process, KEFA has decided to market the same paint under the name KEFA Airless. As such, KEFA emphasizes the structural composition of the paint product: "KEFA Airless contains an enormous number of micropores, giving it an extremely large surface area. Due to its high permeability, condensing or penetrating moisture is adsorbed by the micropore system and spread over the surface area, from where it can quickly evaporate." The biocides in KEFA Airless are now considered by the manufacturer as "in-can" preservatives. "The difference," as Bellinger summarized, "is semantic."

Approximately "99% of the market" for KEFA Airless consists of agricultural applications. Other uses of KEFA Airless, such as duct-work applications, are in preliminary marketing stages. Usage of the product for general commercial applications, however, is unlikely due to cost considerations. According to Bellinger, KEFA Airless "costs about 50 cents a square foot; we don't expect people to buy at these prices during recessionary times."

One concern regarding biocide-containing paints is that they may eliminate one hazard from the indoor environment only to replace it with a new one — the potential for biocide emissions. They may not be necessary for the majority of applications. Asked how he would advise a building manager regarding the use of biocide-containing paints, the EPA's Grable said, "Don't bother; mildew is not a problem except in areas where you have a lot of water, such as bathroom tiles." Cleaners, he added, are appropriate for these situations.

Not surprisingly, manufacturers view the situation in a different light. Collier told ***IAQU*** that, "To date, about 100 commercial buildings have PorterSept on some interior surfaces.... The use of PorterSept is appropriate for any surface where microbial contamination or degradation is a concern." An article in *Engineered Systems* examined the treatment of Cowgill Hall at the Virginia Polytechnic Institute, where PorterSept was applied after an investigation of IAQ problems. According to authors Wallace Rhodes and Y.O. Gilyard, the reduction of bioaerosols "can be attributed to the application of a liquid coating containing an antimicrobial agent. Numerous other buildings have been similarly treated with the same positive beneficial results."

Does it make sense to use biocide-containing paints for IAQ maintenance? Answers to this question should predominately come on a case by case basis. Although some evidence points toward the efficacy of biocide-containing paints, numerous factors must be taken into account: Does microbial contamination currently pose a significant problem? Is the added protection worth the added cost? Could the biocide-containing paint lead to other problems? Anybody considering the application of biocide-containing paints should thoroughly investigate how such products would work in any given indoor environment.

For More Information

Donald Collier, PorterPaints, 400 South 13th Street, Louisville, KY 40203, USA; (502) 588-9285, Fax: (502) 588-9316.

Thomas Bellinger, KEFA Hightech Corporation, 4501 Rowlett Road, Suite #107, Rowlett, TX 75088, USA; (214) 412-3606, Fax: (415) 987-5432.

Carl Grable, US EPA Registration Division; (703) 305-7392.

CASE STUDY

*In each issue **IAQU** presents a case study on an investigation of indoor air problems in a particular building. The editorial staff relies on information provided by the environmental consultants involved in the investigation. **IAQU** presents a variety of approaches to investigation and mitigation implemented by consultants with a broad range of experience, philosophies, and expertise. Inclusion of a particular case study in the newsletter does not imply **IAQU**'s endorsement of the investigative procedures, analysis, or mitigation techniques employed in the case. **IAQU** invites readers to submit comments, suggestions, and questions concerning any case. At the discretion of the editors, correspondence may be presented in a future issue.*

Investigating SBS in an Office-Library Building

The following case study, presented anonymously at the request of the consultants and clients involved, describes a thorough investigation into the causes of the large number of complaints about varied health symptoms and "stuffiness" of the air in an eight-story Canadian office building. Two previous studies failed to shed any light on the source of the complaints. According to the environmental consultants, the variety of symptoms described and the failures of two previous studies to identify a cause was typical of "sick building syndrome" (SBS). The more thorough investigation and subsequent remediation resulted in a successful elimination of occupant complaints.

Building Description

The lower four floors of the eight-story building contain offices and the remaining four floors house library stacks. Each of the lower three floors contains about 51,667 sq. ft. of floor space and each of the upper five floors contains about 25,833 sq. ft. of floor space. The second and third floors contain a number of individual offices, while the rest of the floor plan is fairly open. A central core area houses two passenger elevators and stairwells, service shafts, washrooms, and several small sitting rooms. A strictly enforced building policy restricts smoking to a single room on the first floor with a separate ventilation system. The sixth floor contains six photocopying machines that are in nearly continuous use between 9 a.m. and 4 p.m. and are vented into the floor space.

