INDOOR AIR QUALITY OBSERVATIONS IN PUBLIC SCHOOLS

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ABSTRACT

Investigations of indoor air quality or indoor environment problems were accomplished in seven different Texas schools. The schools were located in hot and humid climates. Comfort and mildew were the most frequent complaints. In all cases, the air-conditioning system maintenance and operation was a primary factor in the problem cause and solution. The significance of problems investigated could have been minimized had the symptoms been addressed when they were reported the first time. Preventive maintenance and better housekeeping of air-conditioning systems in Texas schools will improve the indoor environment.

Schools are encouraged to be more aggressive in preventive maintenance and plan for indoor air quality and energy efficiency in school air-conditioning retrofits.

INTRODUCTION

A qualitative investigation of problems reported in seven Texas Public Schools was accomplished. The problems reported by the school personnel were varied and included mildew, mold, odor, allergy reaction, water on surfaces, and comfort. Only one of the building operators reported the problems as indoor air quality or sick building. Three of the investigations indentifying indoor environmental problems were initiated in response to energy audit requests. One investigation was requested after parents complained to the school board about growth on carpet and wall, and allergy reaction. The seven case studies include complaint and non-complaint buildings. The schools reported in this paper are at various locations throughout Texas. The investigation approach is outlined below.

- Visit school and interview building operator (e.g. principal, administrator, maintenance director)
- Inspect specific areas of building with reported problem and identify nature of problem.
- Conduct inspection of entire building including air-conditioning systems.
- Review building functional and operational characteristics.
- Review construction documents (plans and specifications).
- Formulate hypothesis about causes of problems.
- Conduct additional inspections, obtain limited measured data as needed, and conduct evaluation of air-conditioning systems.
- Recommend solutions to resolve problems.

In all seven cases, this was all the investigation that was needed to identify the problems sufficient to recommend solutions to resolve the observed problems. Because of expense to the building Owners, additional quantitative investigations were not conducted. As soon as the initial investigation and recommendations were provided, the Owners wanted to take immediate action and give no publicity or attention to the subject. Therefore, no additional quantitative investigations were made.

LOCATION OF CASE STUDIES

The seven case studies in this paper are located in hot and humid climates as shown in Figure 1. The severity of the problems as visually detected (e.g. mold, mildew, moisture on walls and floors, etc.) was progressively more pronounced in the schools in the southern part of the State of Texas (See Figure 1).

Observations made throughout Texas in Public Schools during more than 300 on-site energy evaluations, indicate that there are more indoor environment problems in the eastern and southern part of Texas. This should be expected because these areas have higher relative humidities. No schools in north, west, and southwest Texas have been observed or reported to the author as having mildew or mold type problems, or condensation problems. A common observation throughout Texas (all regions) is poor housekeeping and maintenance practices which effect the indoor environment. Common practices frequently observed include (1) mechanical room having free return air systems, and the room being used for storage (e.g. pesticides,

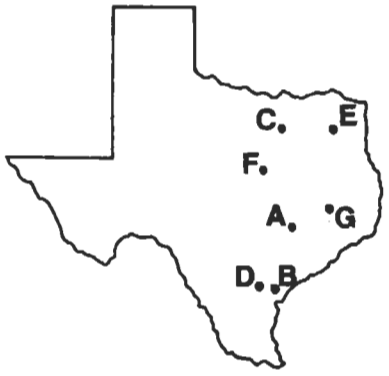

FIGURE 1: LOCATION OF CASE STUDIES

dirty mops, trash cans, dust pans, old filters, gasoline powered lawn equipment, cleaning supplies, etc.) (2) dirty air-conditioning coils (3) dirty air-conditioning filters and installation of copy machines in non-ventilated rooms, (4) fresh outdoor air dampers closed.

CASE STUDY SCHOOLS

The following paragraphs discuss each case study school. Because of requests from several Owners, the schools are not identified by name and district. Figure 2 summarizes the general characteristics of these schools.

SCHOOL A

The single-story school was inspected in response to a request for an energy audit. During the initial on-site visit, review of the utility bills indicated that the air-conditioning equipment was operating continuously. The superintendent reported that the systems were not turned off at evenings, weekends, summer, or anytime because of recent problems with mildew and comfort.

