. If the building is not designed for humidification, more problems will be created than solved by adding a humidification system, such as condensation on the interior surfaces of outside walls. Water from this condensation could saturate the building materials causing mold and bacteria problems. Other problems with humidification systems are that they can be hard to control and difficult to maintain.

However, should humidification be used, it should be supplied by a steam system. The steam should not be taken from the boiler because the steam could potentially contain irritative anti-scaling agents. In all cases, a knowledgeable expert should be consulted, before a humidification system is installed, to inspect the building for potential problems and to specify adequate control systems.

G. Air Handling Unit Inspection.

The inspection of the air handling units showed that very little debris was present in the air handling units or condensate pans. Some debris resembling insulation was left in the units apparently from the work performed inside the units. The inspection, however, was made before the units had entered a cooling season, so how the units would accumulate additional debris is unknown. Overall, though, the units were clean and appeared to have been conscientiously maintained.

The angle of the condensate pans on AHUs 1 and 2 showed that both pans were bowed toward the middle. The pan drains, however, were along the sides of the condensate pans next to the outer walls of the units, a situation leading to the possibility for water to stand in the pan.

By itself, a condensate pan holding water does not mean that a problem exists. Yet, the water combined with dust which bypasses the filters can become a reservoir for biological (algae, bacteria and mold) growth. When the cooling coils are operating, the temperature of the water in the condensate pans is usually too cold to allow much growth. The problem may occur at night and over weekends when units are on night setback and the temperature inside the units increases to a point where growth can occur. When the units are activated, the algae, mold or bacteria, now possibly in large enough numbers to be a problem, can be aerosolized and carried into the building.

A trap on the condensate pan's drain and whether the drain was connected to sanitation lines was not noted. The condensate pan's location on the upstream or negative pressure side of the fan can cause air to be sucked through the condensate drain and can prevent condensate drainage. Normally, a restrictor or P-trap is placed in the line to add a pressure drop or water seal on the line. However, restrictors and traps need to be policed because of the potential for plugging. In addition, the drain line should drain into an open drain and not be directly connected to a drain or sewer line to prevent sewer gas or bioaerosols from being sucked into the air handler.

In the past year, the school had a problem with heat exchanger coil freeze-up. Several possible reasons for the coil freeze-up exist. 1) AHUs 1 and 2 have the outside air and return air entering the unit parallel to each other, directly at the filter face, so there is little chance of mixing. Normally, units are designed so that outside air is mixed with the return air before it is filtered and tempered. To enhance this mixing, the outside and return air streams are usually directed toward each other. 2) Because of the low velocity normally desired for the air stream passing through the filters, the outside and return air streams could have stratified, causing cold air to impinge on part of the coil. 3) The temperature sensors for freeze protection and operation of the dampers may not have been properly located or correctly sensing the temperature. 4) In the past, the control system was set up so that the outside air dampers would open up fully upon start-up of the unit, regardless of the outside air temperature, to purge the air from the building.

Stratification in AHUs 1 and 2 may be prevented by relocating the outside air dampers to enhance mixing of the outside and return air streams. Basically, the dampers should be situated so the outside and return air streams are aimed at each other to enhance mixing. A blender box could also be added downstream of the new damper locations to increase mixing of the two air streams.

If the temperature of the air entering the coils is still too low after redesign of the outside air damper system, inhibited glycol can be added to the cooling system water. Adding the glycol may be necessary if CO_2 levels measured after redesign indicate that additional outside air is needed during the coldest times of the year.

Another incident reported by the school was carryover of the condensate water (pulling of the condensate water by the air) from the cooling coil. The school also reported that the velocity of the air through the coil was reduced to solve this problem. Because there was no cooling on the day of the survey, the existence of this problem could not be observed. Further investigation of this problem is needed because water pulled off the coil could saturate insulation inside the air handling unit. This insulation by itself normally will not grow molds or bacteria, but dust usually accumulates on the insulation serving as a nutrient source for mold and bacteria growth. The addition of water is all that is usually needed to make the mold and bacteria grow. No mold was seen and no moldy odor detected while inspecting the units.

