OBJECTIVE MEASURES AND PERCEIVED RESPONSES OF AIR QUALITY IN TWO HOSPITALS

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ABSTRACT

Investigations of indoor air quality in healthy or problem buildings may produce objective and subjective data (occupant perceptions) which do not correlate and which are difficult to interpret. In this paper we investigate the relationship between objective and subjective measures in six matched sites of two hospitals, one hospital without known "sick building syndrome" (SBS) complaints, and a second hospital with known SBS complaints. Objective data were obtained for thermal, lighting, acoustic, and air quality parameters by direct-reading instruments or, in the case of selected volatile organic compounds, by collection on porous polymer media beds with subsequent GC/MS analysis. Subjective data are human responses to the environment, which were recorded via occupant questionnaire. All objective results met acceptable environmental and health evaluation criteria with the exception of dew point temperature in the hospital with SBS complaints. Perceptions of discomfort were reported by employees of both hospitals but these responses were noted more often in the hospital with known SBS complaints. Perceived responses of occupants are frequently more sensitive indicators of indoor air quality problems than are the objective measures conventionally relied upon for exposure evaluation. Therefore, effective building diagnostic protocols should incorporate observations, investigation of management strategies, measurement of environmental variables, and perceived responses to the environmental conditions as a basis for system evaluation, predictions of future system performance, and recommendations for improvements.

INTRODUCTION

Human responses to the indoor environment are affected by four primary types of environmental stressors: thermal, acoustic, illumination, and air quality. When these stressors are within acceptable limits, they may be perceived to be pleasant or comfortable. Buildings in which these responses are achieved may be characterized as "healthy buildings" (Woods 1988). However, if these stressors exceed acceptable limits, then discomfort, symptoms associated with "sick building syndrome" (SBS), or clinical signs indicative of "building-related illness" (BRI) are likely to result. Sick building syndrome is characterized by symptoms of acute discomfort (e.g., headache, dizziness, eye irritation, fatigue, sore throat, or nausea) which persist for more than two weeks at frequencies significantly greater than 20%; the cause(s) of these symptoms are not recognizable; a substantial percentage of occupants report almost immediate relief upon exiting the building. Building-related illness is characterized by symptoms of frank illness (e.g., fever, muscle ache, and tightening of the chest) which usually persist after leaving the building (Building Research Board 1985).

The goals of indoor air quality evaluations are to identify and control environmental stressors so that health risks are minimized and occupants perceive a healthful and comfortable environment. Objective and subjective measures can be utilized to evaluate the environment, particularly the indoor air quality. However, in some cases, complaints of symptoms or discomfort in nonindustrial facilities are the only manifestation of indoor environmental problems. The importance and difficulty in matching objective data with occupant perceptions have been recognized by several investigators, even in controlled studies (Bergland et al. 1982; Burge et al. 1987; Carlton-Foss 1984; Fanger 1988; Hodgson 1986; Kreiss et al. 1984; Building Research Board 1987; National Research Council 1981; Spengler 1983; Skov 1987). Even greater difficulty in diagnostic investigations may be caused by: 1) impracticality of using ideal instrument(s) or method(s); 2) confounding of human responses by other stressors (i.e., psychosocial conditions including labor-management relations and socio-economic status; or confounding factors, such as age, sex, smoking status, ethnicity, or pre-existing medical conditions); 3) instruments and methods used to obtain objective measures of environmental conditions are often less sensitive than the subjective instruments and methods used to measure occupant perceptions; and 4) impracticality of acquiring sufficient data for conventional statistical analysis.

This paper illustrates the point that evaluation of buildings, whether they are associated with SBS or not, may produce objective and subjective data which are not well correlated and which are difficult to interpret. It is important to note that this paper is based on two field investigations which, by nature, are limited in scope, rather than controlled research studies.

PROCEDURES

Site Selection

To investigate the relationship between objective and subjective measures, two buildings have been selected with similar functions and populations and which are located in the same region within the United States. Hospitals have been chosen because they offer a wide variety of functional categories—some unique—but many that are also similar in function to commercial, administrative, or institutional buildings. For example, administrative functions within a hospital are similar to the administrative function in an office building and the laboratory suite of the hospital is comparable to a laboratory in an educational or institutional setting. These comparable functional categories between hospitals and other buildings are possible because of similarities between activities, populations, and environmental conditions. Thus, the findings within hospitals are apt to represent buildings at large.

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The two hospitals are located in the metropolitan area of a large city in the northeastern United States. Hospital A was used to test indoor air quality procedures and equipment and had no known occupant complaints or symptoms related to indoor air quality. Hospital B was one in which a substantial number of occupants reported thermal discomfort problems and symptoms associated with sick building syndrome and, possibly, building-related illness.

Hospital A is located in a suburban area and contains approximately 270 beds in a total floor area of approximately 292,000 ft². The hospital was built over three construction periods during the mid-1940s, late 1960s, and early 1970s. The two older sections of the hospital had undergone extensive renovation. Heating, air-conditioning, and ventilation in Hospital A were provided by 24 supply and 39 exhaust systems located in 10 mechanical equipment rooms throughout the hospital, in addition to perimeter heating systems in the nursing areas.

