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DIAGNOSING THE CAUSE OF A "SICK BUILDING:" A CASE STUDY OF AN EPIDEMIOLOGICAL AND MICROBIOLOGICAL INVESTIGATION

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ABSTRACT

This report describes the methods and outcome of a physician-led investigation of occupants' prolonged, unexplained illnesses associated with working inside a large, modern office building. Occupants (cases) complained of building-related symptoms including eye, nose, and throat mucous membrane irritation; rashes; respiratory symptoms; profound, unexplained fatigue; and neurocognitive symptoms, including difficulty concentrating and short-term memory impairment. No functional ventilation problems or chemical contamination were detected in a walk-through evaluation and basic air quality testing. An epidemiological survey of the building's 700 occupants was then conducted. With 86% of the occupants responding to the survey, there was an average case prevalence of health-related complaints of nearly 25%, evenly distributed among floors. Cases were geographically distributed in a pattern which coincided with the location of the ceiling-mounted variable air volume (VAV) boxes which distributed ventilated air to the occupied spaces. Re-inspection revealed previously undetected, focal water-staining of 40% of ceiling tiles located underneath the VAV boxes throughout the building. Active growth of *Stachybotrys chartarum (atra)* and other fungi was detected on many of the damaged tiles. All water-damaged tiles were replaced and VAV hot water valves were tightened. Occupants reported significant improvement of symptoms within weeks after these changes.

KEY WORDS:

Sick building syndrome, toxigenic fungi, indoor air quality, environmental disease, *Stachybotrys chartarum (atra).*

INTRODUCTION

"Sick building syndrome" (SBS) is defined as a clinical and epidemiological entity in which a significant percentage of occupants of a building develop unexplained symptoms involving several organ systems, including the respiratory tract, skin, and nervous system. The term "sick building" implies an unknown, environmental etiology for which, after investigation, no specific chemical, physical, infectious, or allergic causative agent has been identified (Hodgson 1995). Current hypotheses of SBS etiology continue to implicate multifactorial causes, including inadequate ventilation, organic vapors, asphyxiant gases (e.g., carbon monoxide) and psychogenic factors (Menzies et al. 1996). However, in recent years, an increasing number of published investigations of sick buildings have identified water damage of ventilation systems or building materials, with consequent growth of fungal contaminants, as the source of illness that is clinically identical to SBS. These cases have been associated with a variety of internal and/or external sources of water infiltration into the building environment, including humid climates (Hodgson et al. 1998), leakage from the building exterior (Johanning et al. 1996; Sudakin 1998), and contamination of the air handling units or ducts of the building's ventilation system. Such water damage may be acute or chronic, and may not have been previously identified as a problem during an indoor air quality (IAQ) investigation. Identification and removal of the offending fungi from the environment via removal or remediation of water-damaged materials or conditions, and/or removal of occupants from the source of exposure, usually reversed occupants' disease/complaints in these reported cases. The hydrophilic fungus, *Stachybotrys chartarum (atra)*, has received particular attention in many of these cases.

The case study reported herein represents a case of a "sick building" for which an etiology was not discovered until an epidemiological study and subsequently a focused, microbiological investigation revealed a previously unrecognized source of water damage to building materials with localized growth of toxigenic fungi and a recognizable route of dissemination of fungal spores to occupied spaces. Shortly after the building's opening, occupants began to sporadically report general air quality and health complaints related to the building. Many noted unexplained fatigue and difficulty concentrating, and what they or their personal physicians labeled as "constant head colds" and "recurrent bronchitis," though many did not initially attribute this to the workplace. Symptoms varied slightly over two years without a consistent pattern, with some questionable symptom and air quality improvement reported during the winter months. Many complaints were reported in one wing of the second floor housing the largest agency in the building, where occupants worked in two large partitioned rooms. Initial IAQ investigations and clinical evaluations of some ill occupants revealed no apparent environmental problem or contaminant. The building was labeled a "sick building."

