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Building Owner's In-House Response to Indoor Air Quality Problems—Four Case Studies

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ABSTRACT

A building owner and property manager formed an in-house team to respond to complaints of indoor air quality. The purpose was to diagnose and mitigate complaints more quickly than was possible using consultants. The two-person team consisted of experts in mechanical systems and environmental issues. Between October 1990 and March 1991 the team responded to nine complaints in commercial office buildings, of which four are presented here. Results of the team effort indicate that the approach is successful in rapidly identifying and remediating indoor air quality problems.

INTRODUCTION

An extensive industry has developed to assist building owners and property managers in need of indoor air quality services (EPA 1989). However, use of external diagnostic services to perform indoor air quality investigations has proved frustrating to one building owner/manager for several reasons. The owner manages approximately 50 multi-family residential properties, 75 commercial buildings, four hotels, and hundreds of retail establishments in the metropolitan Washington, DC, area.

First, although a problem clearly existed, investigators, relying heavily upon instruments to determine cause, frequently produced false negative results. This problem has been identified elsewhere (Light 1989).

Second, a period of four to six weeks often elapsed between the date the investigation took place and acceptance of the consultant's final report, a delay too extended to be acceptable to persons experiencing daily discomfort.

Third, a common consultant recommendation was to perform an evaluation of the ventilation system, but it soon became evident that is where the investigation should have commenced in the first place.

Fourth, consultant-performed evaluations often did not achieve the very purpose for which they were commissioned: to establish cause.

Based on these difficulties, a new approach was developed. In-house resources available to the building owner consisted of professionals with expertise in mechanical systems and environmental issues. Therefore, it was decided that on an experimental basis the consultant approach would be dropped in favor of a two-person in-house response team. One team member is a former building chief engineer with 13 years' hands-on experience in heating, ventilating, and air-conditioning systems. The other participant has conducted numerous indoor air quality investigations over the past several years and holds a master's degree in environmental health science.

The aims of the experimental approach were severalfold: (1) to sharply cut down effective response time, (2) to inspect the ventilation system as part of the initial site visit rather than thereafter, (3) to delineate cause, and (4) to recommend mitigative steps as quickly as possible and ensure they are implemented without delay. It was agreed to reconsider the use of consultants if the in-house approach failed to solve the problem.

The team responded to its first complaint in October 1990 and visited eight additional complaint sites through March 1991. All complaints came from the owner's commercial buildings. The case studies that follow present the results of four of those investigations.

CASE STUDY 1

On November 15, 1990, a commercial tenant occupying the entire 11th floor (35,455 ft^2 [3,294 m^2]) of a 13-story office building in Arlington, Virginia, expressed several concerns related to poor indoor air quality: poor air circulation in interior offices, as evidenced by stuffiness and odors including cigarette smoke; dirt in exterior offices; complaints of fatigue; possible mold growth on ventilation system components; and a suspected increase in respiratory illnesses.

Mechanical heating, ventilating, and air-conditioning for the building is provided by two interior and one exterior zone constant volume air-handling units. Supply airflow from the exterior fan is distributed around the perimeter of the building by wall-mounted induction units. Interior air distribution is provided by troffers installed in the light fixtures. Return air distribution is by means of slots in light fixtures and a plenum ceiling. Each of these units is equipped with backup resistance heat strips. Chilled water is provided to the air-handling units and the induction units from a remote central plant. Office windows cannot be opened.

Air Distribution

From the inspection of the return air plenum ceilings, it was revealed that both the supply air and the return air distribution

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systems were not performing as designed. This lack of air distribution was causing the cigarette smoke to drift out of offices and down the hallways. The smoke was then drawn into other areas by the poorly balanced heating, ventilating, and air-conditioning system.

