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Indoor environmental and air quality characteristics, building-related health symptoms, and worker productivity in a federal government building complex

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ABSTRACT

Building Health Sciences, Inc. (BHS), investigated environmental conditions by many modalities in 71 discreet areas of 12 buildings in a government building complex that had experienced persistent occupant complaints despite correction of deficiencies following a prior survey. An online health survey was completed by 7,637 building occupants (49% response rate), a subset of whom voluntarily wore personal sampling apparatus and underwent medical evaluation. Building environmental measures were within current standards and guidelines, with few outliers. Four environmental factors were consistently associated with group-level building-related health complaints: physical comfort/discomfort, odor, job stress, and glare. Several other factors were frequently commented on by participants, including cleanliness, renovation and construction activities, and noise. Low relative humidity was significantly associated with lower respiratory and "sick building syndrome"-type symptoms. No other environmental conditions (including formaldehyde, PM_{10} [particulate matter with an aerodynamic diameter <10 μm], or mold levels, which were tested by 7 parameters) correlated directly with individual health symptoms. Indicators of atopy or allergy (sinusitis, allergies, and asthma), when present singly, in combinations of 2 conditions, or together, were hierarchically associated with the following: increased absence, increased presenteeism (presence at work but at reduced capacity), and increase in reported symptom-days, including symptoms not related to respiratory disease. We found that in buildings without unusual hazards and with environmental and air quality indicators within the range of acceptable indoor air quality standards, there is an identifiable population of occupants with a high prevalence of asthma and allergic disease who disproportionately report discomfort and lost productivity due to symptoms and that in "normal" buildings these outcome indicators are more closely associated with host factors than with environmental conditions. We concluded from the experience of this study that building-related health complaints should be investigated at the work-area level and not at a building-wide level. An occupant-centric medical evaluation should guide environmental investigations, especially when screening results of building indoor environmental and air quality measurements show that the building and its work areas are within regulatory standards and industry guidelines.

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Building-related health complaints are common and require investigation,[1–4] explanation, and usually some intervention. Building-related outbreaks are troublesome, leading to deep concern and often damaging relations between occupants and the owner, but are heterogeneous and difficult to generalize.[5] Very few incidents represent "building-related illness," the term used when symptoms of diagnosable illness are identified and can be attributed directly to building environmental conditions or airborne building contaminants.[5,6]

Efforts to focus on single causes of building-related complaints have not shown sufficient explanatory power for general application.[5,7–9] Investigations that begin with an isolated focus on the building are frequently expensive and uninformative, leading to dissatisfaction among occupants and frustration among owners and managers. The issues often continue or recur. An integrated approach considering the occupant as well as the building provides a framework through which to investigative, focus diagnostic activities and supports evidence-based and responsive risk communication.[10]

Clearly further insight and investigation are required to develop new approaches for investigation,[11–14] trial intervention,[15] and standards setting.[5,16,17] Building Health Sciences, Inc. (BHS), investigated a refractory outbreak of building-related health complaints, which provided the opportunity to collect complete, simultaneous, and accurate data on building parameters, environmental and air quality, and occupant symptoms and illnesses in a large set of similar buildings. Our approach began with exhaustive field testing

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to completely and accurately quantify building environmental conditions. Our study also used innovative approaches to characterize the building population at risk for symptoms and discomfort.[1–4]

Background

The National Security Agency (NSA) is a branch of the US Department of Defense. Over several years, many, mostly nonspecific, health complaints had been received by the NSA Office of Occupational Health, Environmental, and Safety Services (OHESS) at Fort Meade, Maryland. During the same period, many complaints about building maintenance or environmental conditions had been entered into the NSA's Facility Information Management System (FIMS). Multiple investigations had been conducted, and NSA had implemented extensive guidelines to maintain indoor air quality, particularly for the introduction of new furniture and during construction and renovation.

Several surveys and investigations had already been performed by NSA, contractors, and the National Institute for Occupational Safety and Health (NIOSH), on many of the same buildings selected for the present study. Deficiencies found included poor housekeeping, water intrusion, imbalance in the ventilation system, and inadequate containment of construction. These deficiencies had been addressed, and most of the recommended corrections had already been made prior to the study. However, complaints from occupants continued.

In 2004, the United States Congress passed legislation as part of the defense reauthorization bill for 2005 (Section 1094, Title XI, of the *National Defense Reauthorization Act*) directing "the Secretary of Defense to undertake an epidemiological study and health hazard evaluation related to NSA buildings at Fort Meade. The conferees believe the National Institute for Occupational Safety and Health (NIOSH) of the Department of Health and Human Services is an appropriate federal government organization to perform such a study." NIOSH, having previously investigated indoor environmental and air quality factors at the site, declined to conduct the epidemiological study and health hazard evaluation. BHS, a Maryland-based, physician-led, consulting firm specializing in indoor environment and air quality issues, was then chosen to perform the epidemiological study and health hazard evaluation. BHS retained the services of Westat for biostatistical support.

Methods

Preliminary review

Data and results from a 2005 survey undertaken by OHESS, 2,495 individual FIMS reports from 2003 to 2007 that involved environmental conditions (<5% of total), a 1999 investigation of Building A by Building Dynamics (Arlington, VA), and NIOSH's 2001 health hazard evaluation (HHE) were reviewed to provide a historical background of the issues and to identify study areas for investigation.

The OHESS survey identified a cluster of symptoms, prevalent conditions, and occupant concerns. Most reported complaints were upper respiratory tract symptoms or sinusitis. However, it was not possible to infer causation and only small numbers of employees were involved. NIOSH had concluded that correction of water incursions, poor housekeeping, and adequate containment of construction dust would reduce work-related respiratory symptoms at Fort Meade. These deficiencies were mostly corrected, including improvements in the buildings in the current study; however, complaints persisted,

The initially eligible study population consisted of agency employees 18 years of age or older, civilian and military, working in 40 NSA buildings on or near the Fort Meade campus. This worker population of approximately 40,000 works every day, around the clock, in shifts. Contractors were excluded from the study because of the many complexities and challenges related to private employment agreements and security. Twelve buildings were selected for the study, housing 15,704 NSA employees who were eligible to participate. They were the largest buildings on the site, generated the most complaints, housed operations that were representative of operations in the entire complex (which primarily involves electronic communications and is dense with computer terminals), and provided a large number of discreet individual work areas within each building. Buildings that served strictly service and support functions, such as security offices, maintenance, and the on-site museum, were excluded from the study; they were also much smaller than the study buildings.

The study buildings had the following characteristics: 6 buildings were built prior to 1980 and 6 after 1980; 6 are 4 stories or less and 6 are between 7 and 12 stories tall. Five buildings occupied an area less than 10,000 m^2, 6 between 10,000 and 20,000 m^2, and 1 building greater than 40,000 m^2. "Occupants" of a building were defined as NSA employees or military personnel who worked at duty stations within the building for 20 hours or more per week.

Reference set: The base study

Buildings entered into the US Environmental Protection Agency's (EPA) Building Assessment Survey and Evaluation (BASE) study[1–4] provided a reference set for

comparison. The BASE study examined and compiled a database in the 1990s on 100 public and commercial office buildings in the United States. The BASE sample of buildings is a reference set but not a strict control group for the buildings in the present study. The BASE study included in its sample both buildings without complaints from occupants and buildings for which there had been such complaints, although "complaint buildings that had been highly publicized by the media" were specifically excluded.[18] None had been previously evaluated. By comparison, the buildings in the present study had all been previously evaluated, at least preliminarily, and most had been subject to complaint that were well known within the workforce and the community and had been publicized in the local and national media. Deficiencies had already been identified and corrected, but complaints had continued.

Environmental assessment

The building assessment closely followed the protocol of the BASE study.[1–4] A preliminary walkthrough inspection was conducted on the 12 buildings selected for detailed study. Within the 12 buildings, 353 discreet candidate study areas were identified. Study areas were defined as contiguous space ≤20,000 square feet (1,858 m^2) on a single floor served by no more than 2 air handling units and classified by an experienced building scientist using blueprints and visual inspection of the premises. Seventy-one study areas were selected, 16 on the basis of severity of past complaints (most of which were presumed to have already been corrected), ensuring that at least 1 study area was selected from each of the study buildings, 40 based on location of current complaints, and 15 to ensure statistical representation of the campus environment.

Reference samples and measurements were obtained outside each building in the morning and afternoon of the day that the building was evaluated. (Measurements and sampling performed are listed in Table 1.) Usually the site for reference measurements was the roof of the same building, as close to the air handler outside air intake as possible. In high winds and inclement weather, some samples were taken at ground level outside the building entrance.

Bioaerosol sampling for mold spores was performed using battery-powered pumps at 15 liters per minute (lpm) through an AirOCell impactor cassette. Mold swab samples were collected for analysis by Mycometer enzyme activity reading (a proprietary test for mold-related enzyme activity on 1-inch area swab samples; Mycometer, Tampa, FL).

Volatile organic compounds (VOCs) samples were obtained as grab samples using Summa canisters for 10 minutes filling time to collect a full 1.0 L, without strict regulation of the flow rate because the findings were not intended for conversion into an 8-hour time-weighted average. (Summa [formerly a trademark] canisters are evacuated stainless steel passivated containers that fill through an orifice at a constant flow rate.) VOC sampling was discontinued after the second round of monitoring because of the low concentrations of VOCs.