The main driveway and parking areas are in front of the south end of the building. In the morning, buses drop children off in front of the office area. In the afternoon, the buses park in front of the office area and wait for the children to be dismissed. In the past, the school has had problems with diesel exhaust odor in the school. Reportedly, the same thing has happened when trucks have parked behind the school and left their engines running while unloading. Because of the shape of the school, exhaust from the buses can be carried to and trapped in the area over the roof if the wind direction is favorable. However, school personnel stated that there is a policy that all vehicles turn off their engines when waiting outside of the building.

H. Carpeting.

Research on the health effects of biological materials and dusts in carpeting is controversial. Research has found that carpeting contains materials which cause health effects in some individuals. Researchers also have found that mold counts are greater for water damaged carpeting. Some researchers speculate that carpeting acts as a reservoir for dust and dirt (and molds) carried into the building by people, that carpets stay wet longer than bare floors, that carpets act as a "cultivation media" for the mold, that bare floors can be washed more efficiently than carpeted floors, and that disinfecting sunlight can reach microorganisms on bare floors better than on carpeted floors. Other research has shown that frequent cleaning of carpeting helps to reduce the biological materials in the carpet. However, the main point of controversy is that the link between the materials in the carpet and health effects has not been established.[7,8,9] Therefore, carpeting will continue to be an issue that each organization will have to debate until further research helps clarify the issues.

VII. CONCLUSIONS

Results from the questionnaire given during the survey showed that many rooms with occupant complaints still exist at the Shamokin Elementary. Occupants who appear to have the most problems are those with existing respiratory problems. No health hazards were identified. Many of the other occupant complaints appear to be related to thermal discomfort potentially caused by low humidity; unbalanced air flow, which appears to cause overheating and temperature extremes in some rooms; and a temperature control system which is not adequately responsive to the conditions in the classrooms.

VIII. RECOMMENDATIONS

The following recommendations are made in order of priority. They are presented to assist with, first, getting the current situation under control and, second, correcting obvious problems and then progressing on to more costly and creative solutions.

1. Maintain open and honest communication between parents, teachers, school administrators, and other interested parties. Open communication and trust are very important while solving indoor environmental problems. To facilitate communications, a working committee composed of representatives from all of the interested parties should be formed. This committee should be the center of all information exchange so that persons seeking the latest, most accurate information can have a contact point. This committee should also be charged with receiving information about trial solutions and their results, and planning for the next solutions.

2. Designate one person to receive complaints about the building. This person should be a neutral party who does not have reprimand power over the teaching staff. Files should be set up for the complaints according to air handler and related zones. Complaints should be filed under the air handler controlling the room occupied by the complainant or the complainant's child. All complaints should be acted upon and, once the problem is resolved, the actions taken should be reported back to the complainant. Such actions should also be included in the file along with the complaint.

3. Make one full-time person responsible for the mechanical systems in all of the schools to be sure that the systems are maintained adequately. This person should be formally trained in the operation, hardware, and control systems for the mechanical systems.

4. Rebalance the air flows for AHUs 1 and 2. In addition, have the design air flows and temperatures verified by a mechanical firm. Air flows should be listed on the drawings next to the applicable diffusers. Moreover, the original remediating mechanical firm should supply a theory of design for the mechanical systems. Changes in the systems which affect the theory of design should be recorded as an addendum to the original document. Balancing should be performed using a total flow instrument set up according to the instrument manufacturer's specifications for linear slot diffusers. Personnel performing the test and balance should be certified by the National Environmental Balancing Bureau (NEBB) or other equivalent certifying organization.

5. Obtain up-to-date control schedules from the controls manufacturer along with theories of operation. Schedules should include reset schedules, design temperatures, and the manufacturer and part numbers of major components, as well as operation ranges of all components.

6. Set up a maintenance schedule for all parts of the mechanical systems in the building. This schedule should include cleaning of exhaust systems and return air grates, and monitoring exhaust systems for flow. Manufacturers of the components or a mechanical firm should be able to assist in developing a schedule.

7. Set up and maintain information files on each air handler in the building. Each file should contain, as a minimum, up-to-date mechanical and control system drawings, manufacturer's product literature on each component of the systems, written operation methods for all systems, maintenance schedules and records, and records of changes to the systems. Complaints and their disposition should also be kept in the files of the applicable systems. All drawings, methods, and schedules need to be kept up to date.