The building and systems were inspected as part of the energy audit. The inspections and conservations revealed the following:

. Mildew growth

. High indoor humidity

. Chilled water supply temperature of 59°F.

. Moisture condensation on walls in corridors and other locations.

Discussion with the superintendent revealed that based on a controls company's advice, the chilled water supply temperature had been adjusted to the observed temperature. The observed high chilled water supply temperature did not permit adequate dehumidification of the air passing through the air-conditioning coils. Resulting high indoor humidity made the occupants uncomfortable so the air-conditioning system was operated continuously in an attempt to achieve comfort.

The recommendations to resolve the problems were as follows:

. Adjust chilled water supply temperature to 44°F.

. Clean the mildew off of the surfaces.

. Operate the air-conditioning continuously for 30 days.

Within 30 days after the above recommendations were accomplished, the building occupants complaints totally ceased, the mildew growth stopped, and the condensation on surfaces did not occur. After 30 days from the initial corrective action, the air-conditioning system was turned off on weekends and holidays without any problems.

SCHOOL B

The two story elementary school was investigated on September 8, 1989 because of specific complaints in the kitchen and cafeteria. The complaints were reported as mildew on walls and ceilings, and moisture condensation on walls and floors in the kitchen.

FIGURE 2: SUMMARY OF CASE STUDY SCHOOLS

SCHOOL DESIGNATION	TYPE SCHOOL	HVAC TYPE	SYMPTOM	PROBLEM
A	Intermediate	Central, Chilled Water	Comfort, Mildew	High Chilled Water Temperature
B	Elementary	Central, Chilled Water	Comfort, Mildew	Pressure Under Floor, High Chilled Water Temp., Building Openings, Air Balance
C	Elementary	Central, Chilled Water, VAV	Mold, Mildew, Odor	Pressure Under Floor, Drainage, HVAC
D	High School	Roof top Multizone DX, and VAV	Comfort	Above Ceiling Return Air Connected to Underfloor
E	Intermediate	Central, Chilled Water	Comfort	Controls, Drain
F	Elementary	Central, Chilled Water	Odor	Condensation, High Infiltration
G	Elementary	Central, Chilled Water	High Carbon Monoxide	Boiler Failure

The mildew was observed to be in spots on the cafeteria ceiling tiles. In the kitchen, the problem was more prevalent. Much of the mildew reportedly has been cleaned-up in the kitchen. The mildew in the kitchen was concentrated on the vinyl kitchen wall, and on the furr-down for the duct work.

Room temperatures in other areas of the school were measured in the morning and afternoon. The temperature in the various rooms ranged from 66 degree F. to 71 degree F. during the morning and 69 degree to 72 degree F. in the afternoon. At 1:05 p.m., 69 degree F. dry bulb and 62 degree wet bulb temperature were measured in the cafeteria near the stage. This equates to about 65 percent relative humidity in the cafeteria. The room temperature in the kitchen was 71 degree F. Supply air temperature in the building varied from 55 degree to 57 degree F.

Airflows were measured on the first floor. The cafeteria/stage air handler had 5,775 cfm return air, 105 cfm fresh outdoor air, and 5,880 cfm supply air. According to the plans design supply airflow was 8,850 cfm. The kitchen air handler has 1,075 cfm supply air flow. The plans showed a design airflow of 2,700 cfm.

The following are observations and problems which were related to the mildew problem.

- The two chilled water temperature indicators in the main mechanical room indicated 39 degree and 45 degree F. Both indicators were in a common line, therefore one or both were not reading properly. Accurate measurement with different instrumentation indicated 49° F. chilled water supply temperature.

- The exhaust fan located over the dishwasher was not operational. Natural draft resulted in only 250 cfm airflow exhaust.

- The wall between the main mechanical room, the cafeteria, and kitchen had large openings above the ceiling. Air communicated above ceiling between the mechanical room and the cafeteria and kitchen. The mechanical room is on the back side of the school or an exterior wall. The mechanical room contains the chiller, boiler, pumps, etc.

- The back exterior door of the kitchen needed weather-stripping.