Dust and allergen samples were obtained by means of a high-efficiency particulate air (HEPA) filter-equipped vacuum cleaner drawing air through a special cassette from an area 0.37 m^2 (2 feet by 2 feet) of carpet or chair upholstery. Allergen testing was performed on dust samples from 57 study areas for cat and dog proteins, cockroach, and both dust mite antigens, Der f1 and Der p1. All cockroach and dust mite samples were below the level of detection and could not be analyzed. Because only 3 samples were above the level of detection for cat and dog allergens, allergen testing was subsequently omitted for the remaining 14 study areas.

Epidemiological evaluation

The study team reviewed the findings of the NIOSH study, complaints filed with FIMS, presenting complaints to the health unit, and results of 3 previous questionnaires disseminated to NSA employees: the 2006 and 2007 rounds of the Intelligence Community Annual Employee Climate Survey and the NSA Job Satisfaction Exit Survey. A data collection instrument was then developed in collaboration with Westat and NSA adapting the questionnaire used in the EPA BASE study.[18] The structure of the questionnaire is provided in Table 2. The instrument was reviewed in a focus group before the final version was administered. The final questionnaire was administered online using Survey Tracker (Training Technologies, Lebanon, OH), distributed on 12 May 2007 with a reminder 2 weeks later. Informed consent was obtained online in the introduction to the survey, which also contained assurance of confidentiality and assurance of no penalty if a subject chose not to participate.

Modifications to the BASE study questionnaire consisted primarily of omitting items that were irrelevant (work outdoors, sensitive personal health information, personal finances and relationships) and the addition of specific questions to capture a full year of health complaints, to document mobility among NSA facilities due to indoor environmental conditions, and to add more probative questions regarding asthma. Demographic information was obtained on race, ethnicity, specific individual rank, education level, and duration of service at NSA. Because of the classified nature of the work, data on specific job responsibilities and functions could not be collected.

Table 1. Environmental measurements conducted in each study area.

Measurement	Unit	Instrument or method	Reference samples and notes*
Air temperature	°C	TSI (Shoreview, MN) QTrak model 7565	R Calibrated annually
Relative humidity	%RH	TSI QTrak model 7565	R Calibrated annually
Carbon dioxide (CO_2)	ppm	TSI QTrak model 7565	R Calibrated annually
Carbon monoxide (CO)	ppm	TSI QTrak model 7565	R Calibrated annually
Sound level	dB	Quest 1100 sound intensity meter	Calibrated daily
Lighting	lux	ExTech (Waltham, MA) EasyView light meter	R Factory calibrated
Particulate matter (PM_{10})	$\mu g/m^3$	TSI DustTrak model 8520	Zeroed per manufacturer's instructions
Volatile organic compounds (VOCs)	ppb	Sampling by mini-Summa 1000-mL canister (Air Toxics, Folsom, CA)	R, EM First 2 rounds only; omitted from third round
Formaldehyde	ppm	Passive sampling dosimeters, usually 3/study area: SKC (Eighty Four, PA) UMEX-100 first 2 rounds, 3M (Minneapolis, MN); model 3720 third round	E/T
Bioaerosols—mold	$Spores/m^3$	Collection by AirOCell cassette (Aeroflex USA, Sweetwater, TN) after 10-minute flow at 15 L/min by battery-powered Buck Bio-Aire (Orlando, FL) or Zefon Bio-Pump (Ocala, FL)	R, EM Microscopy analysis
Mold—personal air space sampling	$Spores/m^3$	Collection by MSA (Pittsburgh, PA) ELF pump at 1.2 lpm using EndoFree cassettes with 0.45-μm filter	Calibrated before use
Mold by Mycometer	Dimensionless enzyme activity	Mycometer (swab)* A: 0–25; not above normal background B: 26–240; above normal background, may be due to spores in dust deposit or old mold growth C: >450; high above normal background level due to active growth	UV fluorescence detection
Dust sampling from textiles	See text	Collection by HEPA-equipped vacuum cleaner Microscopy for spores, fiberglass, fibers, and skin cell count Allergen analysis for cockroach, dust mite, cat, and dog	EM Microscopy for spores, fiberglass, fibers, and skin cell count
Ozone	ppm	Ozone Solutions (Hull, IA) OMC-1108	R Precalibrated by vendor

Note. R = reference sample or measurement taken outside building on morning and afternoon of same day as building evaluation.
E/T = formaldehyde analysis was performed in the first 2 rounds of the study by EMSL (Westmont, NJ) and in the third round by TestAmerica (Cedar Falls, IA).
EM = bioaerosol microscopy and VOC analysis was performed by EMLab PK (Fairfax, VA; previously Aerotech P&K).
Mycometer = Mycometer (Tampa, FL, USA, and Copenhagen, Denmark).

Respondents were asked about the frequency of 17 symptoms experienced at work over the last 4 weeks and whether the symptoms improved, worsened, or did not change when out of the work environment, and the period prevalence of the symptoms over the previous 11 months, thereby covering the immediate preceding year. Additionally, NSA respondents were asked, for each of 3 symptom groups (defined as [1] fatigue, tiredness, or drowsiness; [2] difficulty with memory or concentration; [3] any of the other 14 symptoms other than headache), how many days in the previous 4 weeks they were absent from work ("absence") specifically due to symptoms reported to be work-related and how many days during that period they believed their work ability was reduced due to these symptoms ("presenteeism").

Table 2. Structure of the questionnaire.

1. Demographic information (age, gender, duration of employment with NSA)
2. Employment and work station at NSA (building, floor, room number, shared or individual office, work hours)
3. Health-related symptoms (experience in last 4 weeks or previous 11 months of tired/strained eyes, headache, unusual tiredness, fatigue or drowsiness, neck or back pain or stiffness, tension or irritability, dry/itchy/burning eyes, sneezing and/or coughing, stuffy or runny nose, difficulty remembering things or concentrating, dry/itchy/sore throat, feeling depressed, dry/itchy skin, dizziness or lightheadedness, nausea or upset stomach, wheezing or shortness of breath, nosebleeds or hives)
4. Physician-diagnosed medical conditions (migraine, asthma, eczema, hay fever, allergies, sinusitis, cancer, sarcoidosis)
5. Environmental conditions at the work station (carpeting, windows, office equipment; temperature, humidity, odor, noise, cleanliness; comfort, privacy; recent changes)
6. Work characteristics (duration of employment at NSA, major organizational division, shift, length of time in building, whether work station had even been moved due to indoor air quality issues, whether occupant had ever filed a repair or clean requested, skill community)
7. Job characteristics and work-life balance (level, education level; satisfaction, conflicts; commitments of more than 5 hours per week outside of work to child care, elder care, housekeeping)
8. Open-ended responses on the building or health matters (medical history)

Respondents were invited to participate in pulmonary function testing. Spirometry was performed on 73 individuals who volunteered, accepting an invitation that followed completion of the questionnaire. Pre- and postshift spirometry was performed on the first and fourth days of the subject's day of work in rotation by experienced personnel following standard NIOSH protocols using reference values from the National Health and Nutrition Evaluation Survey.

Institutional review

The study design and data collection protocol were approved by the Institutional Review Board of Westat in 2007. Approval was also obtained from the General

Counsel of the Department of Defense, the Department of Health and Human Services, and the Office of Management and Budget. A certificate of confidentiality was obtained from the National Heart, Lung, and Blood Institute of the National Institutes of Health. A statement of confidentiality was obtained from the NSA institutional official for human subject research.

Data analysis

Statistical support, calculation, and comparison data from 2 relevant prior studies were supplied by Westat. All analyses were performed using a standard statistical program (SAS version 9.1.3; SAS Institute, Cary, NC).

Of the 15,704 qualified employees, 7,637 (48.6%) responded to the survey. Figure 1 describes the characteristics of respondents. The response rate for civilian workers (52%) was higher than for active-duty military (24%), but there were many more civilian NSA workers. Response rates among the 12 study building averaged 49%, with all buildings showing a response rate at or above 44% except one outlier (Building K, 28%), which only had 144 NSA employees.

A total of 57,368 field samples were taken from the 71 study areas within the 12 study buildings. Over the course of the study, approximately 4 million data points were collected for analysis.

Preliminary data exploration was undertaken with univariate tabulations of symptom experience and physician-derived diagnoses. Table 3 provides the aggregated outcome groups used in the analysis, following methodology developed by NIOSH. For purposes of analysis, 6 diagnostic groups were formulated with respect to asthma, sinusitis, and allergies, and 8 symptom groups were formulated on the basis of clustered symptoms. The burden of symptoms in time was calculated as "symptom-days" for each of the 6 diagnostic groups. Six symptoms were not included in symptom groups but were included in the count of total symptom-days: dry or irritated skin, tired eyes, feeling depressed, nausea or upset stomach, nosebleeds, and hives.

Environmental sampling and monitoring measurements were obtained for use as independent variables in the analysis, including maximum values of ozone, particulate matter, and carbon monoxide (CO). For other environmental measurements, both maxima and minima were used. For carbon dioxide (CO_2), maxima, minima, and ΔCO_2 (difference in maxima for CO_2 between inside and outside air) were used. Logarithmic transformations were used for analysis of data that demonstrated log-normal distribution, in which case geometric means are reported.