In response to the complaints about poor air circulation, approximately 15 offices and the ceiling return air plenum were visually inspected. One indicator of unsatisfactory conditions was the presence of numerous oscillating fans in many offices. A multitude of problems affecting heating, ventilating, and air-conditioning system performance were observed:

1. Supply air for the suite was escaping into the ceiling return air plenum because (a) light-mounted supply air troffers were disconnected from the supply air ductwork, (b) flexible supply air ductwork lay disconnected in the plenum, (c) take-off caps were missing on main supply air ductwork, and (d) several supply air light troffer dampers were closed.
2. A considerable amount of supply air that did enter the suite was being short-circuited by poorly positioned return air grilles installed in the suspended ceilings of individual offices.
3. The main outside dampers were closed 100% as a result of work being performed on the air handlers in the penthouse by a outside contractor at the time of the inspection.
4. Return airflow in the ceiling plenum was being severely restricted for several reasons: (a) openings were not present in slab-to-slab demising walls; (b) fiberglass bat insulation, previously installed for acoustical purposes, had been rolled up in the plenum ceiling; (c) demising walls and supply air ductwork were placed improperly in one area; and (d) discarded ceiling tiles, apparently from previous remodeling work, were present in the plenum. Besides restricting return airflow, these panels and an extensive network of communication cabling installed by the tenant added sufficient weight to the suspended ceiling tiles to cause cracking and breaking.

Unacceptable air quality conditions in the suite were compounded by several tenant-generated problems. Although tests to confirm heat load were not made, the presence of heat-emitting office equipment appeared certain to exceed the 5 W/ft^2 (54 W/m^2) building design standard. Employee density in some interior offices exceeded local code guidelines (BOCA 1989) of 100 ft^2 (9 m^2). The presence of several poorly maintained supplemental, self-contained, package air-conditioning units installed by the tenant in several areas within the suite possibly contributed to odor problems. The filter in one in particular was completely clogged with debris, and odors provided by the filter media were detected in the discharge air.

Temperature measurements confirmed the existence of marginal thermal comfort conditions. Interior zone temperatures from 77 °F to 82 °F (25 °C to 28 °C), with an average temperature of 78.9 °F (26.1 °C), were detected. Since the outside air temperature was 53.5 °F (11.9 °C), the building should have been on the outside air economizer cycle. Instead, as previously noted, the outside air dampers were closed, and the interior zone fans were supplying air in excess of 65 °F (18 °C).

Remediation consisted of reconnecting light-mounted supply air troffers and the flexible supply air ductwork. In all, deficiencies were found in approximately 25 troffers. Approximately 15 missing take-off caps were repaired. Unnecessary insulation and discarded ceiling tiles were removed from the plenum. A total of 22 ceiling-mounted return air grilles were removed. Approximately 275 ft (84 m) of slab-to-slab partition return air openings were removed to permit improved return airflow in the ceiling plenum.

The condition of the self-contained units and equipment heat load and employee density issues were brought to the tenant's attention; however, no follow-up was undertaken to determine if changes were made.

Although no baseline data were collected, results of measurements performed in the suite four-and-a-half months after the inspection by a consultant industrial hygiene firm revealed conditions conducive to acceptable air quality. Six measurements of carbon dioxide were collected from throughout the suite, and none exceeded 500 ppm. Carbon monoxide measurements taken throughout the day did not exceed atmospheric concentrations, even in smoking areas.

Except for a single reading of 71 °F (53 °C), air temperature in the suite on April 3, 1991, averaged 76 °F (24 °C), with all results between 74 °F and 78 °F (23 °C and 26 °C). The relative humidity averaged 42%, with a low of 36% and a high of 60% (see Table 1). Measurements were taken using a sling psychrometer.

Dirt and Mold

The tenant stated that fine dirt and dust particles were expelled from the louvers on the induction units when the building's heating, ventilating, and air-conditioning system was first activated in the morning. The problem also occurred if the induction unit's housing was bumped or the louvers removed. The existence of excessive airborne dirt was associated with the inability of one employee to wear contact lenses at work.

Inspection of the units revealed an accumulation of debris on the surface of the discharge air nozzles. In some instances, the nozzles, which are approximately 0.12 in. (3.18 mm) in diameter, were restricted by approximately 50%. When the induction units were bumped or the louvers removed, dirt and debris were expelled from the unit. No attempt was made to determine if the dirt represented normal accumulation over the years or came from another source.

