studies or well-designed, blinded, and controlled experiments to better assess the impacts that ventilation rates between 10 l/s and 25 l/s per person have on occupants' health and air quality perceptions. "In addition ... we also need studies to specify the causative agents of adverse health outcomes. The most effective strategies to improve indoor air quality (e.g., source removal) cannot be specified before the agents and their sources are known."

Finally, since increasing ventilation may also use more energy, the reviewers suggest that it is important to identify practical ways to decrease ventilation requirements by reducing pollution emissions from building materials and systems. Alternatively, research teams could determine how ventilation could more effectively control pollutant exposures without boosting energy use.

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CASE STUDY

[In each issue, **IEQS** *presents a case study on an indoor air investigation in a particular building. The information in the cases comes from various sources, including published material, reports in the public record, and, in some cases, reports supplied by the consultants involved in the case.* **IEQS** *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* **IEQS***'s endorsement of the investigative procedures, analysis, or mitigation techniques employed in the case.* **IEQS** *invites readers to submit comments, suggestions, and questions concerning the case. At the discretion of the editors, correspondence may be presented in a future issue.]*

Diagnosing the Cause of a "Sick Building": An Epidemiological and Microbiological Investigation

Occupants of a large, modern office building had suffered prolonged illnesses, with no apparent explanation, since shortly after moving into the building. Their symptoms included irritated eyes; runny nose and sinus congestion; sore throat, cough, and shortness of breath; rashes; extreme fatigue; and difficulty with concentration and impaired short-term memory. Investigations by industrial hygienists and building maintenance staff detected no chemical contamination or functional ventilation problems. Typical air quality tests eliminated carbon monoxide (CO) and volatile organic compounds as possible causes. Baffled managers and industrial hygienists declared it a "sick building."

Sick building syndrome (SBS) occurs when a significant percentage of a building's occupants develop unexplained symptoms that involve several organ systems including the skin and respiratory and nervous systems. Traditionally, environmental investigators have sought causative factors, which include inadequate ventilation, organic vapors, asphyxiant gases (e.g., CO), and psychogenic dynamics — almost always without success. Published investigations of buildings have increasingly revealed mold contamination as the source of illnesses that produce the same clinical picture as SBS.

Building Description

This case involves a five-story state-government office building constructed in Nevada from 1992-1994. The sealed structure gets ventilation from eight roof-mounted air-handling units (AHUs). These AHUs contain the heating, ventilating, and air conditioning (HVAC) units and evaporative cooling components. They provide ventilation through some 250 variable air volume (VAV) boxes distributed throughout the building. Each VAV box contains a secondary heating coil unit with hot water supplied by a separate, treated water system. Return air passes through ceiling-mounted grills into a common plenum in each zone. Exhaust units expel the return air through rooftop vents that are more than 50 feet from the air intake units. Indoor humidity typically ranged from 40%-50% and temperatures ranged from 70°F-74°F. Outdoor humidity tended to be between 10% and 25%. Building managers used the evaporative cooling system with return air mixed with outdoor air in a 20:80 ratio during the summer when outdoor temperatures commonly exceeded 85°F. After occupant complaints

became chronic, building managers began to ventilate with 100% fresh air. The system provided minimum ventilation and air exchange overnight.

Epidemiological Survey

After two years during which occupants' symptoms continued unabated despite various attempts to address the problem, a physician-led team conducted researching including an epidemiological survey. With 86% of 650 building occupants responding, the survey revealed that nearly 25% of them had health complaints. A geographical breakdown of the general location of occupants who reported health symptoms revealed they were equally distributed by floor.

The 650 occupants present at the time received an anonymous survey designed to measure the types of symptoms, their prevalence, and their distribution. The occupants identified themselves only by age, gender, office location, number of hours worked, smoking habits, and the number of years worked in the building. Subjects who answered that they currently have or previously had health problems "related specifically to working in this building" were prompted to answer additional questions. These included questions designed to:

- Glean data about preexisting medical conditions (including allergic rhinitis and conjunctivitis, asthma, chronic bronchitis, recurrent or chronic sinusitis, frequent headaches, or chronic fatigue) to distinguish them from building-related symptoms
- Identify the characteristics of occupants' building-related symptoms (i.e., their timing, whether they improved away from the building, location, duration, lost work time)
- Determine if general work conditions (e.g., noise, temperature, lighting) were relevant to the health complaints
- Pinpoint symptoms "specifically associated with working in the building" (i.e., upper respiratory, lower respiratory, skin, gastrointestinal, ocular, constitutional [headaches, myalgia, fever or chills, exhaustion] and neuro-cognitive [problems with concentration, memory, daytime drowsiness, dizziness, fatigue, or irritability])

The two specialists conducted their research in 1996-1997. Lead investigator James Craner, M.D., M.P.H., is a private consultant in occupational and environmental medicine. He is also an assistant clinical professor at the University of California, School of Medicine in San Francisco, California, and at the University of Nevada School of Medicine in Las Vegas, Nevada. Linda Stetzenbach, Ph.D., is the director of the Department of Microbiology, Harry Reid Center for Environmental Studies at the University of Nevada in Las Vegas.

