SICK BUILDING SYNDROME TRACED TO EXCESSIVE TOTAL SUSPENDED PARTICULATES (TSP)

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ABSTRACT

An epidemiological and environmental investigation into the air quality of a high-rise public office building was conducted in July 1988. A walkthrough inspection revealed particulate (dust) soiling of ceiling and work surfaces in occupied sections of the service floor. Building air samples obtained by high-volume air pumps and cassette filters revealed elevated concentrations of total suspended particulates (TSP) which ranged up to 1.07 mg/m³ (more than 17 times the Building Officials and Code Administrators [BOCA] standard). In 17 (59%) of the 29 areas tested, TSP levels exceeded the BOCA standard of < 0.06 mg/m³ (annual average). Recorded temperatures, relative humidity readings, and supply of outside air were within acceptable limits. Testing for volatile organic compounds, combustion products, formaldehyde, ozone, and fungal spores revealed no levels of concern. A survey of occupants in selected units was conducted with 94% participation. Fifty-five percent indicated that they had experienced symptoms that appeared or worsened during their working hours. Of these, 47% indicated that they had missed work because of their symptoms. Common symptoms were headache and sinus/upper respiratory congestion compatible with air contamination by TSP or other irritants. In multivariate analysis, illness was found to be significantly associated with air TSP concentration ($P < 0.002$), CO_2 concentration, average number of hours worked per week, gender, and smoking status. This is one of very few outbreaks of building-related illness where occupant illness has been associated with exposure to elevated levels of an environmental contaminant (TSP).

INTRODUCTION

Building-related illness episodes have been reported more frequently in recent years as buildings have been made more airtight to conserve energy (Hicks 1984). Modern high-rise office buildings are constructed primarily of steel, glass, and concrete, with large windows that cannot be opened. These buildings have become totally dependent on mechanical systems for air conditioning. The latter situation definitely allows for better central control and certain other advantages. However, this situation may also allow contaminants that have been introduced into the system to remain for extended periods. These contaminants may be present in make-up air or may be introduced from indoor activities, furnishings, building materials, surface coatings, and air-handling systems and/or their treatment components. Symptoms often reported are eye, nose, and throat irritation; headache; fatigue; and sinus congestion (Melius et al. 1984). In some cases, the cause of the symptoms has been ascribed to an airborne contaminant, such as formaldehyde, tobacco smoke, or insulation particles, but most commonly a single contaminant is not found to be responsible and outside air ventilation is often found to be inadequate.

Resources generally consulted that provide air quality criteria, guidelines, and/or recommendations include: National Institute for Occupational Safety and Health (NIOSH) criteria documents and recommendations for occupational exposures; the U.S. Department of Labor (OSHA) federal occupational health standards (CDC 1988); the indoor air quality standards developed by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE 1981a, b); and the standards in the model code of Building Officials and Code Administrators International, Inc. (BOCA 1983). The BOCA standards have been adopted by the Virginia General Assembly as the Uniform Statewide Building Code.

The first two sources provide permissible exposure limits (PEL) based on airborne concentrations of substances to which healthy adult workers may be occupationally exposed in the workplace environment for an 8- to 10-hour workday or a 40-hour workweek during a working lifetime without unreasonable risk (e.g., 1/10,000 chance of death). They also provide the concentration of a chemical which would be "immediately dangerous to life or health" (IDLH), defined as the maximum level from which one could escape within 30 minutes without any escape-impairing symptoms or any irreversible health effects. The ASHRAE standards are general air quality standards for indoor environments and are applicable for the general population exposed continuously for 24 hours a day without known toxic effects. For chemicals not covered in its standard, ASHRAE recommends using a limit that is 1/10 of OSHA's PEL.

Investigations of building-related discomfort and/or illness may incorporate evaluations of one or more factors. These include temperature, humidity, fresh air ventilation, TSP (dust), products of combustion, environmental tobacco smoke (ETS), formaldehyde, microorganisms and allergens, volatile organic compounds (VOC), ozone, and radon.

