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Reaching agreements on indoor air quality

Engineers, tenants and building owners/managers can cause or prevent indoor air quality problems

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The phrases "sick building syndrome" and "indoor air quality" (IAQ) are in common use today because of a heightened public awareness of various environmental issues.

IAQ complaints must be diplomatically resolved because employers and building owners and managers now face a potential impact on their bottom-lines.

To all employers, this impact can be expressed in terms of lost productivity because of alleged or obvious ill-health effects developed from an employee's exposure to compromised air quality. A decrease in productivity can quickly translate into lost revenue. It can also raise the question: Who is responsible for the specific IAQ problem?

In office buildings, with an owner/tenant relationship instead of an employer/employee relationship, the question of responsibility goes unanswered for lack of regulation. Often, the only solution left to the IAQ problem separates the relationship.

This author recently completed a series of IAQ investigations in a typical office environment. The tenant leased the second and third floors of a six-story waterfront office building. The tenant's office space was approximately 8,000 ft^2 (743 m^2) on each floor level.

The office's IAQ was first questioned when 12 of the 47 employees reported complaints particular to the time they spent in the office building. Three employees were so severely affected, they developed respective cases of rhinitis, conjunctivitis and sinus infection.

When the tenant presented this information to the building owner, he was told that there was *not* an IAQ problem within the building.

This article summarizes an unfortunate, yet typical, aspect of IAQ problems. It also offers a more efficient method for evaluating and resolving *all* IAQ problems.

Case study background

The tenant had recently moved from an office building about one mile inland that was much older, had operable windows and no problems with air quality. The new office building was recently constructed, had inoperable windows and was located between a busy harbor and an often congested interstate highway.

Shortly after occupancy, the reports of ill-health effects began. These reported effects included drowsiness, headache, sneezing, sinus and upper respiratory irritation, and congestion. These symptoms soon intensified to include rhinitis, conjunctivitis and sinus infection, among the three employees referenced earlier.

These symptoms were evident by late morning on typical Mondays, and increased throughout the work week. The most severe effects appeared to be specific for occupants whose offices were located along the south side of the building.

All of the affected employees noted remarkable health improvements immediately upon leaving the building. This healthy feeling continued for as long as the employees remained away from the building.

IAQ investigations

The tenant requested that an IAQ survey be conducted in July, 1990, to provide a "snapshot" picture that was representative of the building's IAQ on a given

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summer day. Instantaneous measurements were obtained for carbon dioxide (CO_2), carbon monoxide (CO), respirable suspended particulates (RSP), temperature and relative humidity, as noted in *Table 1.*

Formaldehyde and bioaerosol tests were also conducted to evaluate their potential relation to the ill-health effects noted.

The building is conditioned using parallel fan powered variable air volume (VAV) boxes with reheat coils. On each floor, there are 17 fan powered boxes for the perimeter and four cooling-only boxes (no reheat coils internal) for the interior.

Few filters were located in the fan powered boxes, and the overall system filtration was 30/30.

Outdoor biological samples (taken at street level) measured 400 and 250 colony forming units per cubic meter (cfu/m^3) for bacteria and yeasts/molds, respectively. Along the south side of the office interior, the concentration range was 190 to 260 cfu/m^3 for bacteria, and no growth was detectable for the yeasts/molds category.

These samples were collected by drawing 60 L (2 ft^3) of room air across an agar surface. The samples were then cultivated for 10 days.

The formaldehyde test results were highest along the south side of the interior at 0.09 to 0.11 ppm. These samples were collected using passive samplers. (The ASHRAE guideline is 0.10 ppm.)

Based on these data, both the relative humidity and the formaldehyde were suspicious. Given this information, the building owner told the tenant that, despite the ill-health effects noted, more information was necessary to justify a building IAQ concern.

A second investigation was then scheduled in October 1990 to visually inspect the office, mechanical areas and air plenums for evidence of HVAC modifications or operational obstructions, and to look for contaminant sources. Following this inspection, continuous air monitoring was conducted for carbon dioxide and carbon monoxide.

The inspection uncovered such gross negligence as lack of filters, miswired smoke removal equipment and fungal growth in condensate pans. It was also noted that cigarette smoking was a common employee activity, throughout the continuous hours of the testing.

Cigarette smoking is negligent for IAQ because it can contribute a significant amount of both formaldehyde and carbon monoxide, as well as noxious odors and particulates. No other significant sources of formaldehyde were found within the office area.