HVAC System Description

The building has nine air-conditioning systems to provide continuous air conditioning in all eight stories. Systems 1 and 2 are all-air, two-deck systems that serve floors four through seven. System 3 serves the central core area and the third floor as a 100% outdoor air supply-only system. Systems 1-3 have outdoor air intake and exhaust air openings in the north and south walls of the mechanical room, which is directly above the seventh floor. Systems 3, 4, and 8 serve the ground through the third floor. Systems 5, 6, 7, and 9 serve the ground, first, and second floors. Systems 6 and 9 are induction systems that serve the perimeter wall area. Systems 4, 5, 7, and 8 are all-air, two-deck systems serving the interior area between the central core and the perimeter wall. The outdoor air supply for the six systems serving the lower four floors comes from four intake shafts outside the building beside the north and south walls.

Presenting Problem/History of Complaints

Since 1981, occupants and users of the library and office facilities had complained of a variety of symptoms, including eye irritation, headaches, prolonged allergic reactions, and general decline in health. Many of the occupants complained about air "stuffiness." According to building managers, the largest number of complaints came from occupants on the first and sixth floors.

Previous Investigations

Building managers requested a pilot investigation after occupants first reported symptoms in 1981. In this two-week study, involving only the ground, second, and third floors, investigators found the levels of carbon dioxide (CO_2), carbon monoxide (CO), ozone (O_3), and total suspended particles to be within limits recommended by ASHRAE Standard 62-1981. Since the investigation failed to identify any causal agents, the building managers did not implement any remediation measures.

After a second rash of complaints in 1986, building managers ordered a second investigation, which included measurements of total volatile organic compounds (TVOCs) and fungal spores, in addition to the contaminants that the investigators measured in the 1981 study. This investigation revealed that levels of TVOCs from the exhaust gas of the liquid toner/transfer process photocopiers exceeded recommended levels. Since this investigation was not extensive enough for the investigators to rule out other possible causes of health effects, building managers requested a more thorough investigation.

Current Investigative Focus

A study team consisting of an engineer, an HVAC technician, and several industrial hygienists conducted a more thorough investigation of the suspected SBS problems between March 1987 and August 1988. The study team developed an investigation plan that consisted of:

- Administering an occupant survey using the National Institute of Occupational Safety and Health (NIOSH) IAQ Questionnaire;
- Reviewing the building and HVAC designs;
- Inspecting the building for potential contamination sources and obvious HVAC system misuse or design flaws;
- Measuring air exchange rates with a tracer gas sampling system;

- Measuring air distribution and thermal comfort;
- Identifying and measuring contaminants (chemical, particulate, and bioaerosol);
- Establishing the relationship between contaminant concentrations and air exchange rates;
- Developing a contaminant removal or reduction strategy; and
- Determining the amount of outdoor air required to maintain contaminant concentrations below levels set forth in ASHRAE Standard 62-1989.

Testing Results and Findings

HVAC Investigation

The HVAC inspectors employed a sulfur hexafluoride (SF_6) tracer gas analysis to determine air change rates, air distribution patterns, and levels of exhaust air reentrainment (see Figure 2).

The tracer gas analysis revealed that air change rates varied between 0.4 and 0.6 air changes per hour (ach), which the investigators concluded was common for buildings with complex layouts that experience imperfect air mixing. Even the lower value of 0.4 ach, which is equivalent to 39 cubic feet per minute (cfm) per occupant, exceeded the ASHRAE ventilation requirement of 20 cfm per occupant in an office building. After injecting SF_6 at a point source and sampling at the main return air ducts on each floor and several additional locations throughout the building, the investigators found that airborne contaminants would spread rapidly through the area served by one HVAC system and throughout the rest of the building within 80 minutes. The analysis also showed minimal reentrainment of exhaust air.

The inspectors conducted visual inspections of the HVAC systems and employed smoke pencil tests to determine the flow directions of outdoor air supplies when the dampers were opened to different degrees. The HVAC inspectors concluded that the building was not receiving a sufficient supply of outdoor air as a result of:

- Large numbers of bends coupled with oversized return air dampers and return air fans in the outdoor air supply ducts serving the first four floors;
- Blockage of outdoor air supply for system 8 when the dampers were in partially closed positions (even at 75% open position); and
- Blocked airflow from system 4 air supply registers due to a closed fire damper.

The investigative team found equally high levels of microbial contaminants in the return air and air downstream from the outdoor damper, which they concluded was consistent with the lack of outdoor air entering the system.