- The return air grille for the kitchen air handler was located within three feet of the dishwasher and the non-working exhaust fan grille for the dishwasher. The moisture from the dishwasher was being drawn into the return air for the kitchen air handler.

- The boiler and chiller were on. The cafeteria air handler chilled water valve was full open and the hot water valve was full closed.

- Several exhaust fans have their discharge ducted to the under floor plenum. This results in a higher pressure under the floor.

- Fresh air intake for cafeteria was completely blocked with dirt and lint.

The following were first steps recommended to resolve the mildew problem.

- Set chilled water temperature to 44 degree F. This temperature is required for dehumidification and will be significantly more effective than the 49 degree F. setting.

- Repair the dishwasher exhaust fan. Some of the moisture from the dishwasher stays in the kitchen and some of the moisture is drawn into the return air of the kitchen. Repairing this fan will exhaust to the outdoor significant amounts of moisture containing air. Instruct kitchen personnel to only operate the fan when the dishwasher is operating.

- Seal off the opening in the wall between the main mechanical room and the cafeteria/kitchen. The greatest concentration of mildew was on the furr down for the HVAC ducts. The air handler for the kitchen is in the mechanical room, therefore the opening around the ductwork should also be sealed where it penetrates the mechanical room. Inspect the duct installation in the furr-down area of the kitchen for tight joints and good installation.

- Weather-strip the backdoor to the kitchen.

- Clean the coils in the air handlers of the kitchen and cafeteria. The lower air flows may be partially due to dirty coils. The fresh air grille for the cafeteria was almost totally blocked by dirt. Clean the fresh air grille.

After the above items have been accomplished, monitor the mildew situation. If the mildew continues, accomplish the following additional items.

- Relocate the return air grille in the kitchen away from the dishwasher and pot sink area.

- Revise the discharge from the nearby restroom fans to eliminate the underfloor discharge. The discharge creates a higher pressure under the floor. Moisture will migrate from the area of high pressure to low pressure. Therefore, the moisture under the floor area will tend to migrate into the building.

Other comments include the following:

- Some of the identical classrooms have significantly different air flows supplied and low return air. This will contribute to some of the comfort complaints. However,

the high humidity level in the building will make the rooms feel uncomfortable even at normal room temperatures. It is recommended that the air balance in the rooms not be adjusted until the building mildew items have been accomplished.

. Clean the mildew from the surfaces in the cafeteria and kitchen.

After the investigation and above recommendations were provided, the school personnel immediately accomplished the following:

. Set chilled water supply temperature to 44°F.

. Sealed openings around piping penetrations at common walls between cafeteria, kitchen, and mechanical room.

. Repaired dishwasher exhaust fan.

. Cleaned mildew off of walls and ceilings.

Improvements were reported during the first month after accomplishing the above. The remaining items were to be scheduled for accomplishment during the summer of 1990.

SCHOOL C

School C is a single story modern construction school. The authors were requested to investigate the school after parents complained at a school board meeting. The complaints were as follows:

. Allergic reaction of students.

. Mildew observed on walls and carpet.

. Uncomfortable environment (e.g. low temperature, "stuffy", humid).

The following are related observations made during the on-site investigation.

. Space temperature in the school was relatively low. Some classrooms were 67 to 70°F. Relative humidity was about 65 percent in most areas.

. The central VAV air-conditioning system was run continuously. There was no weekend, holiday, evening, or summer shut-down.

. Five fans are located in a large underfloor crawl space. The fans transfer above ceiling return air to the underfloor crawl space. This arrangement pressurizes the underfloor volume.

. Chases for electrical conduit communicate directly between above ceiling plenum area and underfloor space.

. Some of the economizer controls on the air-handlers were not functioning properly. Malfunction of these controls can permit humid outdoor air to be used for space cooling.

. There is a crack between the walls and building along the ground at the east exterior wall. The principal and maintenance supervisor reported water entering the underfloor area during rains. Drainage from a recreational area flows to this side of the school. Water was reported to stand under the building after rain.

. The outside (fresh air) for all air-handlers were completely closed. No fresh outside air can enter the building via the air-conditioning system.

. Mildew was observed on the walls of a few interior classrooms.

. Mildew was observed on the carpet in the office and floors in a few interior classrooms.

. Coils on air-handlers were dirty.