8. Relocate the drains for the condensate pans in the air handling units, tilt the air handling units, or use other means to prevent condensate water from standing in the pans. Leftover debris from the renovation should be cleaned out of the air handling units. Condensate pans should be inspected regularly and debris cleaned out of the pans to prevent clogging of or damming around the condensate drain, plugging of the coil, and the potential for growth of algae, mold, and bacteria. During these inspections, other debris in the air handling units should be removed. Coils should be spray-washed at least twice a year during non-classroom hours. Drain lines should be equipped with a restrictor or trap and should discharge into an open drain to prevent contaminants from being pulled into the air handling units through the drain.

9. Change the filters in AHUs 1 and 2 to those that are the highest efficiency possible in the 35 to 60% efficiency range without substantially affecting the operation of the air handling units. The rated efficiency of the filter should be according to the ASHRAE Dust Spot Test and determined by an independent laboratory. In addition, filters should be changed out according to the manufacturer's rated pressure drop across the filters. Pressure taps may need to be added to the air handlers to facilitate measuring the pressure drop. Note that with a more efficient filter, a prefilter may be required to extend the life of the more efficient filter. Filter manufacturers or their representatives should be able to help the school

decide which filter to use, at what pressure drop the filters should be changed, and whether a prefilter is needed.

10. Consult with a controls manufacturer and mechanical firm about having AHUs 1 and 2 going to a reduced flow setback instead of a cycling setback. Reduced flow setback can be accomplished by using the vortex dampers still on the fans in AHUs 1 and 2 and the current energy management system (EMS) system. During the setback, outside air should still be supplied to the building. The amount of outside air should be set to obtain CO_2 levels in the building in the morning about equal to that of the outside air. A mechanical firm should determine what the night setback supply air and outside air flows should be.

11. Investigate whether the restriction of the current return air system is causing air to be returned through paths other than the design path. This can be accomplished by measuring the air entering the returns in each room and comparing this air flow to that supplied to the room. If too much of the air supplied to the room is bypassing the design return route, install new, less restrictive returns.

12. Investigate moving the outside air and return air dampers on AHUs 1 and 2 to increase mixing between the two air streams. As part of this change, investigate moving the current outside air dampers to other locations on the units and using a blender box to further increase mixing.

13. After establishing the success of purging the building overnight, check CO_2 levels throughout the day on the coldest days to see if the levels stay below two to three times the outside levels. If they do not, consider resetting the minimum position of the outside air dampers. Changes in Item 13 should help prevent coil freezeups; but, mixed air temperatures should still be monitored. If the mixed air temperature drops below a level considered to be safe for the coils, investigate using inhibited glycol solution in the mechanical systems instead of plain water.

14. Investigate installing temperature sensors in selected rooms for controlling AHUs 1 and 2 supply air temperature instead of temperature sensors in the return air duct. A controls manufacturer representative can perform this investigation and recommend methods to integrate the signals from the various sensors to properly control the supply air temperature. This manufacturer's representative should be instructed to consider using the reheat system to temper the supply air for abnormal demand locations and to continue to provide some control of the classroom temperature by the teachers.

15. Investigate moving the outside air sensor from its current position behind the school to a location where the sensor can more accurately sense the temperature of the outside air entering the air handling units.

16. Continue a routine cleaning schedule of the carpets. In cleaning the carpets, continue to steam clean. Clean the carpets at least monthly, but more often when outdoor conditions are wetter and dirtier than normal. Carpets should be cleaned in a manner so they do not get too wet; the carpets should be able to dry overnight. Clean the carpets only on Friday evenings or the evening before holidays to allow the maximum amount of time for the carpets to dry and aerate before students

return. The ventilation system should be run during the time to provide outside air for purging of contaminants from cleaning.

17. School personnel should continue to enforce the policy of having engines turned off on vehicles near the school. Signs should be posted in parking and waiting areas to help enforce the policy.

IX. APPENDIX--Summary of Measurements Prior to the NIOSH Survey

A. School Personnel Measurements (October 9, 1989 to March 14, 1990).

Measurements were made either in the morning or the afternoon, but primarily in the morning. Measurements were not performed in the same rooms consistently and the same number measurements were not made each day.