Environmental symptom experience responses (air movement, temperature change, humidity) were used to develop "discomfort scores" as derived variables in the

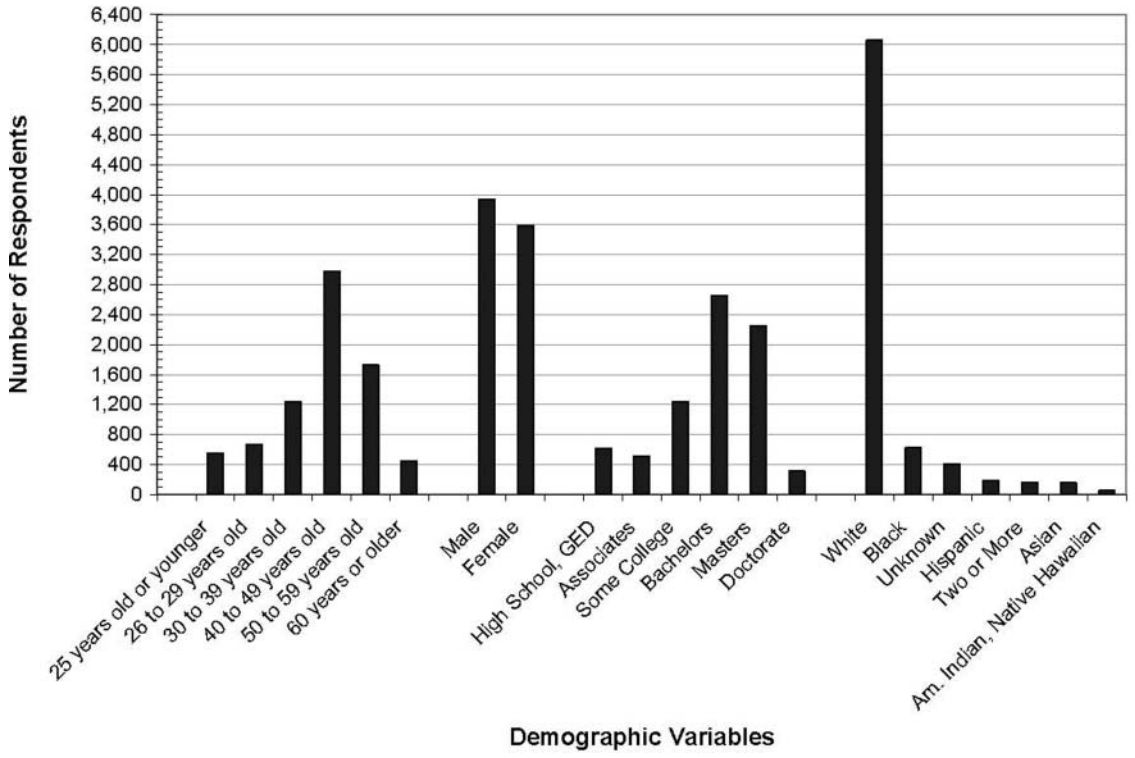

Figure 1. The demographic profile of the study respondents.

Table 3. Aggregation of responses for purposes of data analysis.

Diagnosis groups
- Physician-diagnosed asthma, sinusitis, and allergies (probable atopy)
- All other asthma
- Physician-diagnosed sinusitis and allergies, no asthma
- Physician-diagnosed sinusitis only
- Physician-diagnosed allergies only
- No asthma, allergy, or sinusitis diagnosis

Symptom groups
- "Probable atopy" (at least 2 of eye irritation, nasal or sinus congestion, sneezing and/or coughing)
- Multiple neurological (at least 3 of headache, unusual fatigue or drowsiness, difficulty with memory or concentration, dizziness or lightheadedness, tension, irritability, or nervousness)
- Multiple respiratory (2 of sneezing and/or coughing, respiratory symptom of wheezing, chest tightness, or shortness of breath)
- Musculoskeletal (1 of headache, tension, irritability, or nervousness, pain and stiffness in back, shoulders, or neck)
- Neurological (1 of headache, fatigue, difficulty with memory or concentrating, dizziness or lightheadedness)
- Lower respiratory tract (wheezing, chest tightness, shortness of breath)
- "Sick building syndrome" symptoms (at least 2 irritative symptoms of eye irritation, nasal or sinus congestion, or throat irritation, and at least 1 of neurological symptoms of headache, fatigue).
- Upper respiratory tract (1 of throat irritation, nasal or sinus congestion, sneezing and/or coughing)

Symptom-days (frequency of symptoms at work)

Symptom-day scores were derived for total symptoms and symptom groups as a numerical score from reported frequency of symptoms at work as follows:
- Not in the last 4 weeks (0)
- About 1 workday per week on average (0 if reported to have stayed the same or gotten worse, 1 if reported to have improved, after leaving work)
- About 2 to 3 workdays per week on average (2.5 if reported 2 to 3 days per week and improves after leaving work)
- Every or almost every workday on average (4.5 if reported 4 to 5 days/week and gets better improves after leaving work)

statistical analyses. Table 4 summarizes the scoring system, based on NIOSH methodology, used to evaluate environmental conditions and job strain burden.

Multiple stepwise regression analysis was used to determine the best predictors of work-related symptom outcomes, as quantified by total symptom-days, symptom-days for all 8 symptom groups, absence from work, and presenteeism, the results of which were reported. This regression was followed by 2 generalized linear regression models to check consistency. Several variables (change in FEV_1 [forced expiratory volume in 1 second] from the beginning of the workday to the end of the workday and "sick building syndrome symptoms") were divided into terciles due to lack of normal distribution in both the original scale and log-transformed values; correlations were tested by analysis of variance (ANOVA) and *t* test.

Results

The study yielded 57,368 field samples, measurements on which, combined with personal data on occupants, resulted in approximately 4 million data points. In total, 63 separate regression models were completed. The final model contained 31 significant ($p \leq .05$) variables, $r^2 = .32$, and a p value of $<.0001$. The 2 secondary linear regression models showed nearly identical results. The findings of the stepwise regression are therefore used for all correlations reported below.

Building environment

Figure 2 presents the distribution of respondents reporting adverse environmental conditions experienced in the workplace over the previous 4 weeks, with estimated frequency. Temperatures in the NSA buildings were generally kept within recommendations of the American Society of Heating, Refrigeration, and Air-Conditioning Engineers[19] (ASHRAE), and conditions outside these accepted standards were rare. Respondents to the questionnaire reported discomfort due to the following causes: temperature too low (48%), temperature too high (39%), stuffy air/too little air movement (37%), dry air (32%), and excessive variability in air temperature (31%). Respondents also reported that workstations were very/somewhat dusty/dirty (59%), near live plants (47%), and had trash/recycling accumulations (29%). Given documented environmental conditions at or about the time the questionnaire was administered, the questionnaire responses reflect perceptions of the environment and individual discomfort within the ASHRAE guidelines, not extreme environmental conditions.

Table 5 presents the findings for environmental sampling and monitoring. Air temperature, relative humidity, maximum CO, and PM_{10} (particulate matter with an aerodynamic diameter $<10\ \mu$m) showed statistically significant ($p < .05$) seasonal variation but maximum ozone and $\Delta CO_{2\bullet max}$ did not.

Dust levels were highly variable, ranging from 286 thousand to over 13 million counts per gram, but skewed to lower levels. Dust consisted of desquamated skin cells, which constituted the largest amount by count, as well as fungal spores, fibrous glass particles, other fibers. There was no correlation between total dust load (in count/g dust) and spore count.

Mold spore counts are presented in Table 6, expressed as geometric mean and maximum value observed by month for 3 months, March, July, and November. All counts and indicators showed a log-normal distribution except the ratio of potentially water indicator species to total spore count, which showed a mostly linear distribution, probably reflecting the underlying distribution of free water conditions rather than spore count. Mold assessments were performed by 7 different variables: Mycometer enzyme activity, total spore count (mean = 836.4/m^3, $SD = 3868.6$), ratio of spore counts indoor to outdoor (mean = 0.25, $SD = 0.56$), count

Table 4. Derived scores for environmental and work-related conditions.

Score for	Component variables	Formulae	Range
Discomfort	Too much/little air movement, too hot/cold Large temperature changes, too humid/dry/stuffy	0 = not in last 4 weeks 1 = 1 workday/week 2/5 = 2–3 workdays/week 4/5 = every/almost every workday	0–36
Odors	Experienced odor per descriptors: musty/damp, electrical, new carpet/furniture, food, chemical, copier-related, body, sewer, other	0 = not in last 4 weeks 1 = 1 workday/week 2/5 = 2–3 workdays/week 4/5 = every/almost every workday	0–45 (many odors frequently noticed)
Environmental conditions (total)	Symptom-days applied to discomfort, odor, and distracting noise, then summed	Discomfort score + odor score + distracting noise	0–85.5
Cleanliness (housekeeping)	(1) Pests, (2) Unclean food storage, (3) Accumulation of trash, (4) Work station clean?	Count 1 for each positive response to the 4 component variations	0–4
Water-related problems	(1) Water leak, (2) Visible water damage, (3) Visible mold, (4) Ceiling tiles replaced, (5) Air vent discoloration	Count 1 for each positive response to the 5 component variations	0–5
Renovation activities	(1) New carpeting, (2) New furniture, (3) New partitions, (4) Walls painted, (5) Odor from new carpet or furniture, (6) Other building renovation	Count 1 for each positive response to the 6 component variations	0–6
Job stress	Responses to multipart question: "How often is work…": (1) Interesting, (2) Overburdened, (3) Responsibilities unclear, (4) Expectations unclear, (5) Conflicting tasks	Weight each by 0 if rarely to 4 if always, sum weighted responses for score. (Wording on questionnaire was slightly different.)	0–20
Job influence	Responses to multipart question: "How much influence do you have over…": (1) your workload, (2) Availability of materials to do your work, (3) Arrangements of furniture, (4) Control of temperature and ventilation at work station	Weight each by 0 if rarely to 4 if always, sum weighted responses for score.	0–20
Responsibilities outside work	(1) Child care, (2) Housekeeping at home, (3) Elder/disabled dependent care, (4) Long commute, (5) ≥5-Hour commitment or personal time	Count 1 for each positive response to the 5 component variations	0–5