The investigators took spot readings of relative humidity, air velocity, and dry-bulb and radiant temperatures recorded at 2.75, 29.5, and 73 inches above floor level during the winter. In two locations the investigators found thermal comfort conditions outside those specified by ASHRAE standards for persons performing light, sedentary tasks under winter conditions. These areas were too warm (over 79°F) and drafty (air velocities over 14 inches/second). In several locations with large windows and skylights, the investigators also recorded excessive temperatures, and they concluded that the HVAC systems could not handle the additional solar load. Additionally, relative humidity levels in three high-complaint areas on the first floor ranged from 17%-21%, well below Health and Welfare Canada (HWC) standards.

Airborne Chemical Contaminant Testing

The industrial hygienists monitored levels of CO, CO_2, nitrogen dioxide (NO_2), TVOCs, formaldehyde (HCHO), and settled and suspended particulates and compared measured levels to the appropriate relevant national and international guidelines (Figure 3). HWC specifies two sets of national guidelines for exposure to contaminants. It defines "ALTER" as the concentration to which research indicates a person can be exposed over a lifetime without undue risk to health. "ASTER" represents the corresponding short-term exposure limit.

Three-month infrared monitoring of CO levels revealed indoor levels varying from one to seven parts per million (ppm) and background outdoor concentrations of one to three ppm. The investigators noted that these levels were well within the ALTER limit of eleven ppm for eight hours of exposure.

To determine CO_2 concentrations, the investigators took infrared measurements through PVC tubing connected to an automated system containing 16 sampling pumps, a data logger, and a microcomputer. They took one-week samples under four different HVAC operating modes:

Figure 2 — HVAC Investigation

Assessment Target	Testing Method	Sampling Method	Results	Comments
Air Change Rates	tracer gas decay using sulfur hexafluoride (SF_6) and gas chromatograph/ electron capture detector	automated system collected samples from return ducts on each floor; pumped via 4.8-mm diameter plastic tubing to gas chromatograph; manual samples at 10-min. intervals from two locations per floor; second set via manifolded system which mixed air from east and west return ducts on each floor	varied between 0.4 and 0.6 ach	variation in air change rates common for buildings with complex layouts and imperfect mixing; even lower value of 0.4 ach (39 cfm per occupant) exceeded ASHRAE office building ventilation requirement of 20 cfm per occupant
Air Distribution	injection of small amount of SF_6 at point source	automated and manual sampling at 10-min. intervals from: main return ducts on each floor; eight locations on floors one and two; and four locations on floors three through six	tracer gas spread quickly within area served by HVAC system 9 and to other zones within 80 minutes	any airborne contaminant would quickly spread throughout the building within 80 minutes
Reentrainment of Exhaust Air	injection of SF_6 into exhaust system	sampling by syringe/test tube technique at outdoor air intakes of each HVAC system	minimal re-entry of exhaust air	
Installation and Operational Problems with HVAC Systems	visual inspections; smoke pencil tests to determine flow of outdoor air at different damper settings	HVAC inspectors noted too many bends in outdoor air supply ducts for systems serving floors one through four; system 8 supply air duct 8 brought in no fresh air when the damper was partially closed; very low airflow rates from several system 4 supply air registers due to closed fire damper	equally high levels of microbial contaminants in the return air and air downstream from outdoor damper consistent with lack of fresh air entering system; lack of system 8 fresh air intake ducts and several other ducts result of high fluid resistance in supply air duct, oversized return air damper, and overly powerful return air fan	
Thermal Comfort	spot readings of relative humidity, air velocity, and dry-bulb and radiant temperatures recorded at 2.75 in, 29.5 in, and 73 in above floor level	conditions in two locations on floor two outside comfort range specified by ASHRAE standards for persons performing light, sedentary activities under winter conditions by being too warm (over 79°F) and drafty (air velocities over 14 in/s); relative humidities ranged from 17%-21% (well below HWC guidelines) in three high-complaint areas of floor one; locations with large windows/skylights had uncomfortably high temperatures	insufficiencies in HVAC systems, particularly with large solar loads from windows/skylights	

Key: cfm = cubic feet per minute; HWC = Health and Welfare Canada; ach = air changes per hour; in/s = inches per second.