MATERIALS AND METHODS

BUILDING DESCRIPTION

The building is a modern, 5 story, state government office building located in Las Vegas, Nevada. It was constructed in 1992-94 and opened in 1994 to house approximately 20 state agencies. The building has an atrium which extends from the first through the fifth floor on the south side of the building. The building is completely sealed and is ventilated by eight separate, roof-mounted, air handling units (AHUs) that house heating, ventilation, and air conditioning (HVAC) and evaporative cooling components. Each AHU provides (outdoor or mixed) air to a vertical zone on all five floors of the building. The air is distributed to approximately 250 variable air volume (VAV) boxes throughout the building, each containing a secondary heating coil unit with hot water supplied by a separate, treated water system. Air is exhausted from the occupied spaces via ceiling-mounted return grilles into a common, above-ceiling plenum in each zone. Return air is then exhausted from the building from rooftop-mounted vents that are located more than 50 feet from the air intake units.

Typical operating parameters varied depending on the season, with indoor humidity in the 40-50% range (typical outdoor relative humidity, 10-25%) and temperature ranging from 70 to 74°F, reflective of the dry, hot, Las Vegas desert environment. During summer months when outdoor temperatures exceed 85°F, the evaporative cooling system was utilized with return air re-circulated and mixed with outdoor air in a 20:80 ratio. Following persistent occupant complaints, the system was operated with 100% fresh air. The VAV units were operational during daytime hours, with minimum air delivery/minimum air exchanges during evening hours when the offices were not occupied.

EPIDEMIOLOGY

An anonymous occupant survey was designed to measure the types, prevalence, and distribution of symptoms among the building's occupants. The survey was distributed to 650 of the 700 total full- and part-time occupants in the building (50 occupants were not present during the survey period). All surveys were compiled for analysis by the occupational and environmental medical physician (JC). Information regarding age, sex, office location, number of hours worked, smoking habits, and number of years employed in the building was queried with logistic (yes/no) and continuous variable (integer) responses requested. Respondents were asked "Are you experiencing health problems now or in the past related specifically to working in this building?" with the choice of a logistic response. Subjects who answered "yes" to this question ("positive responders") were asked to answer a series of logistic and multiple-choice questions regarding pre-existing medical conditions (e.g., allergic rhinitis and conjunctivitis, asthma, chronic bronchitis, recurrent or chronic sinusitis, frequent headaches or chronic fatigue); characteristics of their building-related symptoms (e.g., timing, improvement away from the building, location, duration, lost work time); general work conditions (e.g., noise, temperature, lighting); and symptoms "specifically associated with working in the building" (e.g., upper respiratory; lower respiratory; skin; gastrointestinal; ocular; constitutional [headache, myalgia, fever/chills, exhaustion]; and neurocognitive [e.g., problems concentrating, memory problems, dizziness, fatigue, irritability, daytime drowsiness]). Demographic data (distribution of sex, ages, smoking habits) and symptom characteristics data were tabulated but were not statistically analyzed.

Positive responders who indicated at least one symptom in three categories other than gastrointestinal were counted as a "confirmed case." A "possible case" was defined as a positive responder who met the same criteria but who also indicated a pre-existing allergic, respiratory, or other medical condition that was aggravated by the building environment. All negative responders (i.e., those who answered no to building-related symptom question, or left this question blank and did not circle any symptoms) were classified as "non-cases." Seven surveys were rejected because of inconsistent responses. Subjective determination as to case category was made for surveys where the building-related symptom question was not completed but appropriate specific symptom responses were made. Responses were tabulated by general office area and summary statistics were tabulated by office and floor. The office or desk location of all cases was tabulated and marked on a schematic layout for each floor in the building.

ENVIRONMENTAL EXPOSURE EVALUATION

The methodologies for surface sampling using tape impression and swabs, and for air sampling using the Andersen single-stage impactor sampler (Graseby Andersen, Atlanta, GA) and the Burkard personal impactor sampler (Burkard Manufacturing Co., Ltd., Rickmansworth Hertfordshire, England) are described elsewhere (Buttner et al. 1997).