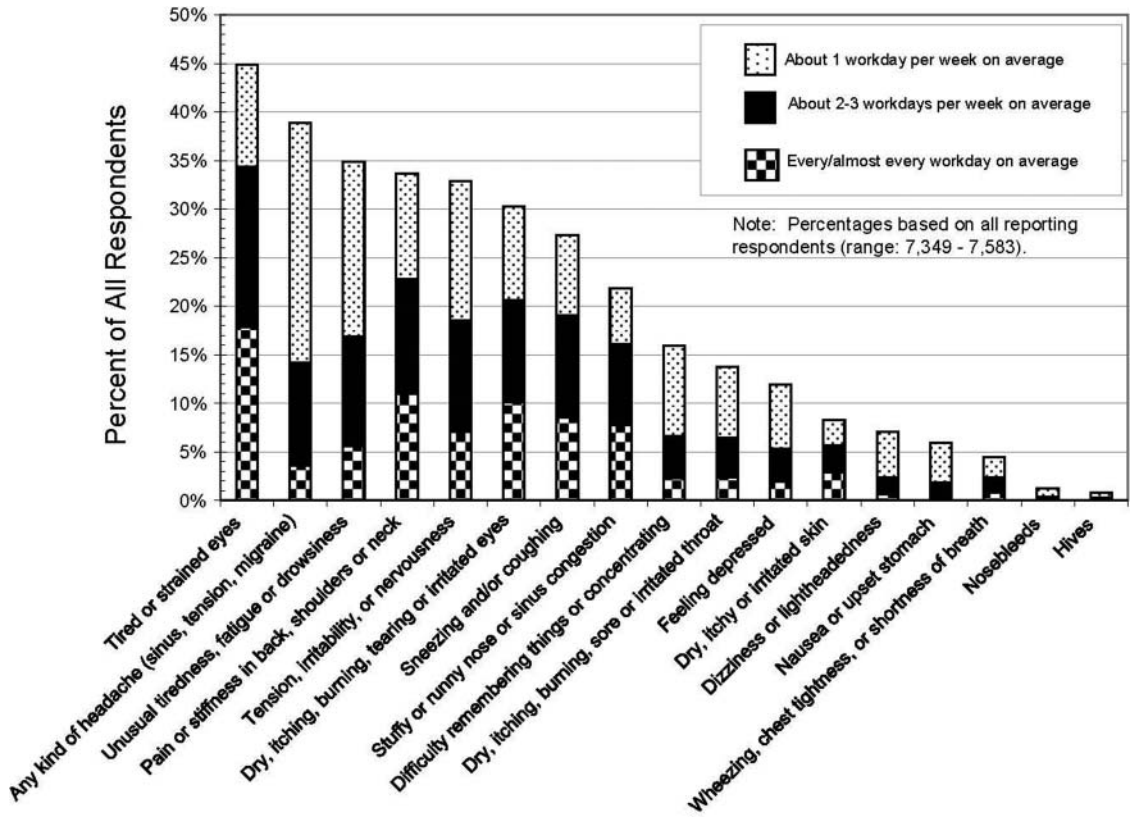

Figure 2. Distribution of environmental complaints by duration.

Table 5. Environmental measurements in 12 buildings at NSA campus.

Environmental factor	Mean (Geometric, G; Arithmetic, A)	Standard deviation (if applicable)	Maximum [minimum] value observed	Reference value and source	Correlation with multiple respiratory symptoms[a]	Correlation with SBS symptoms[a]
Air temperature[b]	22.14°C G 71.85°F G		22.84°C/73.12°F [min 21.43°C/70.58°F]	ASHRAE	N.S.	N.S.
Relative humidity[b]	37.4% G		40.13% [min 34.7%]	ASHRAE	$r^2 = .1465$ $p < .001$ for both max and min, for reduced symptom reports	N.S.
Allergen	Cat: 5.4 μg/g (est.) A Dog: 6.8 μg/g (est.) A		Cat: 38 μg/g Dog: 45 μg/g	Cat: 39.0 μg/g Dog: 37.5 μg/g (convention: $1\frac{1}{2}$ times limit of detection)	N.S.	N.S.
Carbon dioxide maximum ($CO_{2\bullet max}$)[b] and CO_2 maxima difference ($\Delta CO_{2\bullet max}$)[c]	Max CO_2: 770.34 ppm G ($\Delta CO_{2\bullet max}$): 365.57 ppm G		($CO_{2\bullet max}$ 95th %ile: 1,164 ppm) ($\Delta CO_{2\bullet max}$ 95th %ile: 737 ppm)	ASHRAE ($\Delta CO_{2\bullet max}$: 700 ppm	See text	N.S.
Carbon monoxide maximum	1.07 ppm		95th %ile: 2 ppm	50 ppm TWA (OSHA PEL)[d]	N.S.	ANOVA, $p = .0005$ (inverse correlation)
Dust	See text				N.S.	N.S.
Formaldehyde	0.010 ppm G	0.008 ppm	0.046 ppm	LEED Building Criterion: 0.05 ppm	$r^2 = .014$ $p = .16$	$r^2 = .0084$ $p = .59$
Light	430.56 lux A			IESNA: 430–538 lux for computerized office	N.S.	N.S.
Mold (Mycometer)	96.2 A	288.2	1,748.6	Manufacturer standard: $\leq$25	ANOVA, $p = .57$	ANOVA, $p = .35$
Mold (spore count)	123.9 G, 836.4 A	3,868.6	28,133 (outlier)	<1000 (convention)	N.S.	N.S.
Ozone maximum	0.01 ppm		95th %ile: 0.02 ppm	0.1 ppm TWA (OSHA PEL)[d]	N.S.	N.S.
PM_{10} (max)[b]	0.012 mg/m^3 G		95th %ile: 0.04 mg/m^3	ASHRAE 0.15 mg/m^3 (24-hour)	N.S.	ANOVA, $p = .01$ (inverse correlation)
Sound level	53.47 dB G	59.67 dB	47.58 dB	90 dBA TWA (OSHA PEL)[d]	N.S.	N.S.
VOCs (63 compounds)	132.4 ppb A	99.3 ppb	475 ppm		N.S.	N.S.

[a] Correlation of maximum level observed in each study area against health indicator specified.
[b] Variable found to have statistically significant seasonal differences, appropriate adjustments made prior to analysis. ASHRAE standards vary by season.
[c] Difference between maximum CO_2 concentration found inside and outside building.
[d] Permissible exposure level (PEL), 8-hour time-weighted average, Occupational Health and Safety Administration.

Table 6. Mold spore counts by sampling month.

Spore	Sampling month	*n*	Geometric mean	95% CI		Arithmetic mean	95% CI	
Max total spore count in SA (/m^3)	March	17	81.6	41.9	158.7	202.4	−18.0	422.8
	July	41	161.0	101.5	255.4	1,269.9	280.2	2,820.1
	November	9	34.7	16.4	73.3	59.1	−8.9	127.1
AsPen indicator species spores (/m^3)	March	17	17.7	8.2	38.0	31.8	17.2	46.4
	July	41	18.0	9.4	34.5	115.1	−5.1	235.3
	November	8	2.0	0.4	10.3	31.6	−43.2	106.4
Water indicator species spores	March	17	21.0	9.3	47.4	40.1	21.6	58.5
	July	41	22.3	13.2	37.5	106.3	−4.7	217.3
	November	9	2.3	0.5	10.0	28.9	−35.7	93.5

of *Aspergillus* and *Penicillium* (AspPen) spp. (mean = 82.0/m^3, *SD* = 287.4), ratio of AspPen spp. count to total spore count (mean = 0.25, *SD* = 0.30), count of potentially water indicator spp. (*Aspergillus*, *Aureobasidium*, *Chaetomium*, *Cladosporium*, *Eurotium*, *Paecilomyces*, *Penicillium*, *Scopulariopsis*, *Stachybotrys*, *Trichoderma*, *Wallemia*) (mean = 79.1/m^3, *SD* = 278.1), and ratio of potentially water indicator spp. to total spore count (mean = 0.30, *SD* = 0.31). All 7 mold variables were tested by correlation analysis for association with symptom groups and with allergy-related symptom groups and with the frequency of respondents by study area in reporting high scores for discomfort, renovation, odor, and water issues, and low scores for cleanliness and environmental quality; no statistically significant associations were observed ($p > .05$ for all). No correlation was found between the 7 mold measures and frequency of SBS symptoms, by ANOVA and *t* test ($p > .18$ for all).

One location was found to have visible mold growth due to the overflow of a condensation pan. This was discovered because of the exceptional mold spore count. The space was immediately remediated, and subsequent testing showed no further mold amplification. The space was not associated with a symptom cluster. This was the only study area to show visible mold growth.

Most allergen samples were below or close to the limit of detection. Only 3 cat and 3 dog allergen samples were above the conventional threshold for concern, which is $1^1/_2$ times the detection limit. The cockroach and dust mite samples were below the level of detection and could not be analyzed. None of the allergen samples showed an association with symptoms by ANOVA and *t* test.

Pest and rodent sightings, notwithstanding an aggressive integrated pest management program on site, were mentioned by 12% of respondents in the questionnaire. However, this variable was never predictive in the regression analysis, either by itself or in combination with other indicators of cleanliness.

Epidemiological assessment

The overall response rate for the questionnaire was 49%, which is relatively high for studies of this type.