Induction units were cleaned by a contractor approximately a month and a half after the inspection. Reinspection of cleaned units indicated that the problem had been largely corrected. However, dirt was still present within some units, and in others, discharge nozzles were found to be blocked by factory-installed plastic plugs. The findings suggest a need for closer supervision of this work in the future.

An unusual amount of dirt was also observed in a copy room on the door frame, ceiling tiles, and a ceiling vent. These areas were cleaned and the tenant was asked to ensure that the copy machine, believed to be the source of much of the dirt, was being properly maintained. No follow-up to the tenant request was made.

TABLE 1
Temperature and Relative Humidity Measurements on 4/3/91
Case Study 1, 11th Floor*

Time	Location	Temp. (°F/°C)	R.H. (%)
0755	Southwest Corner, Core	78/26	39
0757	Northwest Corner, Core	76/24	40
0759	Northeast Corner, Perimeter	76/24	44
0803	Southeast Corner, Perimeter	76/24	40
0900	Outside	46/8	50
0905	Southwest Corner, Core	77/25	36
0907	Northwest Corner, Core	75/24	40
0910	Northeast Corner, Perimeter	71/22	38
0915	Southeast Corner, Perimeter	78/26	36
1105	Southwest Corner, Core	76/24	48
1108	Northwest Corner, Core	75/24	38
1110	Northeast Corner, Perimeter	75/24	38
1115	Southeast Corner, Perimeter	78/26	60
1300	Outside	57/14	40
1315	Southwest Perimeter Hallway	74/23	58
1317	Northwest Perimeter Hallway	76/24	39

*Heating, ventilating, and air-conditioning system activated at 0805.

On April 3, 1991, four-and-a-half months later, sampling for nuisance dust was performed in the suite. Six samples were collected, three before the heating, ventilating, and air-conditioning system was activated and three thereafter. Pre-operating results ranged from none detected to 0.20 mg/m^3, post-operating results, from 0.02 to 0.07 mg/m^3. All results are below the U.S. Environmental Protection Agency's benchmark of 0.26 mg/m^3 (24 hours) for ambient air. Sampling was performed per NIOSH Method 0500 using a 37-mm cassette with a preweighed PVC filter.

Concern for mold growth was raised because at least one employee claimed to be allergic to it. No visual evidence of mold growth was seen during the survey, nor were significant levels detected during sampling in the suite on April 3. Analysis of three bacteria samples produced results from 0 to 4 cfu/m^3; seven samples for fungi, 0 to 1 cfu/m^3. Samples were collected both before and after HVAC system activation. Results of outside (roof) baseline data were comparable: two samples each for bacteria and fungus yielded results of 0 to 1 cfu/m^3 and 1 to 2 cfu/m^3, respectively.

Measurements for viable microorganisms were collected following a protocol of the American Conference of Governmental Industrial Hygienists (1989) using a cascade impactor. Soy agar culture plates were used to collect viable bacteria and dextrose agar for viable fungi.

CASE STUDY 2

A commercial tenant occupying approximately 1,750 ft^2 (163 m^2) of space on the fifth floor of a 12-story office building in Arlington, Virginia, complained of stuffiness and poor ventilation. Among the five-person staff, symptoms included headache, sore throat, allergies, and unspecified respiratory illnesses.

Building staff responded to the complaints on December 19, 1990, two days before the response team arrived. Six disconnected supply air troffers were found in the ceiling plenum above the suite; several others were closed. The devices were reconnected, opened, and the tenant reported an immediate improvement in air quality. Subsequently, building staff traversed all supply troffers using a flow hood to ensure they were discharging supply airflow at the design specification. Four were found to be discharging four times the design specification and were adjusted downward.

While it is believed that the disconnected troffers were the primary source of the complaints, several additional problems were detected during the response team's inspection that could have played a minor role in air quality then or in the future. Dirt was observed accumulating on air jet nozzles located within the suite's three induction units. This would eventually affect airflow adversely. These were subsequently cleaned by a contractor and the discharge airflow checked to ensure it was compatible with design volume and static pressure. Static pressure on one of the three was adjusted upward. The tenant expressed complete satisfaction after the changes were made.