Accordingly, it was recommended that smoking be banned for a two-week period. After that, the formaldehyde and carbon monoxide concentrations would be evaluated again.

As a next step, interviews were conducted with 11 affected employees. The questions asked included: opinion of air quality, specific irritations, length of ill-health episodes, reaction time from irritation to ill-health effect, personal health condition, history of ill health during the last six months, any current medications, similar effects when away from work, and level of activity.

The collective responses clearly communicated the opinion that the air was stagnant and smoky in addition to the ill-health effects noted.

Table 1. Averaged Results of Preliminary IAQ Investigation[1]

Location	Time	CO_2 (ppm)	CO^2 (ppm)	RSP (mg/m^3)	Temp. (°)	RH (%)
Outside Building	Mid-morning	325	2	0.23	74	92
South-west corner office		625	2	0.05	72	66
South side office		575	2	0.03	73	60
South side office		575	2	0.03	73	63
South-east corner office		600	2	0.02	75	56
Outside Building	Mid-afternoon	350	1	0.79	77	87
South-west corner office		750	2	0.03	70	71
South side office		700	2	0.03	73	62
South side office		700	2	0.02	72	63
South-east corner office		650	2	0.01	76	63

1. Conducted in July 1990.
2. CO was measured at 3 ppm in the central area of the third floor where several employees were smoking.

For political reasons, only one week could be arranged as a no-smoking period. By the end of this week, formaldehyde and carbon monoxide concentrations had decreased in most areas, but remained unchanged along the south side of the office interior. Carbon monoxide, previously measured at 3 ppm during typical smoking activity, measured less than 2 ppm throughout the third floor.

At this time, the building owner conducted some limited maintenance activities. Formaldehyde tests taken after this work found no significant change in the test results.

Summary of investigations

To briefly summarize the information gathered during this investigation:

- Cigarette smoking may be contributing to the adverse health effects noted.
- Improper maintenance of the HVAC system components may be contributing to the accumulation of contaminants within the HVAC system and plenums.
- Ventilation effectiveness should be evaluated to determine the best performance capacity of the HVAC system.

Following the one week of smoking cessation, cigarette smoking resumed in the office in January 1991, but tenant emphasis continued on HVAC system inadequacy and formaldehyde levels. To more closely evaluate HVAC system performance, the tenant retained an HVAC engineering consultant.

The consultant found that the minimum setting for outside air was less than 5 cfm/person (cfm/pp) during the winter. This number was achieved by evaluating HVAC system characteristics and air temperatures. The building owner had previously represented this value to be greater than 20 cfm/pp, throughout the year.

To evaluate other possible reasons for the ill-health effects noted, a scanning for 34 common volatile organic compounds (VOCs) was conducted. The sampling results revealed no significant concentrations of VOCs in the boiling point range of −15° to 200°C (5° to 392°F). This testing was done using EPA methods T-01 and T-02.

Additional formaldehyde sampling was conducted (in May 1991) in the HVAC supply and return air ducting systems at the mechanical room and terminal points. For increased accuracy, formaldehyde sampling techniques were conducted following NIOSH method 3500.

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The results of this testing showed no significant concentrations of formaldehyde in either ducting system. The formaldehyde concentration in the outside air at this time was measured at 0.015 ppm.

At this time, the building owner conducted necessary maintenance work (rewiring) to make the smoke removal equipment operational. The HVAC system's operation was also adjusted to approximate the guidelines of *ASHRAE Standard 62-1989*.[1]

Formaldehyde measurements were taken again (in August 1991) and were now found to range from 0.02 to 0.05 ppm along the south side of the office interior prior to HVAC system operation. After two hours of operation, the levels were 0.02 to 0.03 ppm in the same test areas. Formaldehyde in the outside air was measured at 0.010 ppm.

Based on the presence of a formaldehyde concentration indoors, the tenant decided to pay for the installation of a dry process carbon composite (DPCC) filtration[2] system to remove formaldehyde below detection. This system was installed in May 1992.

Additionally, a smoking lounge was constructed to control smoking activity. This lounge was constructed following the guidelines of *ASHRAE Standard 62*.

Follow-up formaldehyde testing (in June 1992) in the office space found concentrations of less than 0.002 to 0.008 ppm. The client was at last satisfied with these results.

Discussion

Each party held some responsibility for the IAQ problem in this office building. The tenant should make some provision to control cigarette smoke and the building owner should ensure regular maintenance of the HVAC system.