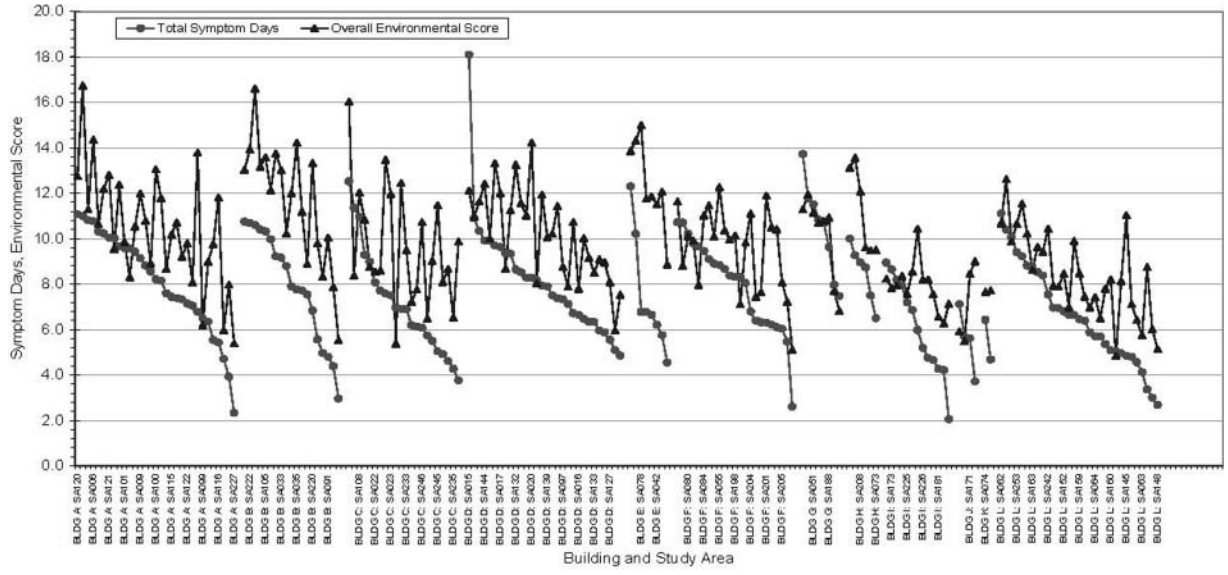

Figure 3. Distribution of environmental conditions: period-prevalent and symptom-days by building and study area.

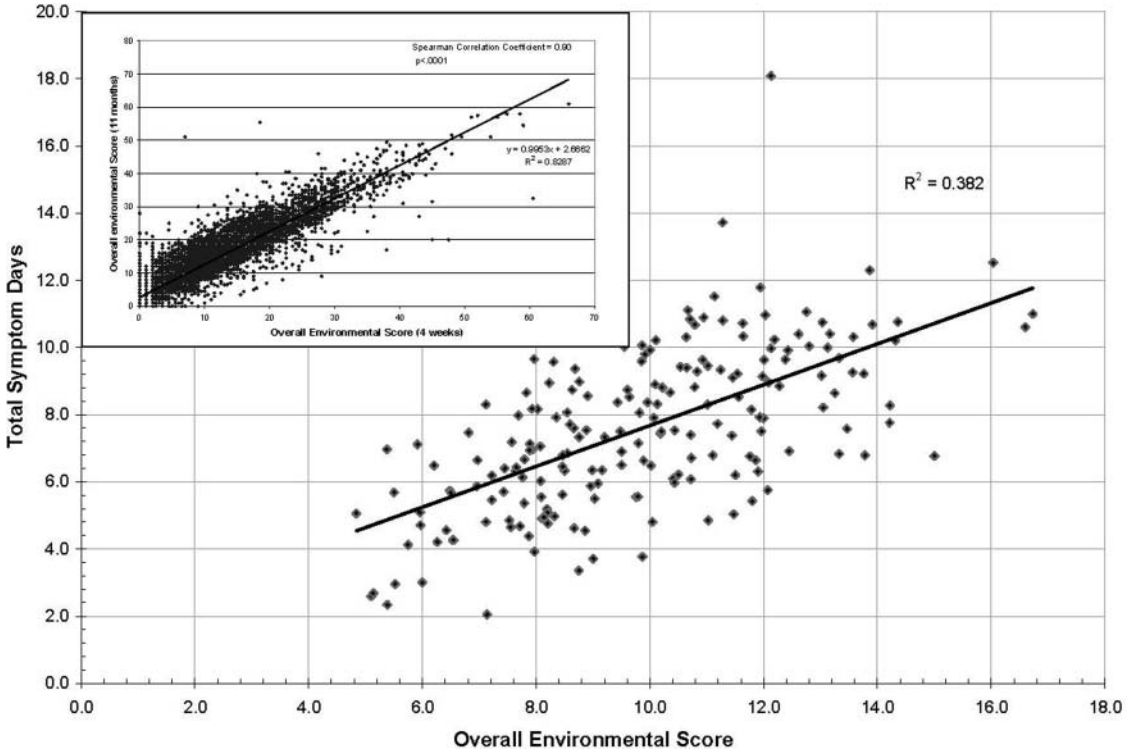

Figure 4 Correlation of period-prevalent symptom-days and environmental conditions. (Inset) Correlation between short- (4-week) and long- (11-month) term environmental scores.

Figure 3 presents the total symptom-days over the previous 4 weeks and total environmental score by study area and by building ($r^2 = .382$). The ranges for all building are roughly the same, but there is considerable variation among study areas within each building. Figure 4 shows the relatively high correlation ($r^2 = .382$) of symptom-days with environmental score. There was a very close correlation between symptoms reported recently (last 4 weeks) and long term (11 months), as shown in the inset Figure 4, inset. Because of the high correlation, findings in both periods were essentially identical.

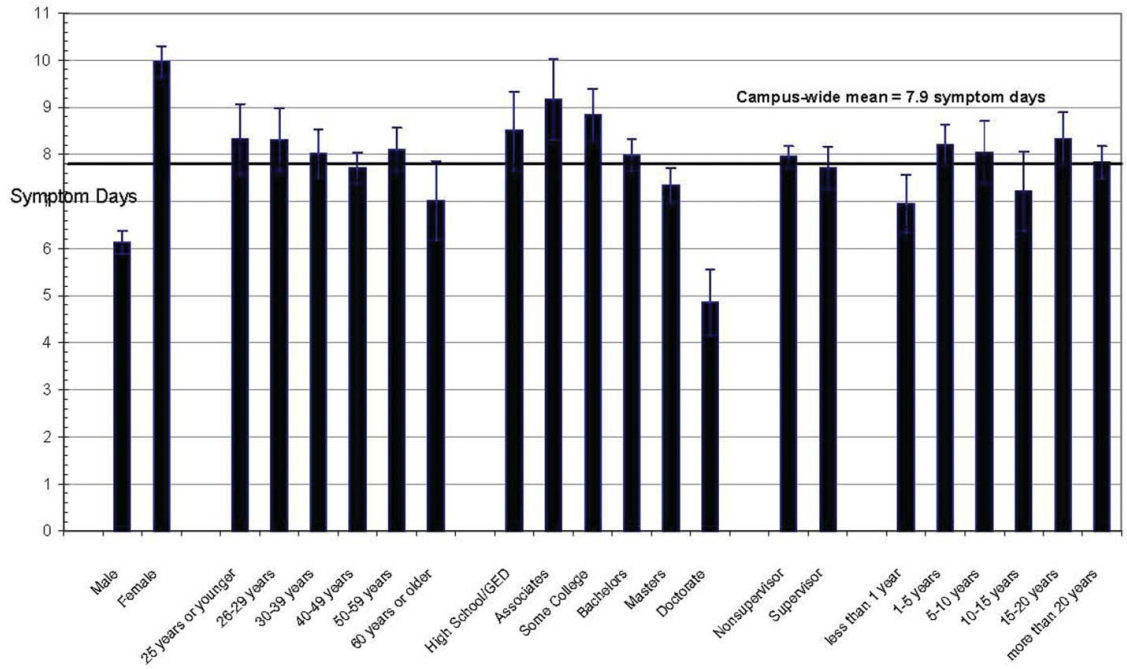

Figure 5. Reported symptom-days by demographic characteristics in the NSA population.

Table 7. Symptom prevalence compared with EPA BASE study.

	Number of respondents and associated proportional %				
	NSA study		EPA BASE study		Test of proportions
Reported symptoms or health conditions	*n*	%	*n*	%	*p* value
Dry, itching, burning, tearing, or irritated eyes	7,524	59.1	4,081	58.52	.54
Tired eyes	7,518	72.1	4,070	62.19	<.0001
Dry, itching, burning, sore or irritated throat	7,487	31.5	4,006	44.13	<.0001
Stuffy or runny nose or sinus congestion	7,528	63	4,103	62.86	.88
Wheezing, chest tightness, or shortness of breath	7,443	11.4	4,061	21.98	<.0001
Dry, itchy, or irritated skin	7,461	36.32	3,998	38.62	.02
Eczema	7,577	10.8	3,972	8.63	.0002
Sneezing and/or coughing	7,492	61.2	4,103	58.56	.006
Any kind of headaches	7,583	59.1	4,092	67.45	<.0001
Migraine headache	6,711	15.9	4,099	21.46	<.0001
Migraine (males)	3,575	7.75	1,400	10.57	.001
Migraine (females)	3,061	25.5	2,679	27.17	.15
Tension headache	6,376	11.5	NA	NA	NA
Musculoskeletal headache	7,149	6.1	NA	NA	NA
Sinus headache	6,657	15.23	NA	NA	NA
Unusual tiredness, fatigue, or drowsiness	7,534	54.5	4,069	55.91	.15
Difficulty remembering things or concentrating	7,544	38.9	3,985	33.32	<.0001
Dizziness or lightheadedness	7,432	14.3	4,005	23.52	<.0001
Tension, irritability or nervousness	7,426	49.4	3,996	51.63	.02
Pain or stiffness in back, shoulders, or neck	7,477	63.9	4,080	60.98	.002
Depression	7,414	23.3	3,976	30.18	<.0001
Nausea or upset stomach	7,427	14.9	3,986	26.69	<.0001
Nosebleeds	7,399	4.2	NA	NA	NA
Hives	7,349	2.3	NA	NA	NA
Asthma	7,589	12.5	4,032	12.38	.85
Allergy/hay fever	7,582	45.6	4,208	42.25	.0005
Sinusitis or sinus infection	7,583	48.3	NA	NA	NA
Sarcoidosis	7,585	0.55	NA	NA	NA