The investigated building was a high-rise state government office building housing more than 1200 employees. Completed in December 1980, it would be considered energy efficient by current construction standards. No asbestos insulation was used in construction. Shortly after occupancy, some of the windows were discovered to leak when it rained; they were subsequently sealed. The service floor was designed for storage of office materials and maintenance equipment and was not intended for occupancy by office personnel. However, some of the equipment (e.g., film library) used by one state agency was too heavy to be placed on the tower floors and was placed in an area of the service floor along with associated personnel.

The heating, ventilating, and air-conditioning (HVAC) system supplied air to the building tower via a variable-volume, multi-zone system. Air intakes were located near ground level approximately 50 ft from a major interstate highway and on the 13th floor. Filtration was provided by elec-

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trostatic filters (estimated efficiency of 10% to 20%). A spray unit was designed to aid in the evaporative cooling process during the spring and fall by applying water to the evaporator coils. Subsequently, this unit was believed to be defective in design when excess water, which should have collected in a drainage pan under the coils, was carried over the pan by air currents to the floor between the unit and the air ducts. This standing water promoted the growth of slime. Slime control was achieved through cleaning and use of biocides.

The perimeter of the tower is heated and cooled by two air-handling units (one for the northeastern and northwestern quadrants, and one for the southeastern and southwestern quadrants). Originally, these units were designed to be linked to sensors that detect solar heat gain on the building and automatically vary the air supply and temperature. Due to limitations in funding, this automatic system was never completed and manual adjustments are made by building engineers. Two air-handling units supply 55°F air to the interior of the building (one for the northeastern and northwestern quadrants, and one for the southeastern and southwestern quadrants). The temperature of this air is adjusted, via thermostats on each floor, by mixing with the necessary amount of warmer air. Separate air-handling units provide ventilation to the service floor, the second and third connector floors, the mezzanine, and the first floor (cafeteria). Air ducts terminate in double, slot-type registers mounted in the suspended ceiling. Air to the exterior perimeter is supplied via registers above the windows. Air is returned via ducts located in the plenum above the ceiling. It is a policy of the Virginia Department of General Services (VDGS) that the indoor temperature in state buildings be maintained at a maximum of 68°F during the heating season, and at a minimum of 78°F during the cooling season.

In January 1984, the Virginia Bureau of Occupational Health (then within the Virginia Department of Health) investigated the 24th and 25th floors of this building in response to air-quality complaints. The principal finding of that study was an average humidity level of approximately 22%.

METHODS AND MATERIALS

Site Inspection

A walkthrough inspection was carried out, and the ventilation system was reviewed in detail with the maintenance engineer assigned to this building.

Environmental Sampling

It was decided to focus most of the sampling on randomly chosen floors (hereinafter referred to as the "study floors"): 9, 10, 14, 15, 16, 24, and the service floor (both floor 24 and the service floor were identified as "worst-case" floors). Additional, less extensive sampling was performed on other floors in the tower, as described below. Samples were collected on different days, depending on the type of test, during the period June 30 through July 19, 1988.

Infrared wavelength scans in the range between 2.5 m and 14.5 µm were performed on air samples taken in the office area of the service floor and in each quadrant (northern southern, eastern, and western) of the tower study floors (as well as the 17th floor) using a portable, single-beam, infrared spectrophotometer (limit of detection equal to 1% to 5% of PEL values). Conventional, half-shift sampling methods were employed on study floors for TSP using high-flow pumps (calibrated at 10 L/min), and pre-weighed cassette filters. After sampling, the filters were desiccated overnight and reweighed to determine TSP. Carbon monoxide (CO), carbon dioxide (CO_2), formaldehyde, sulfur dioxide (SO_2), and ozone were sampled with multigas detector pumps utilizing colorimetric tubes (detection limits were 5 ppm, 50 ppm, 0.1 ppm, 0.25 ppm, and 0.025 ppm, respectively). Carbon dioxide was measured at least once on each floor and twice (morning and afternoon) on the study floors. Carbon monoxide, nitric oxide, and formaldehyde were measured on the study floors and floor 17. Ozone was measured on floors 14 and 15; SO_2 was measured on these floors, as well as on 16, 17, 19, and 24. A sling psychrometer was utilized to determine the temperature and relative humidity on each floor.