Unfortunately, the responsibility was passed back and forth for nearly two years before the problem took a *proactive* direction. This is the perspective of preventative maintenance.

The measurable impact that the *reactive* perspective had on the bottomline is presented in the lefthand column of *Table 2*.

The building owner's insensitive attitude can involve an interesting progression of political detail as well as unnecessary expense. For example, the total cost to restore proper IAQ was $45,000 in consultation fees. Of this amount, the tenant paid $36,000 (*plus* medical fees for employee sensitivity evaluations) and the building owner paid about $9,000.

These figures are further compounded by the productivity losses of affected employees. Of course, productivity is a subjective parameter, but sufficient information is available to assist an evaluation.[3,4,5,6,7] A productivity example is given in *Table 3*.

For the two years of this building's IAQ problem, the productivity value lost could well have approached $66,000, based on:

11 employees × $30,000/yr-employee × 10% productivity loss × 2 years

In contrast, a very thorough IAQ evaluation can typically be conducted for under $5,000. This is less than 10% of the total cost expended in the example.

Recommendations

The observations and conclusions developed during the IAQ evaluations resulted in recommendations for both parties. The tenant should eliminate cigarette smoking in the office, or provide a smoking lounge that directly exhausts air to the outside.

For the building owner, there were two general recommendations:

- Evaluate the HVAC system's operation. Bring the system into compliance with the minimum criteria established in *ASHRAE Standard 62-1989*. Measure the ventilation efficiency and balance of the HVAC system.
- Because of the accumulation of biological growth on the HVAC coil surfaces,

Table 2. Analysis of Problem and Mitigation Methodology

$K	Phase	Tenant		Building Owner/Manager	
		Reaction	Action	Reaction	Action
2	I	Employee complaints	Building tested. Test results are within current guidelines, HCHO and CO are elevated.	Decides there is no problem.	Further information is required to warrant action.
8	II		Detailed analysis is conducted. Results find both parties at fault as source generators (e.g., poor maintenance and cigarette smoking in office).	Contests tenant is greater source.	Excuses for maintenance. Will rectify in time. Retains IAQ and engineering consultants for defense.
					Building owner agrees to perform maintenance activities but secretly does nothing.
20	III	Tenant effects a non-smoking policy for one week	Additional HCHO and CO tests are conducted. HCHO results are not largely affected, but CO results drop significantly.		
			Based on HCHO results, tenant points to HVAC inadequacy, hires an EC and inadequacy is confirmed.		Operational adjustments are made and a thorough review of system maintenance is done. However, system is only marginally adjusted.
3	IV	Complaints continue	More HCHO sampling is done with assumption system has been properly balanced. HCHO results are unchanged.		Building owner modifies HVAC systems beyond EC recommendations. System is put on 100% outside air in violation of state energy code.
2	V		More HCHO sampling. Test results are lower by about 20%.		Selects system.
4	VI	Complaints continue	Installation of DPCC system.		
6	VII		Follow-up testing. Test results are lower by factor of 10.		

Table 3. Productivity Perspective[1]

Assume: 1. An average office space is 7,500 ft^2, and contains 28 employees (BOMA).
2. Average maintenance costs are \$8.31/SF-year of office space (BOMA). Energy costs average \$1/SF-year—just for the conditioning of outside air in temperate zones (J. Ventresca).
3. 20% of the occupants in 20% of the US office buildings are 10% unproductive (S. Rosenfeld).
4. Average salary/employee is \$30,000/year.

Example: Value of productivity lost in \$/year and per day:
= (28 employees) × (0.20 affected) × (0.10 productivity loss) × (30,000\$/employee-year).
= \$16,800/year affected revenue for 5.6 employees (20% of 28).
= \$67.2/day for 5.6 employees "on the job." 10% less productive.
= \$672 if all 5.6 employees miss work *one day* (out of 250 days/year) due to poor IAQ.

Example: Energy costs at \$1/SF for outside air = \$7,500 per year (typical office).
\$7,500 = 44% of the potential affected revenues/year (\$16,800).
\$7,500 = \$30/day (250 operational days/year) ≅ 1/2 the productivity impact of affected workers on the job (\$67.2) at the risk of encouraging a sick day of greater financial impact.

1. Using references 3 through 7.

review current HVAC maintenance practices, identify deficiencies and implement corrective action where warranted.