Several minor tenant-related issues were noted during the visit. Ice buildup was detected in a small refrigerator used by the tenant. A water-stained carpet caused by a leaking five-gallon container of bottled water was also observed. Due to a concern about buildup of microbial growth, the tenant was advised to defrost the refrigerator at once and periodically thereafter and to provide spill containment for the water containers.

Finally, a microwave oven was observed to be inadequately vented and in contact with combustible materials. The tenant was advised to remove the combustibles and relocate the unit to permit improved ventilation.

CASE STUDY 3

Four persons occupying a 500 ft^2 (46 m^2) commercial suite on the sixth floor of a 15-story office building in Arlington, Virginia, complained of headache, fatigue, stuffiness, dry air, and poor air circulation. One occupant associated an upper respiratory infection with the work environment and said cigarette smoke from an adjacent office was discomforting. The investigation was performed on January 22, 1991.

Although the office work force is small, a large number of persons enter the facility to sign in before being permitted access to secured areas elsewhere in the building. The result is that 100 or more persons may pass through the reception area of the suite in a single day.

Supply air is provided through two perimeter induction units and by distribution troffers located in the light fixtures. Return air passes through the slotted light fixtures and into the ceiling plenum. Inspection revealed that several return air openings were partially closed, creating a pressurized condition in the suite. Frequent opening of the door of the suite actually benefitted occupants because it acted as a relief to permit air movement. One supply air troffer was disconnected.

All troffer problems were corrected, and a 2 ft by 2 ft (0.6 m by 0.6 m) perforated return grille was installed in the suspended ceiling between the reception area and the offices. Supply air troffers were then traversed using a flow hood to ensure they were providing air at design criteria, i.e., between 62 and 100 cfm (31 and 50 L/s). To alleviate the cigarette smoke, two return air grilles were installed in an adjacent office where the odor originated.

Inspection of the induction units revealed an excess of dirt and debris. One of the units, situated in the office of the employee who complained of the respiratory infection, was found to be on the maximum cool setting. Moreover, several directional diffusers on the unit were placed to direct discharge air toward the employee's desk, rather than away from it. Several other diffusers were covered with plastic to restrict airflow.

Both induction units were subsequently cleaned and discharge air static pressure set to design conditions. In response to the complaint associated with dry air, controls on the central plant's humidification equipment were adjusted to maintain between 35% and 45% return air relative humidity. After these changes were made, occupants reported that indoor air quality in the suite was acceptable. The changes also reduced the adverse impact of the smoking problem, but this issue was only completely resolved when the smoker was reassigned elsewhere.

Temperature readings taken during the January visit ranged from 70°F to 72°F (21°C to 22°C). Relative humidity was 22%. Temperature and relative humidity measurements were taken in the suite during the period April 1-4, 1991, more than two weeks after all changes had been made. Relative humidity was 36% in the morning with the humidification system off. The next day, with the system on, the relative humidity in the morning was 59%. Afternoon relative humidity measurements, all taken when the humidification system was operating, ranged from 48% to 71%. Temperature readings ranged from 75°F to 77°F (24°C to 25°C). The tenant reported a perceived improvement in air quality.

During the visit, two of three operating video display terminals were positioned in a manner that could give rise to musculoskeletal problems for operators after intensive use. Also, screen contrast was poor. An employee said the units are used two to four hours a day with frequent breaks. Suggestions to mitigate the problems were made; however, no follow-up was performed.

CASE STUDY 4

A tenant occupying approximately 3,150 ft^2 (293 m^2) in two separate areas of the top floor of a 13-story commercial office building in Washington, DC, voiced concerns regarding chemical odors, low relative humidity, temperature extremes, and poor air distribution. The investigation took place on January 28, 1991.

One source of chemical odors was traced to an adjacent suite, where a film processing laboratory was set up. The facility was cluttered and poorly maintained. Standing waste water was observed in drain pans, and local exhaust ventilation consisted merely of a penetration through the wall above the processing facility that opened into a return air shaft.

It was speculated that odors from the facility were being drawn into the suspended ceiling above the darkroom and carried into complainants' offices by the corridor's return air system. As the presence of the laboratory constituted a lease violation, it was shut down by building management.