Duplicate, 10-minute fungal spore counts were obtained on each study floor and outside (for comparison) using a particle-fractionating viable sampler with a calibrated air intake of 1 ft^3/min. Sabouraud's agar with chloramphenicol was used to culture fungi. Colonies were enumerated after a 48-hour incubation period at room temperature.

Epidemiology

A questionnaire was distributed to a majority of study-floor personnel on July 5, 1988. Requested information included job description, temperature/humidity and odor perceptions, presence and temporal characteristics of any work-associated symptoms, smoking status, and allergic history.

Data Analysis

Questionnaire and environmental data were analyzed separately using microcomputer software, then merged using floor quadrant as the linking variable. Statistical comparisons were performed utilizing the appropriate chi-square test, Fisher's exact test, or unpaired t-test. Statistical significance was defined as $P < 0.05$. Multivariate analysis (a stepwise, conditional, logistic regression model) was performed using microcomputer statistical software. The following independent variables were eligible for inclusion in the model: CO_2 concentration, temperature, relative humidity, TSP concentration, average hours worked per week, employee classification, gender, and current smoking status. Floor location was considered a surrogate for other, more relevant, risk factors, and it was not eligible for inclusion. The criterion for entry was $P < 0.1$.

RESULTS

Observations

On several floors, water stains were noted on some of the ceiling panels near windows, consistent with previous window leaks. Most floors were covered with carpet and furnished with movable, cloth-backed partitions. Remodeling construction and dust associated with such activity were noted on the tenth floor. Dark particulate soiling around the air registers was noted in the occupied section of the service floor. In addition, desks and other surfaces on the service floor were covered with fine, sootlike particulate matter. Evidence of high humidity also was noted on the service floor (e.g., carpet buckling and rusting of film canisters).

The HVAC inspection revealed little, if any, standing water in the condensate trays. Evidence was seen of leakage from a spray unit onto the floor adjacent to the unit, although no visible slime was present. Pre-filters were curling at the edges, apparently allowing a sizable amount of air to escape filtration. Outside air louvers were open, allowing outside air to constitute an estimated 20% of total airflow within the building.

Environmental Sampling

Volatile organic compounds (VOC), products of combustion (CO, nitrous oxide [NO], and SO_2), formaldehyde, and ozone were not detected on any of the study floors.

Air sample CO_2 concentrations ranged from 300 ppm (an outdoor control sample) to 850 ppm on floors 19 and 24 (the lowest indoor value was 400 ppm). The mean concentration for the study floors was 693 $\pm$ 91 ppm. As expected, the highest readings were obtained late in the afternoon and the lowest readings early in the morning.

Temperature readings ranged from 69°F (floor 17) to 76°F (floor 10) and relative humidity readings ranged from 25% (floor 14) to 51% (floor 5). For the study floors, the mean temperature was 73.7° $\pm$ 1.3°F. Twice a day during the period June 23 through July 9, 1988, temperature and relative humidity readings were made in each quadrant of several floors. The only extreme temperatures recorded were readings of 67°F on the morning of June 27 on floors 10 and 14 (the outside air temperature that morning was 56°F).

Viable fungal spore counts (average of duplicate measurements) were $\leq$ 18 colony-forming units (CFU)/m^3 on all study floors. This compared with outdoor counts of 85 CFU/m^3 on the tower rooftop, and 106 CFU/m^3 on the building patio.

The TSP concentrations ranged from negligible (southern quadrant of floor 16) to 1.070 mg/m^3 (service floor offices). The mean TSP concentration for the study floors (four quadrants per tower floor) was 0.128 $\pm$ 0.256 mg/m^3. Of the 29 areas tested, and assuming these results reflect 24-hour averages, only 12 (41%) had TSP concentrations within the building code standard ($\leq$ 0.060 mg/m^3). Two areas (service floor and the western quadrant of floor 10) had TSP measurements above 1.0 mg/m^3 (more than 17 times the building code specification). Construction activity on the tenth floor was probably responsible for the high reading there.