. Mud and debris were on all hot water reheat coils.

. Above ceiling return air plenum was very dirty.

The following were recommended as initial steps to improve the indoor environment.

. The greatest contributor to the problem is the transfer of ceiling return air to the underfloor crawl space. The underfloor fans pressurize the crawl space. Some of the underfloor fans were not operating (failed) and this results in moist underfloor air flowing into the building through the openings in the piping chases and operative underfloor fan ducts. Turn off the underfloor fans, seal the floor openings to the crawl space, and seal the underfloor fans ductwork.

. Construct a retaining wall or provide other methods to direct drainage away from the building. Eliminate water standing under the building. Seal the crack along the exterior wall at the ground.

. Set the outdoor air dampers on each air-handler to provide for fresh air.

. Repair the economizer controls.

. Clean the mildew off the walls.

. Clean the carpet.

. Clean all books and furnishings.

. Clean all air-handlers and reheat coils. Replace filters.

. Seal chases communicating with return air plenum.

. Operate the air-conditioning continuously for 30 - 90 days to dry out and purge the building.

The school personnel immediately shut-off the underfloor fans, set dampers for introduction of fresh outside air, and cleaned the interior surfaces with visible mildew. Other work was planned for the summer. Improvements were noticeable to the extent that complaints from students and parents stopped.

SCHOOL D

School D was originally constructed as a single-story high school. A two-story classroom addition has been constructed. The complaint responded to was comfort (high humidity) in the area of the north-south corridors along the auditorium and the surrounding classrooms. Mildew was reported to occur in this area. The occurrences were reportedly isolated and periodic. Investigations revealed the following contributing conditions.

. The building has an underfloor crawl space which is frequently wet, muddy, or standing in water.

. The package rooftop multizone air-conditioning units have above ceiling return air in the halls. Some of the return air passages from the rooms to the halls were blocked.

. Plumbing chases extending from the floor to the above ceiling return air plenum have openings around the piping. The underfloor moist air is being induced into the return air plenum.

. Multiple large double doors and windy conditions result in introduction of moist outdoor air into the subject corridors when students are changing classes.

The following recommendations were provided to resolve the problem.

. Clean all surfaces in the areas.

. Seal openings between underfloor and return air plenum.

. Remove items blocking-off the return air grille in some classrooms.

Accessible areas have been sealed and the return air restrictions removed. The school's architect is evaluating vestibule options and alternative pedestrian flow to minimize a "wind-tunnel" effect in the north-south corridors during class change.

SCHOOL E

School E is a new single-story intermediate school. There are individual small fan coil units for each classroom each having its own separate outdoor air duct. The complaint investigated was comfort stated as periodic, "high temperature and high humidity."

On-site investigations revealed the following contributing conditions.

. Fan coil units motor operate continuously. Chilled water control valves were observed closed and/or almost closed due to thermostat (sensible heat) being satisfied. There were no dampers in the fresh air ducts.

. Coil and drain arrangement allows moisture to enter supply air on downstream of cooling coil.

Recommendations included the following:

. Install fresh air dampers and air balance system.

. Revise thermostats/controls to cycle fans.

. Revise drain arrangement to eliminate water from entering supply air.

SCHOOL F

School F is an older single-story elementary school. The classroom walls are about 50 percent (area) operable glass windows. Cabinets and book cases are along the exterior walls to a height about equal to the bottom of the windows. The school originally had air-conditioning supply outlets washing the exterior glass. Renovation work including new air-conditioning eliminated this air-flow pattern. The complaint investigated was odor which the school personnel believed was coming from under the floor. The odor was reported after the renovation work was accomplished.

On-site investigations revealed the following conditions:

. The old operable windows did not close tight. There were large amounts of air-infiltration.

. Condensation was observed on the windows. There was mildew appearance behind and inside some cabinets. Condensate was running down the windows, and behind and into non-ventilated cabinets. The previous air-conditioning system air-flow washed the windows and the condensate condition reportedly had not been occurring.

Recommendations which resolved the problem include the following:

. Seal cabinets and cabinet/wall interface to prevent water flow to the cabinet interior and behind cabinets.

. Seal windows to significantly minimize infiltration of humid air.