In addition, in the course of resolving indoor air quality problems, building staff discovered foul odors coming from a broken connection on a sanitary drain line vent pipe located in the wet stack passing through the space. The connection was repaired.

Relative humidity measurements during the visit averaged 30%. This level was deemed to be acceptable. Building staff reported that complaints occurred when the exterior and single interior fan spray humidification systems were shut off. Therefore, since remediation clearly lay in keeping them in operation, this was done for as long as possible while avoiding excessive comfort range conditions.

Temperature extremes were traced to conditions in the ceiling void above the suspended ceiling tile. The air temperature in the void over two perimeter offices was ten degrees colder than the suite temperature. Drafts were noted in the ceiling, and a stack effect of cold air was found at the top of the riser chases. This cold air was being drawn down into the suite through openings in the tenant-installed light fixtures by the corridor's return air system, creating localized drafts. Average space temperature within the offices was 73 °F (23 °C). Corrective action involved sealing the tops of the riser chases with insulating material.

A number of findings supported the contention of poor air circulation. Numerous leaks through inspection doors and duct seams installed on the high-pressure riser ductwork located in the suspended ceilings were detected in both suites. A 3-in. (76-mm) discharge air flexible duct was found disconnected from a diffuser, further reducing conditioned airflow. Discharge airflow from office induction units was determined to be below design criteria in some units, above in others.

Moreover, despite the fact building management stated that the induction units had been professionally cleaned in 1990, unit interiors were excessively dirty and held assorted food and trash, such as popcorn, cigarette butts, and plastic spoons containing dried food. Condensate pans were coated with dried waterborne debris. The presence of dirt was also detected on the main corridor return air grilles; balancing dampers inside the devices were restricted approximately 50% by debris.

Leaks were repaired by replacing worn gasketing around the inspection doors and sealing seams. The discharge duct was reconnected. The induction units were recleaned professionally, this time under close supervision. Static pressure measurements were adjusted to manufacturer's specifications on the air jet nozzles in the induction units.

Other problems potentially impacting on air quality were also detected. In the ceiling above one office, a five-gallon bucket of water, more than half full, was observed. It was there to collect water from an active roof leak. The bucket was removed immediately and a separate investigation begun to determine the location of the leak. Odors from consumables were produced by the tenants themselves from coffee pots and popcorn machines. Because of the odor, noise, and potential food source for pests, the tenant was advised to refrain from using the popcorn machine and to consider installation of a properly vented kitchenette.

After the changes were made, the tenant reported a marked improvement in air quality.

CONCLUSIONS

If our experience is representative, most indoor air quality complaints do not require the services of outside consultants performing extensive sampling and analysis to identify problem sources. On the contrary, if experienced in-house personnel are available, since most complaints involve straightforward deficiencies in the heating, ventilating, and air-conditioning distribution system, they can easily be remedied.

Appropriate in-house expertise would be an individual at the managerial level with extensive experience in the operation and maintenance of mechanical systems. While an individual with environmental expertise is a welcome addition to the response team, in our experience this individual does not play a pivotal role in indoor air quality investigations.

Use of internal personnel is advantageous for reasons other than the fact that such resources are capable of solving most indoor air quality problems at apparently significant cost savings to the building owner. In-house personnel are motivated to respond swiftly and to solve the problem without delay. Market forces, i.e., a distressed tenant who could move elsewhere if grievances go unaddressed, dictate no other than decisive action.

Building staff themselves do not appear to be the best investigators. After all, in our case studies, effective action was taken by building staff in just one instance prior to the arrival of the response team. Although the reasons remain unclear without further study, it appears that both a lack of proper training and the perception that indoor air quality complaints are not serious concerns are major contributing factors to ineffective building staff response.

Our work appears to underscore the need for such training, as well as more in-depth instruction and training in the operation and maintenance of mechanical systems.

The case studies further point out the need for close supervision of mechanical system cleaning contractors and contractors servicing building HVAC systems and for thorough inspection of air distribution systems in spaces undergoing renovation. Finally, it is also clear that tenant-induced activities, most commonly introduction of heat-generating equipment and overcrowding, carry the potential both for causing and/or aggravating indoor air quality problems.

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