Figure 3 — IAQ Assessment

Contaminant	Measurement Technique	Accuracy	Measurement Locations	Results	Comments
carbon monoxide (CO)	three-month monitoring with infrared detector	range: 0-100 ppm; precision: 1% full scale	return duct and near center of occupied area on floors one through seven; on ground floor from return duct only; one outside background sample near roof	indoor concentrations varied from 1-7 ppm; outdoor concentrations varied from 1-3 ppm	within HWC ALTER limit of 11 ppm for eight-hour exposure
carbon dioxide (CO_2)	infrared detector in automated system with 16 sampling pumps, 2 detectors, data logger, and microcomputer; samples through PVC tubes; one-week tests under four HVAC operating modes: • outside air dampers at 100% open (2.8 ach); • dampers set at 75% open (1.9 ach); • automatic mode adjusting to outside temp. (0.9 ach); • all dampers set at minimum open position	range: 0-5,000 ppm; precision: 1% full scale	at return duct and near center of occupied space on floors one through seven; near return duct on ground floor; one outside background sample near roof	levels ranged from 340-440 ppm; 0.8-1.0 ach	building met both 1,000 ppm ASHRAE standard and 3,500 ppm HWC ALTER; occupant complaints increased with CO_2 level especially above 520 ppm
nitrogen dioxide (NO_2)	chemiluminescent detector; one-month continuous monitoring	range: 0-1 ppm; precision: 2.5 ppb	floor one complaint area served by HVAC system 8; at system 8 outdoor air intake, near shipping/ receiving dock	less than 0.04 ppm	within HWC ASTER limit of 0.25 ppm (one-hour avg.) and ALTER limit of 0.05 ppm
total volatile organic compounds (TVOCs)	continuous indirect monitoring of total hydrocarbon concentrations by flame ionization detector	range: 0-100 ppm; precision: 1% full scale	floor six photocopying area; return ducts of HVAC systems 2 and 8	3-68 mg/m^3 for floor six photocopying area; 3-11 mg/m^3 for library stacks; 1-2 mg/m^3 for office floors; 0.8-1.0 ach	no HWC TVOC acceptable exposure range; reduce VOC exposure by eliminating sources or installing supplementary exhaust systems
formaldehyde (HCHO)	passive dosimeters with absorbent 1% sodium bisulfite solution five days; analyzed by modified chromotropic acid method; seven-hour monitoring with midget sodium bisulfite impingers		book-binding room; mechanical room; cataloging area; floor one complaint area; receiving office; printing office; conference rooms; library stacks	exceeded 0.025 ppm (as high as 0.046 ppm) at three locations during automatic HVAC mode; highest levels at floor six photocopying area; outdoor levels of 0.031 ppm (due to exterior painting/caulking)	no correlation between observed formaldehyde levels and air change rates. levels within 0.10 ppm WHO guideline and 0.05 ppm HWC ALTER limit

Note: Health and Welfare Canada (HWC) specifies two sets of guidelines for exposure to contaminants. HWC defines "ALTER" as the concentration to which research indicates a person can be exposed over a lifetime without undue risk. "ASTER" is the concentration to which research indicates a person may be exposed over a short time period without undue risk.

Key: ach = air changes per hour; WHO = World Health Organization; RSP = respirable suspended particles; ppm = parts per million levels were similar during the winter, and that levels inside HVAC systems were elevated in water spray units (10,600 cfu/m^3). Though the bioaerosol levels were generally low, the consultants recommended the removal of indoor sources. Analysis of the liquids in the HVAC water sprayer systems for endotoxin contamination showed elevated levels in the reservoirs of systems 1, 3, 8, and 9 (the latter with 6,000 endotoxin units/milliliter). There are no established guidelines for endotoxin levels.

Sampling for settled particulates by tweezers and transparent adhesive tape and eight-week sampling on glycerine-coated microscope slides showed extremely low levels of plant pollens, fungal spores and hyphae fragments, bird fibers, and plant fragments.

Conclusions

The investigative team concluded that, in general, the office/library building did not have abnormally high concentrations of CO, CO_2, NO_2, formaldehyde, suspended particulates, or fungal spores. Additionally, they found the air supply and distribution rate to be acceptable.

The investigators did, however, detect a number of deficiencies in the HVAC system that may have been causing the reported symptoms on the first and sixth floors. Specifically, the HVAC investigation revealed that on the first floor:

- Relative humidity levels were well below guidelines set by HWC;
- Temperatures were outside ASHRAE comfort zone standards; and
- Very little outdoor air was reaching the area.

Investigation of the sixth floor revealed:

- Consistently high concentrations of TVOCs; and
- Increasing the outdoor air supply to the whole building did not substantially reduce TVOC levels.

Recommendations

Based on their 18-month study, the investigators concluded that the most likely causes of the health and comfort complaints from first floor occupants were the lack of outdoor air supply through the HVAC system and unsatisfactory thermal conditions. The investigators found that sixth floor occupants were most likely experiencing similar ventilation insufficiencies complicated by the elevated VOC levels from the photocopying equipment.

To improve ventilation and reduce airborne contaminants in these high-complaint areas, the investigators recommended that the building managers:

- Balance the airflows of the main supply and return air fans for all systems serving the first and sixth floors;
- Install an outdoor air supply fan on both floors; and
- Install separate exhaust air systems for photocopying equipment.