RESULTS

EPIDEMIOLOGICAL INVESTIGATION

A total of 557 of the 650 surveys were returned (86% response rate). The distribution of symptoms by floor was relatively constant, with a mean of 25% total case prevalence. Confirmed cases were mapped by geographic distribution on each floor. Cases were observed to be clustered around the perimeter of each floor, though not necessarily next to windows. When this graphic representation was superimposed over the building's engineering blueprints, the pattern closely matched the distribution of the VAV boxes on each floor.

Although the statistical analysis of the occupant health survey was limited in nature for the purposes of the investigation and excluded other available data, the findings of a relatively uniform distribution and consistent (14-35%) prevalence of symptomatic occupants on each floor, the consistent nature of the symptoms (principally respiratory, mucous membrane, constitutional and neurocognitive), and the significant number of (possible) cases involving aggravation of underlying allergic rhinitis or asthma were sufficient to formulate a hypothesis of a non-infectious, microbiological etiology with an allergic-type component.

ENVIRONMENTAL INVESTIGATION

Based upon the results of the occupant survey, a walk-through evaluation was conducted which located previously undetected water damage (stains) to ceiling tiles beneath the VAV boxes throughout the building. Additionally, areas of the 2nd floor atrium wall, ladies restroom, and surrounding office areas were found to have evidence of water damage to sheetrock walls, and walls on the 5th floor were found to have significant water staining behind wallpaper resulting from rooftop leakage.

A total of over 50 water-stained ceiling tiles beneath VAV valves were removed throughout the building. On the occupied side of the tiles, only a water stain was visible, but on the plenum side many of the tiles demonstrated visibly active fungal growth. Transparent tape sampling was conducted on water-stained ceiling tiles from selected areas on the 2nd floor. Tape samples and bulk sample cultures of the occupied side of tile samples identified colonization by *Alternaria*, whereas *Stachybotrys chartarum* was observed on the plenum side. Tape samples from the ceiling plenum above a 2nd floor women's restroom and atrium wallboard (non-occupied side) also revealed *Stachybotrys* spores and conidiophores. Visual observation of the water-stained 5th floor sheetrock beneath wallpaper revealed visible mold growth. Tape samples also confirmed the presence of *Stachybotrys* spores and conidiophores, as well as spores and hyphae of *Chaetomium* and *Alternaria.*

Andersen sampling in select locations on the second floor revealed few airborne culturable fungi and Burkard air sampling was negative for *Stachybotrys* spores. Swab samples of roof-top AHU supply ducts and fans, supply registers, and fire damper liners obtained on the second floor, isolated few, if any, culturable fungi.

Engineering Evaluation

The hot water valves which supply the VAV heating coils were found to be the source of the moisture to the ceiling tiles. Approximately 40% of the 250 VAV hot water valves in the building revealed evidence of past or present water leakage, as manifested either by a stained ceiling tile below, or rusting or discoloration of the metal components of the valve. The two "O-ring" seatings on all of the leaking valves were found to be significantly worn for their age. Water stains on the atrium wall and in the ladies room pipe were attributable to unrelated, localized plumbing leakages which were not found to be prevalent elsewhere in the building. The water-damaged sheetrock on the 5th floor appeared to be the only occupied area damaged by leakage from the roof and a single, isolated drainage obstruction from the rooftop was identified as the cause.

Exposure Intervention

All water-stained ceiling tiles were removed while the building was unoccupied. Area containment was not utilized. The tiles were sealed in plastic bags and transported off-site. All VAV hot water valves were tightened, and defective O-rings were replaced. (The specific cause for the defective seatings remains under investigation with the manufacturer and building contractor). Other identified areas of water-damaged building materials were removed and replaced. A program for ongoing maintenance surveillance of ceiling tiles was implemented by the building maintenance staff.

Within four (4) weeks of these interventions, occupants' complaints (verbal and by e-mail) subsided substantially. A formal follow-up occupant survey was not performed due to logistical and cost constraints.