Epidemiology

Completed questionnaires were returned by 94% (218/233) of personnel on the study floors. Only 28% of respondents felt that the temperature of their work location usually was satisfactory. Eight percent felt the environment was usually too hot, 24% felt it was too cold, and 39% felt it was usually too hot or too cold. Thirty-seven percent felt the humidity in the work location was satisfactory. Seven percent felt the humidity was usually too high, 36% thought it was too dry, and 15% judged it too high or too low. Sixty-four percent of the respondents had noted a foul odor coming from the ventilation system; the vast majority described it as a "dead fish" or "wet dog" smell, last noted in late May or early June 1988.

Fifty-five percent of the respondents indicated that they experienced symptoms that appeared or worsened during their working hours. The frequency of selected symptoms is shown in Table 1. Of these symptomatic respondents, 61 (51%) indicated that they had seen a physician because of their illnesses. Fifty-six (47%) indicated that they had missed work at some time because of these symptoms, and 15% noted that they had missed one to three days of work during the preceding 30 days. Although their symptoms appeared or worsened while at work, most symptomatic respondents indicated that there was no apparent connection between their symptoms and any particular season of the year, day of the week, or time of day. Dates of onset of illness, provided by 87 of the 120 symptomatic respondents, showed no temporal clustering of onsets other than at the time the building was first occupied (many who moved in after the building first opened noted that their onset dates were the same as the dates that they moved in).

The proportion of persons on each study floor reporting uncomfortable temperature and/or humidity, foul odor, or symptoms is shown in Table 2. The variation in the proportion of persons noting temperature- or humidity-related discomfort on study floors was significantly different from variation that one might expect due to chance alone ($P < 0.0001$). Illness rates also varied significantly by floor ($P < 0.02$). The proportion of persons noting a foul odor did not vary significantly by floor.

Preliminary univariate analysis suggested no association between illness and any of the environmental results (i.e., concentrations of CO_2, NO, formaldehyde, CO, viable fungal counts, TSP, temperature, or relative humidity). Univariate analysis indicated that illness was significantly associated with respondent employment classification. Personnel were grouped into three categories based on apparent level of responsibility: clerical, intermediate, and managerial. Although the range of attack rates for these three groups was not large (from a low of 47% for managers to a high of 67% for clerical staff), there was a significant inverse relationship between these ascending categories and illness rates ($P < 0.02$ by chi-square for trend). Illness was significantly associated with the average number of hours worked per week, ranging from 38% for those working less than 40 hours per week to 55% for those working more than 40 hours ($P < 0.005$ by chi-square for trend). Other questionnaire variables found to be significantly associated with illness were female gender (relative risk [RR] = 1.53, 95% confidence interval [CI] = 1.18-1.99, $P < 0.003$), and nonsmoking status (RR = 2.28, 95% CI = 1.39–3.76, $P < 0.003$). The following questionnaire variables were not found to be significantly associated with illness: agency where employed, length of time employed at current location, age of respondent, or history of allergies or of treatment for a lung condition.

For multivariate analysis, a computer model was constructed which was significantly predictive of illness ($P < 10^{-6}$). Through a stepwise process of forward selection and backward elimination of variables to achieve the best predictive capability, the computer model selected the following risk factors for inclusion: female gender ($P < 0.002$), nonsmoking status ($P < 0.002$), floor TSP concentration ($P < 0.002$), respondent's average number of hours worked per week ($P < 0.02$), and floor CO_2 concentration ($P < 0.09$). The following variables did not improve the model and were rejected: temperature, humidity, and respondent employment classification.

DISCUSSION

This investigation documented that a sizable fraction of the personnel surveyed have experienced symptoms primarily consisting of headache; eye, nose, and throat irritation; drowsiness; and difficulty concentrating. The situation is consistent with indoor air pollution or "tight building syndrome," which is now commonly recognized in many modern, climate-controlled, sealed buildings. In most instances, no specific chemical contaminants can be identified as the source of the problem, but inadequate ventilation with fresh outside air can frequently be demonstrated to contribute to the problem (Whorton et al. 1987).