Results of the measurements, excluding unusual events:
Overall Average Carbon Dioxide--Indoor 736 ppm (N=188; sd=127)
Overall Average Carbon Dioxide--Outdoor 277 ppm (N=15; sd=46)
Overall Average Number of Occupants   23.8   (N=188; sd=5.5)
Overall Average Room Temperature   72.2 NF (N=187; sd=1.6)

Morning Average Carbon Dioxide--Indoor 743 ppm (N=130; sd=115)
Morning Average Carbon Dioxide--Outdoor 279 ppm (N=12; sd=45)
Morning Average Number of Occupants   23.6   (N=130; sd=5.3)
Morning Average Room Temperature   72.2 NF (N=129; sd=1.7)

Afternoon Average Carbon Dioxide--Indoor 719 ppm (N=158; sd=149)
Afternoon Average Carbon Dioxide--Outdoor 267 ppm (N=3; sd=58)
Afternoon Average Number of Occupants   24.2   (N=58; sd=6.1)
Afternoon Average Room Temperature   72.2 NF (N=58; sd=1.4)

(Note: "N" means number of measurements and "sd" means standard deviation).

Unusual events which occurred during the measurements were the freeze-up of a coil in the air handling unit and an elevated temperature due to an unspecified mechanical failure.

B. Texas Research Institute (January 9, 1990).

Average results from six grab samples:

Carbon Dioxide 724 ppm (sd=194)
Carbon Monoxide 3.0 ppm (sd=0.3)
Methane 2.6 ppm (sd=0.2)
Nitrogen Dioxide   Every sample = 78.1%
Oxygen   Every sample = 20.9%
Total hydrocarbons   Every sample < 1.0 ppm

C. Lancaster Laboratories, Inc. (January 14 and 21, 1988).

Average results from the first day of this company's sampling for carbon monoxide and dioxide, aerobic bacteria, and mold and yeast:

Indoor Carbon Dioxide 800 ppm (N=7; sd=252)
Indoor Carbon Monoxide All samples < 5.0 ppm
Indoor Relative Humidity 20.4% (N=7; sd=6.1)
Indoor Bacteria SPC 174.9 CFU/m^3 (N=7; sd=135.2)
Outdoor Bacteria SPC 136 CFU/m^3 (N=1)
Indoor Molds and Yeast All samples except one = 0
One sample = 68 CFU/m^3
Outdoor Molds and Yeast 0 CFU/m^3

(Note: "SPC" means standard plate count and "CFU/m^3" means colony forming units per cubic meter of air).

Average results from the second day of measurements and sampling:

Carbon Monoxide All samples < 5.0 ppm
Indoor Carbon Dioxide 775 ppm (N=8; sd=128)
Outdoor Carbon Dioxide 300 ppm (N=1)
Indoor Relative Humidity 30.0% (N=8; sd=3.5)
Outdoor Relative Humidity 24.0% (N=1)
Indoor Bacteria SPC 272.3 CFU/m^3 (N=8; sd=194.6)
Outdoor Bacteria SPC 132 CFU/m^3 (N=1)
Indoor Molds and Yeast 20.0 CFU/m^3 (N=8; sd=37.8)
Outdoor Molds and Yeast 198 CFU/m^3 (N=1)

Peak levels of bacteria on January 14 and 21 were 408 and 594 CFU/m^3, respectively, and peak levels of molds and yeast on the two days were 68 and 94 CFU/m^3, respectively. No speciation of the bacteria, and molds and yeasts was made.

This same contractor also collected surface wipe samples on both days from the supply diffusers in each of the rooms where other measurements were made. These samples were analyzed for aerobic bacteria, and molds and yeasts. Results from the first day were that only one sample had a bacteria surface concentration of 15 CFU/ft^2; all other bacteria, and mold and yeast samples were negative. On the second day, one sample from a different location had a bacteria surface concentration of 15 CFU/ft^2; four samples had mold and yeast surface concentrations of 15 CFU/ft^2 each.

D. Radon Detection Services (July 24 to 28, 1987).

The average result from 21 samples collected was 0.5 picoCuries/Liter (pCi/L) (standard deviation = 0.5). The average result from these samples was 0.7 pCi/L.

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