The researchers considered responders who had at least one symptom in three categories other than gastrointestinal as "confirmed" cases. They dubbed responders with the same criteria but who also indicated a preexisting condition aggravated by the building environment as "possible" cases. They classified occupants who reported no building-related symptoms as noncases. They rejected seven surveys that contained inconsistent responses. They made subjective decisions in the cases of surveys where respondents either answered "no" to the question about building-related symptoms or didn't answer it, yet made "appropriate specific symptom responses." The researchers tabulated the responses by general location and summarized statistics by office and floor. They plotted a schematic layout of the office or desk location of every case.

Epidemiological Results

Respondents returned 557 (85.7%) of the 650 surveys. The survey revealed that about 25% of respondents had the aforementioned SBS health complaints. The researchers observed from the general location of occupants who reported symptoms that they were equally distributed by floor, yet after they mapped the confirmed cases, they observed that they tended to occur along the perimeters of each floor. When they superimposed this distribution over the engineering blueprints for the building, they saw that the confirmed cases clustered at the VAV boxes on each floor.

The researchers' statistical analysis of the health survey showed the following results:

- It revealed a relatively uniform distribution and consistent (14%-35%) prevalence of symptomatic occupants on each floor.
- It substantiated the consistent nature of symptoms (respiratory, mucous membrane, neurocognitive, and constitutional) among occupants.

- It pinpointed a significant number of possible cases involving aggravated underlying rhinitis or asthma.

As a result, they felt confident in hypothesizing a "noninfectious, microbial etiology with an allergic-type component" as the cause of the symptoms among the occupants. That prompted Craner and Stetzenbach to conduct a more focused visual survey of the building during which they found previously unnoticed water-stain damage in ceiling tiles under VAV boxes throughout the building. They found active fungal growth on the plenum side of many of those tiles. While tape and bulk culture samples of the occupants' side of the tiles revealed *Alternaria*, samples collected from the plenum side of the tiles contained *Stachybotrys chartarum*. They also found mold growing under wallpaper on water-stained Sheetrock on the fifth floor. Tape samples from under the wallpaper also revealed *Stachybotrys* spores and conidiophores, and spores and hyphae of both *Chaetomium* and *Alternaria.*

Andersen (culturable) air sampling on the second floor revealed few airborne culturable fungi, and Burkard air sampling found no *Stachybotrys* spores. Swab samples of rooftop AHU supply ducts and fans, supply registers, and fire damper liners from the second floor isolated few or no culturable fungi. (Time and cost constraints prevented the investigators from conducting additional sampling they wanted to perform throughout the building.)

Source of Moisture

The investigators found that moisture was coming from the hot-water valves in the VAV boxes. An inspection revealed that approximately 40% of the 250 hot-water valves in the building either were leaking or had previously leaked, based on stained tiles or rust or discoloration of the valves' metal components. The O-ring seating on each leaking valve was significantly worn for its age. Water stains on the atrium wall and in a restroom pipe were attributed to unrelated plumbing leaks not found elsewhere. The water-damaged Sheetrock on the fifth floor apparently was the only damage to an occupied area traced to a roof leak. Investigators identified a drainage obstruction on the roof as the cause.

When the occupants weren't present, crews removed all water-stained tiles, sealed them in plastic, and removed them for disposal. They replaced defective O-rings, tightened all hot-water valves, and launched an investigation with the manufacturer and contractor into the cause of the O-ring failures. They also replaced all other water-damaged materials. Finally, maintenance managers implemented a program of continuously monitoring ceiling tiles.

Within four weeks, occupants' complaints about building-related ills substantially subsided. Due to cost constraints, the investigators did not conduct a formal followup health survey.