. Clean the mildew appearing substance. Dry out space inside and behind cabinets.

SCHOOL G

School G is a modern single-story elementary school. Air-conditioning is provided by a central four-pipe system having a cast-iron sectional boiler to produce hot water for space heating. The indoor air quality problem was discovered during energy audit investigations. No symptoms or complaints had been reported by the school.

The indoor air problem was detection of very high carbon monoxide in the main mechanical room during boiler flue gas sampling for boiler performance analysis. The boiler stack indicated 728 ppm carbon monoxide. Samples in the mechanical room near the boiler were comparative to the flue stack readings. The boiler was located in a mechanical room having two exterior walls. A door (which was open) to a custodial room (e.g. supplies, desk, etc.) communicated with this main mechanical room. School officials were immediately notified, and the boiler was immediately shutdown. The burners were removed for inspection and they had deteriorated significantly. The four inch high concrete pad supporting the boiler was cracked from appearance of overheating. Large metallic rust deposits were under the boiler. The combustion air intake area for the boiler is undersize.

The school district is acting on the following recommendations:

. Replace boiler.

. Enlarge combustion air area.

In addition, this school had measured relative humidity in the classrooms as high as 79 percent. The air-handler cooling coils and filters were so filthy and blocked that the coils could not function properly. Roof leaks resulted in damaged ceiling tiles and such moisture that mildew growth was observed on the ceiling tiles. Openings to the outdoors were observed at one place above a ceiling area which served as a return air plenum. A comprehensive building and air-conditioning system preventive maintenance program was recommended.

CONCLUSIONS/RECOMMENDATIONS

1. The significance of all problems in the case studies could have been prevented if investigations and corrective action had been taken when the problem was initially reported.

2. Preventive maintenance could have minimized or averted most of the problems in the case studies.

3. Inspections during construction for proper sealing of piping penetrations to the building is essential. Periodic inspections after construction is recommended.

4. Many schools have a need for good preventive maintenance education, program, budget, and personnel allocation.

5. Periodic inspections by trained school personnel are recommended for improvement of the indoor air environment in schools. Inspections should be accomplished at least two times per year. Individual check lists should be prepared for each school building.

6. Pressurizing the void space under a building is not recommended. If underfloor ventilation is required, accomplish using methods to create negative pressures.

7. School administrative and maintenance personnel need training of proper operation, inspection, and maintenance of air-conditioning systems.

8. Building occupants and parents are becoming increasingly aware and educated about environmental issues. They are becoming more alert, vocal and less tolerant. Some of the schools investigated had problems since original construction.

9. Smoking should be banned and the ban enforced in all Texas Public Schools. Areas designated as smoking were observed to have return air communicating with other non-designated areas.

10. Based on the emotional situations observed and factors in item eight above, schools are encouraged to be more aggressive in preventive maintenance and good housekeeping practices of air-conditioning systems. If not, they are likely to encounter mandatory inspections and remedies imposed by governmental entities.

11. In all cases investigated by the authors there were actual problems.

12. Annual performance testing of boilers is recommended.

13. Technology, design knowledge, and operating information are available to prevent the types of problems reported in the case studies presented.

14. In all seven cases, resolving the problem will improve building energy efficiency.

15. In all seven cases, the solution was to eliminate the problem rather than dilute or mask.

16. Intelligent schools should include monitoring of indoor air quality (e.g. chemical composition, parts per million). This would have been beneficial in School G. The energy management system or building automatic controls will need to include additional environmental conditions such as air movement, location, number of occupants, and air samples. VAV fan speeds will need to be influenced by indoor air quality to minimize the effects of individual air patterns and low air flows that were observed in some of the case study school classrooms.

17. Based on observations in more than 300 school districts, air-conditioning systems for schools should be simple and easy to maintain. Fresh air can be controlled easier in individual zones and classrooms by using multiple, smaller

air-handling units. This approach also will result in less total fan horsepower. With the reduced horsepower using the multiple individual air-handling approach and the resulting flexibility of operation, energy operating costs will be less.

18. Texas Public Schools have many facilities with aging and deteriorating air-conditioning systems. This situation provides retrofit opportunity for improving indoor air quality and energy efficiency. Careful planning is required to achieve this goal.