In general, the symptoms identified here were experienced by a large proportion of the staff for varying lengths

TABLE 1

Frequency of Selected Symptoms Reported by High-Rise Office Building Personnel

Symptom	Frequency
Headache	61%
Sinus congestion	59%
Nasal irritation	58%
Throat irritation	58%
Drowsiness	53%
Eye irritation	52%
Cough	37%
Difficulty concentrating	26%
Muscle aches	19%
Chills	16%
Dizziness	15%
Shortness of breath	13%
Weakness	9%
Stomach ache	8%
Diarrhea	8%
Fever	7%
Rash	5%
Faintness	4%

of time while at work and disappeared within a period of hours after persons left the building. These features are consistent with an irritative rather than infectious or allergic process. Consistent with this was the finding of elevated TSP concentrations on many of the study floors. Also, based on multivariate analysis, TSP concentrations were found to be a statistically significant predictor of illness. Although elevated TSP levels were found on a number of floors, the TSP problem was most severe in the service floor office space, based on observation and measurement. Apparently, soot from vehicular traffic on the adjacent interstate highway was being drawn into the ventilation system, escaped adequate filtration, and was dispersed indoors, especially on the service floor.

Epidemiological studies linking health effects to TSP exposure have been conducted primarily in outdoor environments. In those studies, it has been difficult to accurately assess the independent contribution of TSP to health effects, given that polluted air usually contains multiple contaminants. In one study of 10,106 pre-adolescent children, the frequency of cough, bronchitis, and transient lower respiratory illness was significantly associated with increased TSP levels in the outdoor air (Ware et al. 1986). The lowest annual average TSP concentration at which temporary health effects were observable in sensitive groups (children and persons with underlying lung or heart disease) was about 0.24 mg/m^3, and the lowest 24-hour TSP concentration at which health effects were seen in bronchitic patients was about 0.35 mg/m^3 (Holland et al. 1979).

Three host factors were found to be associated with illness. Several explanations could be offered for why the average number of hours worked per week was found to be one such risk factor. The most obvious is that if TSP in the air were responsible, at least in part, for many of the symptoms, then one would expect to see a "dose-response" effect where increasing exposures led to increasing probabilities of illness. Second, persons who indicated that they worked more than 40 hours per week were more likely to enter the building on weekends. This is a time when the ventilation system was partially shut down to conserve energy, and prevented the dilution of other contaminants that might have contributed to illness. Finally, ill respondents who had worked less than 40 hours per week may have been less inclined to mention symptoms because of temporary job status and fear of dismissal.

TABLE 2

Prevalence of Complaints by Floor in a High-Rise Office Building

Floor	Too Hot/Cold	Too Humid/Dry	Odor	Symptoms
09	82%	79%	82%	76%
10	69%	69%	63%	31%
14	67%	48%	67%	38%
15	87%	50%	44%	38%
16	85%	60%	70%	60%
19	59%	43%	63%	50%
24	71%	74%	52%	55%
Service	71%	79%	71%	75%

Nonsmoking status also was identified as a host risk factor. The reason for this is not clear. One possibility is that some smokers with a history of bronchitis may have attributed any exacerbation of smoking-related symptoms to their habit instead of to the building environment. In addition, given the inherent biologic variation within the human population, one would not expect all individuals to be equally susceptible to the irritative effects of TSP pollution. It is reasonable to speculate that the more sensitive individuals among the respondents would have experienced TSP-related symptoms earlier in their lives. These more sensitive individuals may have been less likely to be smokers than less sensitive individuals.

It is doubtful that there is any biologic reason for the higher illness rates among women (64% vs. 42% in men). The same finding has been noted in some other surveys and outbreak investigations of illnesses where gender differences were not anticipated (Henderson and Shelokov 1959). Given that complaints of symptoms may be interpreted by peers as a sign of weakness. and given strong cultural influences to avoid any appearance of weakness (especially among men), it is reasonable to speculate that such gender differences might be a result of greater reluctance among men to admit to having symptoms.