Discussion and Conclusions

This study describes how previously unexplained chronic building-related health complaints were traced to fungal contamination through a combination of epidemiological, microbiological, and physical evidence. The investigators theorize that the occupants were exposed to fungal spores that migrated through the air from the ceiling plenum to the offices below at night after the office spaces became negatively pressured when the HVAC system provided minimal ventilation. The limited air sampling performed by other investigators "may thus have missed detection of culturable fungi in the air," the team concluded. "Nevertheless, the direct association between mold contamination of ceiling tiles and chronic, building-wide illness was confirmed by the rapid, uniform response of the occupants' symptoms to removal of the contamination problem," researchers noted.

Identifying a common, ongoing source of water damage to building materials was vital to validating microbiological contamination as the cause of the SBS symptoms, the researchers note. They speculated, "Most likely, this problem started before the building was opened for occupancy. The finding that 40% of the valves leaked suggested that the leakage was an intermittent, building-wide problem. Improperly sized O-rings, defective or incorrect rubber or polymer used in their manufacture or application, or the use of an incompatible corrosion inhibitor in the VAV hot-water valve system are plausible explanations for the ubiquitous valve leakage. In the presence of a continuous or intermittent (warm) water source and low-nitrogen cellulose ceiling tile material, fungal colonizers such as *Stachybotrys* and other hydrophilic fungi can thrive indefinitely, or sporulate and grow in

cycles as the water evaporates and the surface desiccates, followed by another episode of leakage." They added that mechanical vibrations typical of ceiling tiles and vibrations from the VAV fans might have helped distribute mold spores in addition to the negative pressure in the offices at night. The researchers note that imposed time and fiscal constraints prevented a more rigorous statistical, microbiological, and exposure assessment, thus precluding a conclusive identification of the routes of exposure and illness.

Despite the risk that occupants might overstate symptoms to substantiate their concerns about the building, the survey analyses "suggest that these sources of bias were minimal," the researchers say. They suggest a possible explanation why the earlier investigators' air sampling on one given day did not detect the active fungal growth that the epidemiological-led team subsequently found. "Release of spores from certain hydrophilic fungi, including *Stachybotrys chartarum*, is known to be intermittent and subject to various physical and mechanical factors.... Additional sampling in various locations at various times of the day would probably have helped to confirm the route of exposure of spores from the plenum to the occupied areas."

The researchers conclude, "An epidemiological investigation of occupants' symptoms in a 'sick' office building [coupled with] a subsequent, focused microbiological investigation" led them to "correctly diagnose and remediate" water-damaged building materials and fungal contamination, which was "consistent with occupants' health complaints." Developing an environmental investigation strategy based on the results of a formal epidemiological methodology, they continue, "served to properly define the nature, extent, and validity of the clinical illness, which had previously been dismissed after a limited medical and air quality evaluation." Identifying a common, ongoing source of water leakage and its underlying cause "was critical in validating the microbiological explanation for this 'sick building,'" they add. "Other cases of sick buildings may have similar unrecognized sources of microbiological contamination which would benefit from this investigative approach."

Postscript, December 2000

Asked whether he believed the suspected cases of aggravated underlying rhinitis and asthma he and his colleague identified were possibly caused by the mold contamination, Craner tells ***IEQS***, "Absolutely. People who had mild or inactive cases of asthma [or rhinitis] before going to work in that building had these conditions aggravated when they worked there. When these people were removed from the building, they got better." Craner also noted that the mold exposure had a significant (negative) impact on overall worker productivity and employee turnover at the state office building. "Before this investigation, these people were told by their industrial medicine doctors that they were 'whiners and complainers' and that the initial industrial hygiene results 'prove there's nothing wrong with the building,'" he adds.

Craner says that after his study, additional investigation found "massive *Stachybotrys chartarum* contamination" between the firewalls of the building elevator shafts caused by rain intrusion. That mold has been remediated, and the firewalls probably prevented it from becoming a source of exposure, he believes.

Most occupants are well now, but "a limited number" continue to complain of building-related symptoms, he says. Craner says that the stained ceiling tiles were not removed under negative pressurization. He believes another study might determine if mold spores remain in the building — perhaps from the original contamination, possibly stemming from the lack of containment when contaminated tiles were removed — and are the cause of the lingering, building-related health complaints.

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(Editor's note: This case study, "Diagnosing the Cause of a 'Sick Building': A Case Study of an Epidemiological and Microbiological Investigation," was published by the Eastern New York Occupational and Environmental Health Center in Albany, New York, in *Bioaerosols, Fungi and Mycotoxins: Health Effects, Assessment, Prevention and Control*, edited by Eckardt Johanning, M.D., M.Sc., 1999, pp. 158-165.)