DISCUSSION

This case study describes the outcome of an investigation of previously unexplained, chronic, building-related health complaints among occupants of a modern office building that had been ongoing for more than two years since the building opened. The evidence that a unifying, scientifically plausible etiology of the health problem was microbiological - and specifically, the colonization of water-damaged ceiling tiles throughout the building by *Stachybotrys chartarum* and *Alternaria* - was provided by a combination of epidemiological, microbiological, and physical evidence. Exposure to *Chaetomium* spores was also a potential source of illness, though this contamination was confined to just one (5th) floor of the building. The route of occupant exposure to fungal spores was theorized to occur through airborne migration of dessicated spores from the plenum to the occupied spaces when the latter became negatively pressurized at night when the ventilation system was dormant. The limited air sampling which was conducted may thus have missed detection of culturable fungi in the air. 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.

The identification of a common source of ongoing water damage to building materials, and the underlying cause of this previously undetected water damage, was critical in validating the microbiological explanation for this "sick" building. Most likely this problem started before the building was opened for occupancy. The finding that 40% of the valves had 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. Potential contributory sources of dissemination of spores to the occupied space include normal mechanical vibration of ceiling tiles, vibration from the operation of the VAV fans, and temporary negative pressurization of the occupied space relative to the plenum during periods when the VAV in an area is non-operational.

Stachybotrys chartarum and other toxigenic fungi are becoming increasingly associated with building-related illnesses (BRI) and SBS in other published cases of IAQ building investigations ((Johanning 1996; Harrison et al. 1992; Sorenson 1987). It is possible that potential microbiological sources of contamination were overlooked in previously published and unpublished "sick building" cases that were investigated and labeled with "psychogenic" or "multifactorial" etiologies (Skov et al. 1989; Stenberg et al. 1994). The potential mechanisms of disease due to this and other toxigenic fungi is currently the subject of active research (Fung et al. 1998). Trichothecene mycotoxins produced by these fungi have been identified in the dust of ventilation systems of "sick" office buildings (Smoragiewicz et al. 1993). Additional SBS investigations have identified other colonizing fungi, such as *Chaetomium* which was identified in wet sheetrock in this building, and certain *Penicillium* and *Aspergillus* species (Bernstein et al. 1983), among many others, in water-damaged building materials (Sudakin 1998; Hodgson et al. 1998).

Practical constraints of time and financial resources for more rigorous statistical, microbiological, and exposure assessment measurements were a limiting factor in providing more "objective" evidence of routes of exposure and disease, as well as follow-up evaluation. The case definition employed in the occupant survey analysis was intentionally designed to be sensitive rather than specific because the study was employed primarily to estimate disease prevalence and distribution, to form a differential diagnosis, and to guide the environmental and exposure assessment. The occupant health study was subject to misclassification bias (overdiagnosis of cases) due to the component of subjective decision-making required, and the reliance upon a single, logistical question for case definition. Occupants could conceivably over-report symptoms to validate their concerns about building-related health problems and concerns. The results suggest that these sources of bias were minimal. The currently available immunological tests (e.g., IgE and IgG *Stachybotrys* antibodies) used as markers of exposure or disease related to indoor mold exposure are of low specificity and positive predictive value (Hodgson et al. 1998; Johanning et al. 1996; Malkin et al. 1998). For this reason, as well as cost and logistical considerations, these diagnostic tests were not employed in confirming or detecting the microbiological etiology.

The finding of negative air sampling for culturable fungi (spores) on a single sampling date should not negate the significance of the finding of active fungal growth on ceiling tiles throughout the building. Release of spores from certain hydrophilic fungi, including *Stachybotrys chartarum*, is known to be intermittent and subject to various physical and mechanical factors (Flannigan 1994). 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 and breathing zones of occupants.

CONCLUSION

An epidemiological investigation of occupants' symptoms in a "sick" office building and a subsequent, focused microbiological investigation led investigators to correctly diagnose and remediate previously undetected water damage to and fungal growth on building materials that was consistent with occupants' health complaints. The implementation of a formal epidemiological methodology 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. The identification of a common source of ongoing water damage to building materials, and an underlying cause of this previously undetected water damage, was critical in validating the microbiological explanation for this "sick building." Other cases of "sick buildings" may have similar, unrecognized sources of microbiological contamination which would benefit from this investigative approach.

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