Although a number of the survey respondents complained of temperature- and humidity-related discomfort, our measurements showed very few deviations from the ranges recommended by ASHRAE or specified by the building code. A major limitation of our study is that it represents only a "snapshot" of conditions within the building. Since humidity control is not part of the HVAC system in this building (or any other state office buildings) and outdoor humidity levels are lower in the winter, it is very likely that indoor humidity levels would be much lower during the heating season. This was found to be true in the study of the 24th and 25th floors of this building in 1984. In that study, the average relative humidity level was found to be approximately 22%. At this level, it would be difficult, if not impossible, to manipulate temperature (even if energy conservation restrictions were not in place) in order to achieve a combination of temperature and relative humidity within the comfort zone suggested by ASHRAE.

Many survey respondents also had noted transient foul odors coming from the ventilation system. Most had last noted the smell in late May, which coincides with the time when the HVAC system spray unit was taken out of operation for the summer. It is likely that the smell observed by these occupants was generated by microorganism growth as a result of the believed design defect in this unit. Our sampling for fungal spores found no increased indoor concentration over outdoor levels, although our testing occurred after the spray unit had been dismantled and cleaned for the season.

RECOMMENDATIONS

Several recommendations were suggested to help remedy the situation in this office building. Better air filtration was needed to reduce indoor TSP concentrations to a level that complies with building codes, and which would not cause any adverse health effects. Better housekeeping, at least as a temporary measure until better filtration was in place, was suggested to help reduce TSP levels (especially important in areas where remodeling construction was taking place). At a minimum, it was suggested that a thorough dusting of surfaces and vacuuming of the movable partitions (in addition to routine cleaning) should be carried out on a semiannual basis. An examination of the cost-benefit ratio of adhering to ASHRAE comfort guidelines should be conducted. This would require a reexamination of the policy of not controlling humidity in state office buildings. If the spray unit was to continue to be used, an augmented maintenance program should be instituted to control microbial growth; ASHRAE considers the prophylactic use of disinfectants in the HVAC system, excluding cooling towers, to be unacceptable in most instances (ASHRAE 1987). After administrative review, the findings of this study and any plans for follow-up action should be shared with each agency in order to better inform concerned occupants in the building.

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DISCUSSION

David Mudarri, U.S. Environmental Protection Agency, Washington, DC: How do you suspect the TSP levels were related to smoking in the building or the use of ultrasonic humidifiers or to fungal spores, particularly in the basement? Each of these could be major sources of TSP.

P.C. Sherertz, Virginia Department of Health, Richmond, VA: Under the time constraints of this project, we were not able to consider much other than the TSP levels. We recognize many of the conditions you mentioned may have been directly related to our observed TSP levels.

Behzad Samimi, Graduate School of Public Health, San Diego State University, San Diego, CA: The use of the MIRAN gas analyzer is inappropriate for low concentrations of volatile organics. This instrument is only appropriate when known organic volatiles with relatively high concentrations are suspected to be present, which makes this instrument suitable for use primarily in occupational environments (where employees are working with solvents, etc.) and not in an office building situation.

You stressed in your study that TSP is the major factor in causing symptoms among employees. Did you conduct any analyses, i.e., scanning electron microscopy, elemental analysis or size distribution analysis, to determine the nature and sources of these particulate matter?

Sherertz: No.

Samimi: Did you take any air samples for incoming air (dampers) to see whether any particulates are present in incoming air?

Sherertz: No.

Carl Lawson, LRW Engineers Inc., Tampa, FL: Did you find humidity more heavily concentrated at lower floors? Did you test the computer room or not? What was the mildew content in this project?

Sherertz: No (to the first two questions). There were no gross fungi infestations noted during this study—only the smell which was reported by some personnel.

Charles J. Weschler, Bell Communications Research, Red Bank, NJ: The motors used in high-volume samplers can, themselves, generate particles. Were any precautions taken to prevent re-entrainment of these particles during the sampling for TSP?

Sherertz: No.