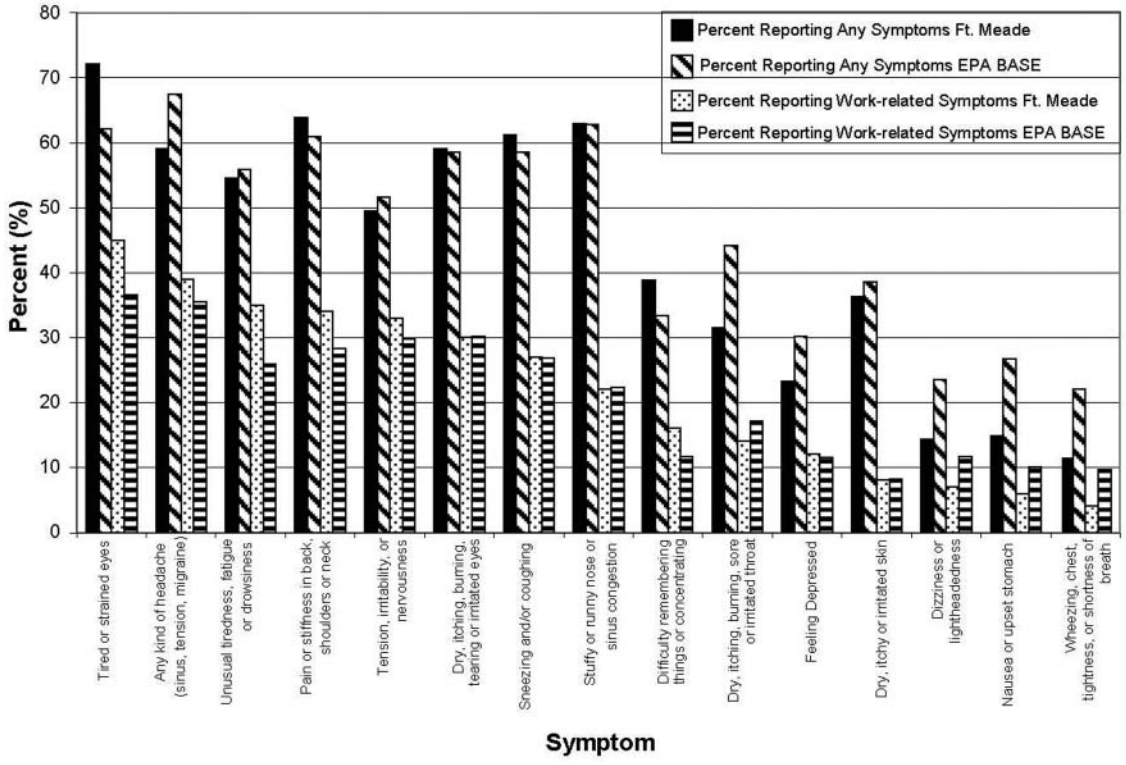

Figure 6. Symptom prevalence and reported relationship to work.

Figure 5 presents the distribution of self-reported symptoms by demographic characteristics. Symptom-days tended to be higher for female, younger, and less well-educated employees, with no association with duration of employment or supervisory responsibilities.

A negative correlation was found between lower respiratory symptom prevalence ($r^2 = .165$, $p < .001$) and multiple respiratory symptom group prevalence and maximum and minimum values of relative humidity within a study area ($r^2 = .147$, $p = .001$). This suggests that dryness or lack of humidity was exacerbating lower and upper respiratory symptoms. Additionally, minimum sound levels were also negatively associated with lower respiratory symptom-days ($p \cong .005$); the study team determined no known biological association for this relationship and therefore considered it spurious. There was no association between these and other symptom groups and no association between any symptom groups and the other environmental sampling and monitoring data.

Table 7 presents the symptom prevalence over the previous 4 weeks as compared with the EPA BASE study. NSA employees reported tired eyes, eczema, sneezing or coughing, difficulty with memory, neck and back stiffness, asthma, and allergies more often than the EPA BASE population, but the differences were small. On the other hand, NSA employees reported much lower prevalence of respiratory tract symptoms, episodes of dizziness or lightheadedness, nausea or upset stomach, and depression. Figure 6 presents symptoms reported by the NSA population compared with the EPA BASE study along with percentages of employees reporting of work-related symptoms (ie, gets better when leaving work). Figure 7 presents health conditions reported as diagnosed by a physician among NSA respondents. Sinusitis and allergies were reported most frequently. Special attention was given to definitions in the questionnaire items. Respondents were considered to have had allergies if they reported ever having been diagnosed with hay fever or allergy to a specific allergen; sinusitis if they reported ever having been diagnosed with sinusitis or sinus infection; asthma if they reported ever having been diagnosed with asthma and had one of the following: current asthma medication, at least 1 asthma episode since entering employment at NSA, or had been diagnosed with asthma since entering employment at NSA. This was done to exclude individuals with a history of childhood asthma but no recent events.

General environmental monitoring in the study areas were analyzed for associations with reported SBS clusters. Both CO and PM_{10} showed statistically significant inverse associations with symptoms by tercile. The levels were low, the association was small, and the relationship

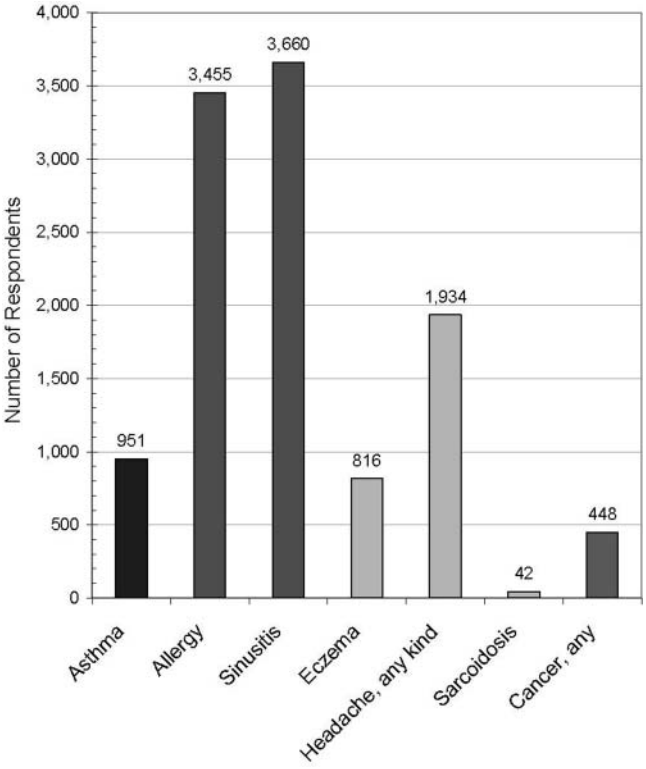

Figure 7. Health conditions reported to have been diagnosed by a physician.

was inverse, suggesting a random statistical association. No statistically significant association was found for other study area environmental factors, including mold spore count, maximum and minimum relative humidity, ozone, maximum and minimum temperatures, and formaldehyde.

Environmental sample and monitoring results in occupants' personal workspace during the individual health evaluations were analyzed for association with change in pre-and postshift FEV_1. No statistically significant association was found for environmental factors,

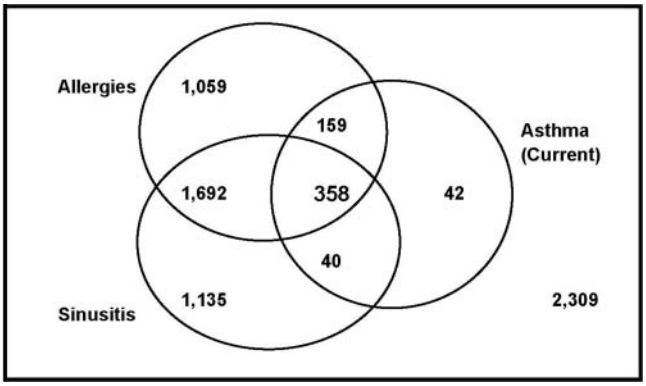

Figure 8. Venn diagram of distribution within allergic diagnostic group.

including mold spore count, maximum and minimum relative humidity, ozone, CO, PM_{10}, maximum and minimum temperatures, and formaldehyde. FEV_1 change did show a borderline statistically significant association (by ANOVA, $p = .04$; t test, $p = .06$) with $\Delta CO_{2\bullet max}$. However, the pre/postshift change did not show a gradient associated with $\Delta CO_{2\bullet max}$, and the highest trans-shift change was observed in the lowest tertile of $\Delta CO_{2\bullet max}$.

Figure 8 is a Venn diagram showing the overlap of symptoms associated with allergy and asthma. There were 599 subjects with asthma, of whom 93% had other symptoms of allergy, including sinusitis. Figure 9a and b present the distribution of symptom-days for selected symptoms for each health symptom category pertinent to sinusitis, asthma, and allergies. All symptoms tended to occur most often and for longer within broader allergy symptom categories, especially for work-related symptoms. Subjects with more symptoms suggesting allergy or asthma showed an increased number of days absent or presenteeism (Figure 10a, b, and c).