According to the investigators, ventilation insufficiencies, unsatisfactory thermal comfort conditions, and elevated bioaerosol levels from contaminated HVAC water reservoirs indicated the need for a remedial plan that would improve the IAQ throughout the rest of the building as well. The investigation team therefore recommended to the building managers the following remedial measures:

- Check and adjust all thermostats and humidistats;
- Install shades for skylights;
- Clean and disinfect all water spray systems;
- Conduct a general housecleaning in the building; and
- Periodically check all HVAC systems for unintentionally closed dampers.

The consultants additionally recommended that building managers develop and implement a new preventive maintenance program to reduce or eliminate the potential for future IAQ problems.

Followup

The investigators report that in the two years since the building managers implemented the majority of the recommended remedial measures, there have been no further health or comfort complaints from building occupants and users.

Preventive Maintenance Programs Could Reduce Incidence of SBS

Investigations into SBS often do not turn up unusually high levels of airborne contaminants, leaving investigators with no particular source to point to. Further investigation, however, often reveals various inadequacies of the HVAC systems in the affected building. In many cases HVAC systems are not properly maintained or are not being used in a manner that would provide sufficient fresh air, particularly to handle the increased loads of contaminants such as

VOCs from photocopying equipment. While the levels of chemical or microbial contaminants from sources within the building may not be high enough to exceed recommended guideline limits, they can nonetheless cause irritation in susceptible individuals. Combined with sensations of air stuffiness and unsatisfactory thermal conditions, such irritation may lead to increased reports of adverse health effects.

In the experience of many consultants, improvements in ventilation effectiveness, often feasible by merely bringing existing HVAC systems into the maximum operational state for which they were originally designed, can dramatically reduce the incidence of building-related complaints. Improper or nonexistent maintenance programs and the operation of HVAC systems with restricted or closed outdoor air dampers are often at the root of HVAC-related IAQ problems. [See ***IAQU***, February 1991, for a more thorough discussion.]

The consultants involved in this case advocate the development and implementation of a preventive maintenance program for large office buildings to reduce the incidence of SBS. From a building manager's or owner's perspective, the expense of a well-designed maintenance program may well be less than the cost of future IAQ investigations and potential work loss from employees who suffer from adverse health effects.

For More Information

Dr. C.Y. Shaw, Building Performance Section, Institute for Research in Construction, National Research Council Canada, Ottawa, ON K1A 0R6, Canada; (613) 993-9702, Fax: (613) 954-3733.

Note: A more detailed writeup of this case study is slated to appear in *ASHRAE Transactions*.

NEWS AND ANALYSIS

EPA and Industry Wrap Up Carpet Policy Dialogue

On September 26, 1991, the US Environmental Protection Agency (EPA) entered into three nonregulatory Memoranda of Understanding (MOUs) with three carpet-related industry associations. The MOUs resulted from the Carpet Policy Dialogue (CPD) on total volatile organic compounds (TVOC) emissions, touted by the EPA as "a nonregulatory approach focusing on product stewardship through voluntary actions on the part of industry." Each MOU is based on consensus statements generated during May/June 1991, between industry, public, and governmental representatives.

The three MOUs included:

- An agreement with the Carpet Cushion Council, which will voluntarily conduct testing to determine TVOC emissions factors in carpets;
- An agreement with the Floor Covering Adhesive Manufacturers Committee, which will voluntarily develop an analytical test method for measuring TVOC emissions from adhesive products; and
- An agreement with the Styrene Butadiene Latex Manufacturers Council, which has voluntarily agreed to report data from its ongoing research on 4-phenylcyclohexene (4-PC).

These MOUs follow an MOU between the EPA and the Carpet and Rug Institute (CRI) in May 1991, which was based on a consensus statement issued in February 1991. This consensus statement pertained to the CRI's undertaking of "voluntary testing for TVOC emissions from new carpet products, establishment of a database for reporting periodic TVOC analysis for new carpet products, and communication of useful information about TVOC emissions from new carpet products."

CPD Results

CPD Coordinator Richard Leukroth told ***IAQU*** that the accomplishments of the CPD have been substantial. "The commitments made by the carpet industry during these proceedings have been far-reaching. For example, the CRI has gone beyond the commitment to conduct TVOC testing by agreeing to implement a Quality Assurance Certification Program." Concerning the role of the CPD in bringing the different industry groups together, Leukroth said that, "Although there had been some communication between the different carpet-related industries, the [CPD] encouraged the groups to work together in harmony. Getting these different industries to work together was in itself a significant accomplish-