IAQ engineers have an ethical responsibility to quickly resolve IAQ problems, and these problems can be efficiently resolved, often without excessive expense. If a *proactive* approach had been taken from the start, the costs in this example could have been dramatically reduced.

One may encounter the lack of published literature and regulatory requirements as a defense shield. Furthermore, energy costs may be used as a reason for limited outside air.

From the productivity perspective cited in *Table 3*, the annual cost to condition the outside air for one employee is \$267 per year (\$1 per $ft^2 \times 267$ ft^2 per employee). This is less than the value of productivity lost if that employee is only 1% unproductive:

$$\$30{,}000 \times 0.01 = \$300.$$

Therefore, if an employee is affected, energy and HVAC design parameters should be thoroughly evaluated. OSHA regulations specifically state that employers *must* provide a safe and healthy work environment, in general, for their employees.[8] These regulations work well in employer/employee relationships.

In building owner/tenant relationships, where there may appear to be a lesser responsibility, there is also a connection to the *intent* of the OSHA regulations.[9] Regulatory authority looks to find the negligent party.

Regarding physical capacity, office HVAC systems are not designed for pollutant removal. Reliance on them for this purpose overlooks the comfort parameters of their design. As comfort systems, only a certain efficiency in the dilution of IAQ parameters can be expected.[10] Compliance with *ASHRAE Standard 62-1989* is approximately this point of efficiency for most HVAC systems.[6]

Simple regular system maintenance is a central theme of building management.[11,12] However, as simple as this advice may be, it often goes unheeded because of the current economic climate and corporate budget constraints. Unfortunately, maintenance is often appreciated more by the facilities engineer than by the building manager.

Furthermore, HVAC system balancing is often purposely not conducted during a building's construction to make the project appear to come in under budget. Such tactics during construction as well as budget constraints and insensitive attitudes years later encourage poor HVAC system maintenance and its inevitable degradation. IAQ problems are typically the end-result of this.

The strongest point herein is that the emphasis, throughout the office building example, was *reactive* rather than *proactive*. Again, the financial impact of this attitude is shown in the lefthand column of *Table 2*.

Facility managers of successful corporations understand the proactive management strategy very well. Accordingly, they receive little interference with their success.

Efficient problem resolution begins with a team of qualified professionals including the building owner/manager or facility engineer, and the IAQ consultant. The IAQ consultant should preferably have an HVAC engineering background to facilitate efficient communication.

Recommended methodology

The following proactive methodology is designed to efficiently resolve problems with the least impact on either party's bottom-line. The methodology is applicable whether or not an IAQ problem has been expressed:

• Conduct via objective medical questionnaires an evaluation of the occupants' perception of the indoor air quality, especially those occupants who have complained. Pay particular attention to the most common responses (e.g., cigarette smoking has an offensive odor and may be the cause).

• Review HVAC system blueprints and design criteria (as-built drawings are preferable to design drawings). Modified use of systems designed for other criteria can be the cause of the problem.

• Physically inspect the maintenance of each HVAC system component (outside air dampers, control valves, filter banks, condensate pans, etc.) and the air distribution path (outside building, inside building air plenums, obstructions below and above the ceiling). Clean if necessary. If biological growth is noted, contact a qualified microbiologist who can identify the organism and specify appropriate treatment.

• Evaluate HVAC system performance, minimum control settings and their effects on the system (e.g., at minimum variable air volume demand, how much outside air is brought in and what is the occupancy at that time). Test and balance data should be updated every five years.

• If the above actions do not uncover any inconsistencies, the air *quality* (as defined by *ASHRAE Standard 62-1989*) should be tested to provide further information. When testing the air, be sure to evaluate the HVAC system's performance and the outside air conditions and quality at the same time as indoor testing.

VAV systems are typically designed for maximum cooling load capacity. However, for IAQ control, VAV systems must be sized for *minimum* capacity as well. Additional thought should be given to likely air flow patterns as well. This places the burden on the HVAC designer to specify variable frequency fan drives or other controls to modulate fan speeds effectively.

Conclusion

A building in compliance with *ASHRAE Standard 62-1989* has few, if any, IAQ problems because the building receives adequate outside air even at minimum internal demands.

While we await the necessary research regarding low-level exposure risks to indoor air contaminants (formaldehyde, carbon monoxide and VOCs), prudent HVAC system selection, maintenance and evaluation provide an unwritten insurance policy for the building owner and HVAC system designer. ■

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