Work organization

Work-related stress emerged as a major concern during the study. However, the questionnaire, and the EPA BASE study on which it was based, had not been designed to assess this dimension of the work environment in detail. Three items in the questionnaire that indirectly captured information on stress (clarity of job responsibility, expectations of others, and conflicting tasks) were taken together as a stress index. Additionally, questionnaire items regarding job stress and "job influence" (the "control" factor of the Karasek demand-control model) were analyzed.[20,21]

The EPA BASE study and 2 other reference populations were used for comparison: the Library of Congress Madison Building ($N = 2{,}773$, studied in 1989) and the EPA Waterside Mall building ($N = 3{,}022$, studied in 1989), each of which had a long history of occupant complaints. Figures 11 and 12 show the distribution of responses to each item in 4 studies: the current study, the EPA BASE study, and investigations of the Library of Congress Madison Building and EPA Waterside Mall. Job satisfaction scores are presented in Figure 13, with 5 relevant comparisons; NSA employees reported similar levels of job satisfaction to comparison workplaces, an unexpected finding. This was apparent despite the intense demand under which the NSA population operates. The results demonstrated that the distribution of reported stress levels were similar across these 4 very different buildings and working populations.

Multivariate analysis

The stepwise regression for all NSA respondents showed consistent results for almost all models in demonstrating

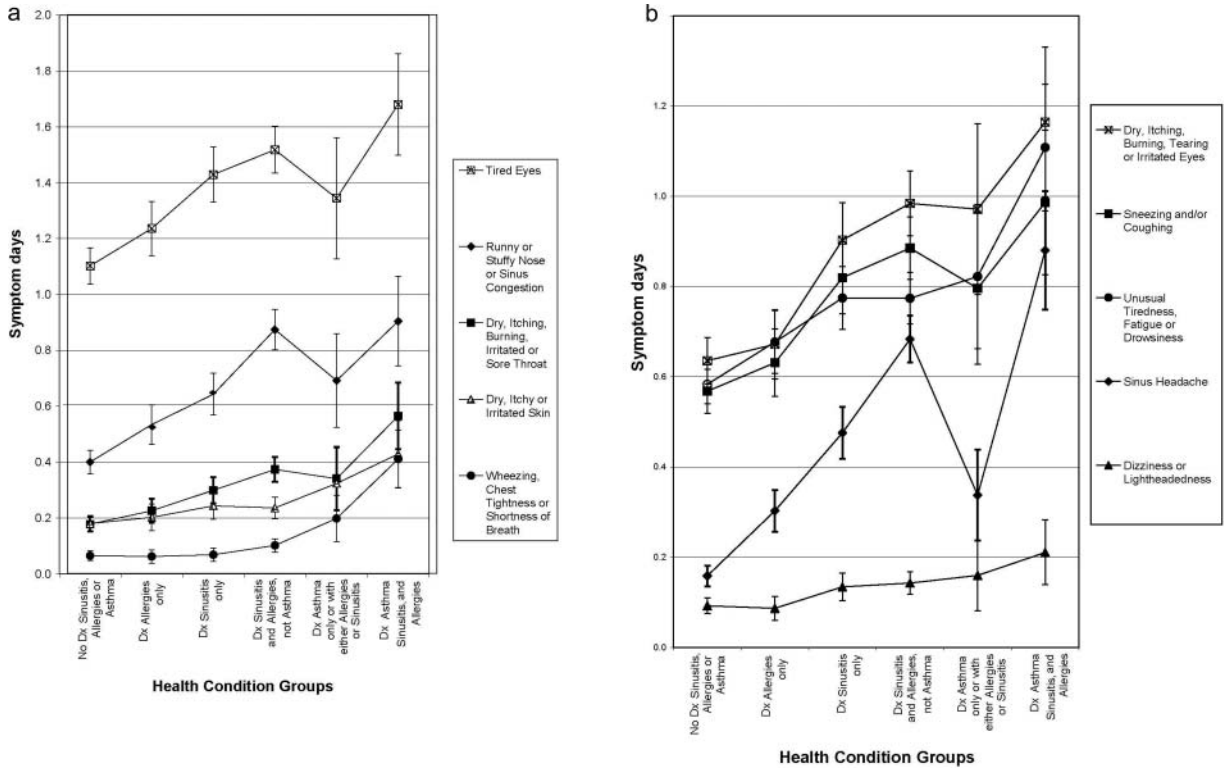

Figure 9. (a and b) Symptom-days for selected symptoms by health symptom category.

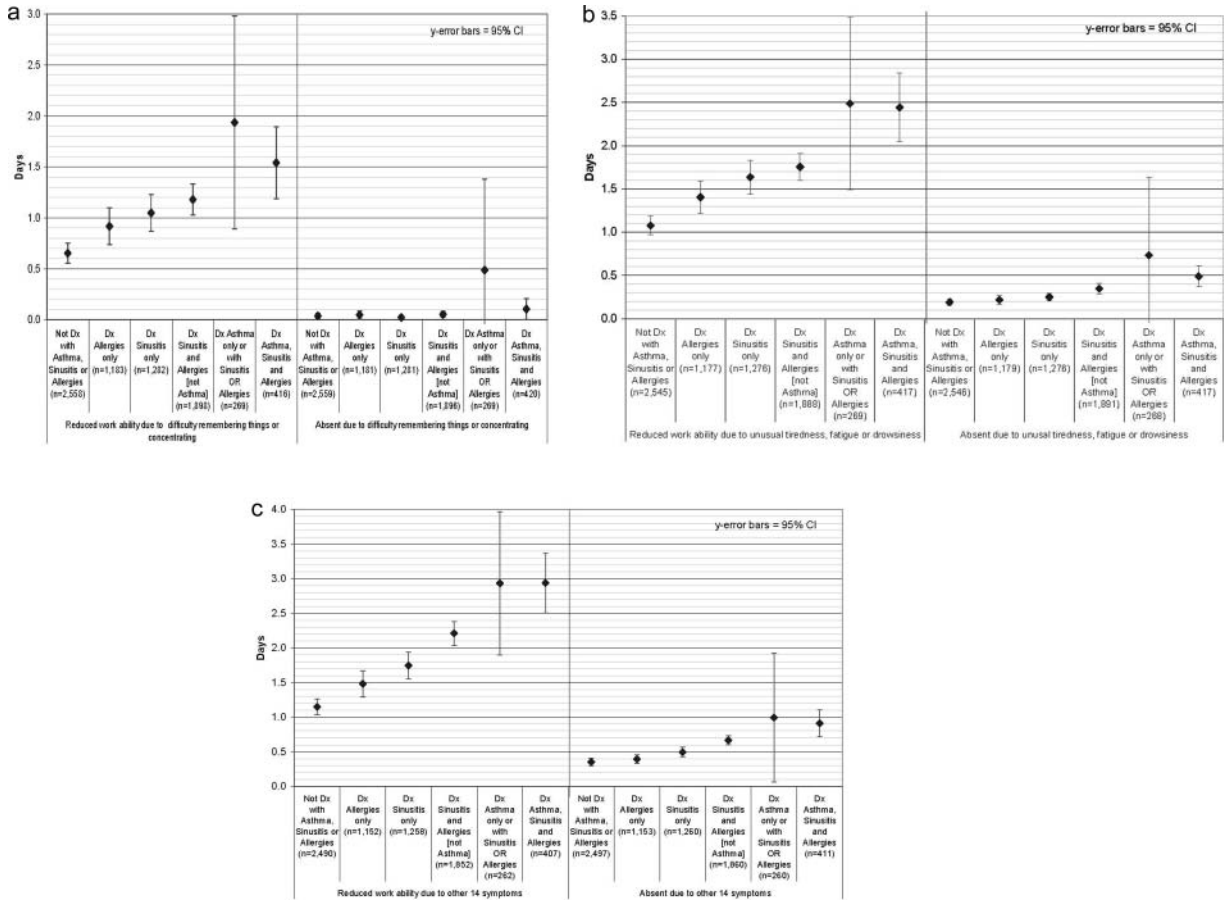

Figure 10. (a) Days presenteeism or absence by diagnosis group for difficulty concentrating. (b) Days presenteeism or absence by diagnosis group for unusual tiredness, fatigue. (c) Days presenteeism or absence by diagnosis group for 14 other symptoms.

4 variables that were most predictive of symptom outcome (all $p < .0001$). These were discomfort ($r^2 = .154$, estimated .283 symptom-days per respondent per score point), total days per week with odor ($r^2 = .043, .304$), job stress score ($r^2 = .026, .267$), and glare at the workstation ($r^2 = .022, .891$).

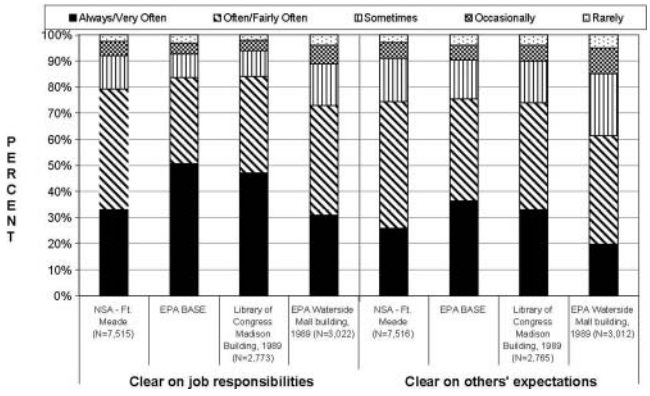

Figure 11. Comparison of job stress levels—job responsibilities and expectations: comparing NSA employees with 3 relevant comparisons.

Comment

The current study ranks among the largest studies investigating the relationship among building characteristics, workplace characteristics, symptoms experienced by occupants, and personal health status. As such, it has greater power to resolve associations than most similar investigations. Because of multiple comparisons, many statistically significant associations are unlikely to be of functional significance and some, because of the large number of comparisons made, are likely to have arisen by chance alone (eg, the association between minimum sound levels and lower respiratory symptom-days). For this reason, converging evidence was sought in this report rather than placing emphasis on single, isolated findings.

The major advantages of this study were its scale, the opportunity to match environmental sampling and monitoring data with reported symptoms, and the documented absence of a substantial indoor air hazard. Recall bias was minimized by querying symptoms over the last 4 weeks and validated in longer-term reporting by

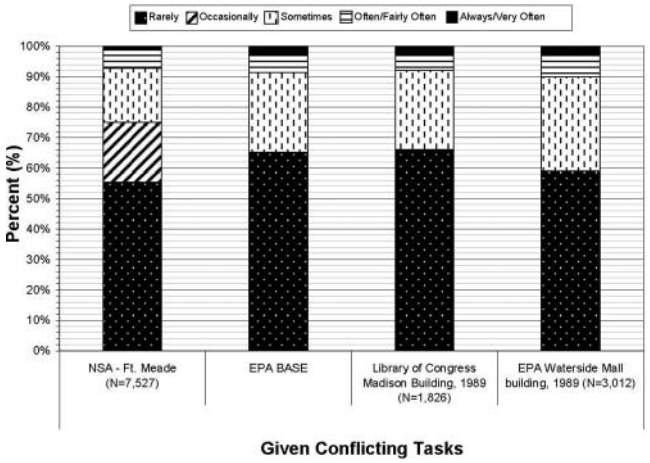

Figure 12. Comparison of job stress levels—conflicting tasks: comparing NSA employees with 3 relevant comparisons.

demonstrating consistency over the short and long term. Another advantage was the individual health evaluation arm, which allowed the investigators to "drill down" into the characteristics of the most susceptible group, something not possible in the EPA BASE study and rarely attempted in similar building-related studies.

This study was not designed as a research project and had to be conducted under operational limitations, reflecting the mission of the agency and security requirements. For example, all data had to be hand-recorded because electronic recording devices were not permitted. Although supervisory position could be determined, items pertaining to military rank or branch of service were not allowed and the response rate among the eligible military population (24.2%) was low compared with that for civilians, raising the possibility that respondents are not representative of military personnel at the site.

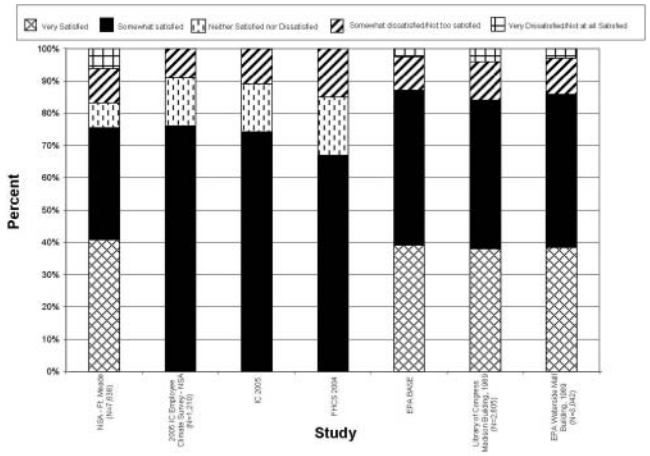

Figure 13. Job satisfaction reported by NSA employees with multiple relevant comparison studies.

This is unlikely to bias the findings overall, because active-duty military personnel were a small minority of the study population. Information on gender of the subject was obtained on the questionnaire and included in the analysis but was not available for the working population as a whole.

Environmental complaints and respiratory symptoms varied more among study areas within buildings than between buildings. This, and the variation in cleanliness measures, suggests that buildings should be evaluated area by area, with particular reference to the service area of the air handling unit.

The 4 most important environmental characteristics contributing to symptom frequency were (1) discomfort, (2) odor, (3) job stress, and (4) glare at the workstation. At the low levels observed in the present study, the usual exposures implicated as indoor air quality problems (formaldehyde, VOCs, mold, bioaerosols, PM_{10}, CO, CO_2, and ozone) were not associated with symptoms.

Discomfort was mostly driven by perceptions of temperature, relative humidity, and air exchange, even though these factors were kept within conventional guidelines. ASHRAE recommendations[19] are formulated to satisfy 80% of people, a figure validated with empirical studies. It is therefore not surprising that in any building complex there would be complaints about temperature and humidity arising from as many as 20% of occupants in buildings fully in compliance with ASHRAE recommendations. We conclude that both the discomfort index and the environmental conditions index primarily reflect individual tolerance and comfort rather than building characteristics. These indices function to identify respondents from the minority whose preferences and comfort level fall outside the ASHRAE-recommended range.

Odor was closely related to food (60%) and fragrances (26%). Odor was also closely related to housekeeping, which emerged as a significant concern for many occupants. In the NSA complex, some work areas are inaccessible to cleaners for weeks at a time for security reasons, but this is unusual.

Job stress emerged as the third major factor associated with self-reported building-related symptoms. Work at NSA is intensely stressful in terms of demand and sustained vigilance and is driven by military and national security concerns. In comments entered into the open-ended item of the questionnaire, respondents described 80-hour work weeks, hypervigilance, coming in for work on weekends, and lack of recognition of their work, both by society and within the organization. Thus, it was unexpected that job stress was reported no more frequently than in conventional settings. One possible explanation is adaptation over time, as small reductions

in the stress level from high sustained peaks may be perceived by employees involved as relief, in effect resetting the baseline and causing underreporting of stress relative to other workplaces. Another explanation may be selection bias, because the NSA's culture may select a unique working population.

Visual glare emerged unexpectedly as the fourth major factor associated with symptoms, a plausible contributor to the frequency of reports of eye strain, headaches, blurred vision, eye irritation, and neck and backaches observed among respondents. Other factors, such as low humidity (and therefore dry eyes), may interact with glare to cause additional eye discomfort.

Subjects with asthma, allergies, and sinusitis demonstrated greater responsiveness to environmental conditions, as measured by presenteeism and absence. Each of these conditions may occur individually, but when they occur together they are likely to be a marker for atopy, a hereditable condition of predisposing to allergy that is characterized by airways hyperreactivity. It comes as no surprise that subjects with diagnosed allergies and asthma are more likely to report symptoms of respiratory origin. However, they were also more likely to report symptoms of all kinds, including musculoskeletal complaints.

The association between a seemingly relatively benign environmental condition ($\Delta CO_{2\bullet max}$) and the degree of supradiurnal variation in airflow reduction was unexpected, given that atmospheres were within the range of ASHRAE guidelines and is not biologically plausible. This is likely to be a random statistical association of no biological significance, due to multiple comparisons, as suggested by the lack of an exposure-response and that the largest effect was in the least exposed tertile. Likewise, the associations between CO and PM_{10} and symptoms were small and in the wrong direction, and not biologically plausible for causation; they were also not supported by associations with the individual workplace monitoring data.

The present study fulfilled the Congressional mandate and was able to report that there was no building-specific factor that was associated with illness or symptoms among NSA personnel. The study identified a few areas within buildings where conditions were less than ideal. A number of recommendations were made to NSA, mostly related to housekeeping, job stress, and the response to future health-related complaints. These were taken under advisement and handled internally by OHESS.

We found that individuals with atopy, allergy, and/or asthma may experience symptoms manifest as discomfort, absence, and presenteeism despite building environmental conditions within standards and ASHRAE recommendations.

We extrapolate from the experience of this study that building-related health complaints should be investigated at the work-area level and not building-wide. The causes of building-related health complaints in "normal" buildings (without an identifiable air quality problem) are likely most often to be multifactoral, reflecting conditions that involve environmental comfort, cleanliness, job stress, and workspace glare but also individual host factors, particularly conditions associated with atopy and allergy. The investigation of building-related health complaints should of course rule out obvious indoor air quality issues. An occupant-centered medical evaluation, which requires a licensed health professional, should guide environmental investigations, especially when screening building air quality measurements show no exceptional hazard and the building and its work areas are in compliance with ASHRAE recommendations.[10] An occupant-centered medical evaluation can provide guidance regarding the environmental investigation and overcome any of the usual issues in building only investigations by focusing the investigation and providing evidence-based responsive risk communication.

List of abbreviations

ANOVA	Analysis of variance
ASHRAE	American Society of Heating, Refrigeration, and Air-Conditioning Engineers
AspPen	*Aspergillus* and *Penicillium* species of mold
BASE	Building Assessment Survey and Evaluation (an EPA study)
BHS	Building Health Sciences
EPA	(US) Environmental Protection Agency
FEV_1	Forced expiratory volume in 1 second
FIMS	(NSA) Facility Information Management System
HEPA	High-efficiency particulate air filter
HVAC	Heating, ventilation, and air conditioning
IEAQ	Indoor environmental and air quality
NIOSH	(US) National Institute for Occupational Safety and Health
NSA/CSS	(US) National Security Agency/Central Security Service
OHESS	Occupational Health, Environmental, and Safety Services
PM	Particulate matter
VOCs	Volatile organic compounds

Disclosures

This investigation was performed under contract on behalf of the National Security Agency, a US federal government agency. The work is now completed and the

report was released under the Freedom of Information Act (FOIA). There is no current conflict of interest.

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