Hospital B is located in the core of the metropolitan area and contains about 430 beds in a total floor area of approximately 387,000 ft². Most of Hospital B was built in the early 1960s, however, an addition was completed in the mid-1980s. Most of the hospital had not undergone substantial renovation. Heating, air-conditioning, and ventilation were provided by 10 air-handling systems in addition to perimeter heating systems in the nursing area.

A notable difference between the two hospitals was the relative importance placed on the engineering departments. In Hospital A, the director of facilities management reported to the hospital administrator. The director was a professional engineer and was active in professional organizations. The engineering staff was well-trained and capable of all aspects of facilities operation and maintenance. An excellent set of as-built drawings was maintained. The engineering department had excellent relations with the medical and administrative staffs and had the authority to execute its responsibilities. In Hospital B, the hospital engineer was two levels of management removed from the hospital administrator. Although the hospital engineer had formal engineering education, he was not registered nor was he active in professional organizations. The skeleton staff was not trained in all aspects of facilities operation or maintenance. As-built drawings did not exist. The engineering department was not respected by the medical or administrative staffs and little authority was given to the department to execute its responsibilities.

Measurements

Objective and subjective environmental data were obtained at both hospitals. These data were collected at several different sites within the various functional areas of each hospital. Representative sample sites at each hospital were selected with the use of a "standardized site selection procedure" developed for diagnosis of indoor air quality problems. This selection process was accomplished through the visual evaluation of each room in order to assign the room scores for three indices: 1) contaminant sources, 2) susceptibility of the occupants, and 3) ventilation effectiveness. Generally, the room having the most undesirable combination of these three characteristics was selected as the sample site for the functional area that it represented (i.e., "maximum potential exposure site"). Data acquisition periods were typically 90 minutes at each site.

Comparison of the sample sites of the two hospitals identified six pairs of sites which emerged as having sufficient similarities to allow comparison of the objective and subjective data obtained at each of these sites. These six pairs of sites represent six different functional categories. Table 1 lists the six pairs of sites discussed in this paper.

TABLE 1

Sites Selected for Comparison of Objective and Subjective Measures.

Site No.	Functional Category	Hospital A	Hospital B
1.	Administrative Facilities	Medical Records	Medical Records
2.	Diagnostic Treatment Facilities	Laboratory Suite — Chemistry Lab	Laboratory Suite — Chemistry Lab
3.	Nursing Facilities	Patient Room — Oncology	Patient Room — Oncology
4.	Surgical Facilities	Cystoscopic Room	Operating Room
5.	Central Sterilizing & Supply	Sterilization Room including Wraproom	Sterilization Room including Wraproom
6.	Obstetrical Facilities	OB Recovery Room	OB Recovery Room

Objective Measures

Objective data were obtained for thermal, lighting, acoustic, and air quality parameters. Thermal measures include dry-bulb temperature, dew point temperature, plane radiant temperature, and air movement, which were measured by a platinum resistance element, chilled mirror mechanism, radiant heat exchanger, and an anemometer, respectively. Lighting measures in terms of illuminance were obtained by a cosine-corrected silicon photocell. Acoustic measures, specifically sound pressure levels, were obtained through the use of a sound level meter with an A-weighting.

A number of air quality components were measured, including particulate size distribution, particulate mass, microbiological aerosols, oxides of nitrogen, carbon dioxide, various volatile organic compounds, and ventilation rates. Particulate counts by size distribution (≥ 0.3 μm diameter) were obtained by an instrument utilizing a light-scattering mechanism; and total mass of particulates in the size range of 0.1 to 20 μm was also measured by a light-scattering instrument. Microbiological aerosols were collected via a multi-orifice, single-stage impactor onto 100 mm agar plates with media selective for the growth of mesophilic fungi according to the American Conference of Governmental Industrial Hygienists' guidelines for sampling and assessing bioaerosols (Burge et al. 1987). The oxides of nitrogen were quantified using an instrument that utilized chemiluminescence. Carbon dioxide (CO_2) data were obtained with an infrared analyzer.

The methods of measuring selected volatile organic compounds (VOC) varied between the two hospitals. One of the objectives in the study of Hospital A was to develop a diagnostics protocol and to select air quality indicators and methods of measuring air quality components. The instrument selected for use in Hospital A for measuring air quality constituents utilized fourier transform infrared spectrophotometry. Interferences from atmospheric water and ambient carbon dioxide masked the low VOC concentrations, so a more selective method of VOC analysis was chosen for Hospital B. In Hospital B, VOC were collected on porous poly-

TABLE 2

Comparison of Thermal Data in Two Hospitals.

Functional Area	Site	Hospital A (n = 90) Dry-Bulb Temp. (Mean ± SD°C)	Hospital A (n = 90) Dew Point Temp. (Mean ± SD°C)	Hospital B Dry-Bulb Temp. (Mean ± SD°C)	Hospital B Dew Point Temp. (Mean ± SD°C)	n
Medical Records	1	24.2 ± 0.1	13.8 ± 0.1	25.9 ± 0.6	1.1 ± 0.2	n = 90
Chemistry Lab	2	24.4 ± 0.6	12.0 ± 0.1	24.4 ± 0.2	2.1 ± 0.6	n = 88
Patient Room	3	26.8 ± 0.3	16.2 ± 0.2	26.6 ± 0.4	−2.7 ± 0.3	n = 87
Surgical Facilities	4	19.6 ± 0.2	9.6 ± 0.3	19.1 ± 0.2	−1.8 ± 0.3	n = 117
Central Sterilizing and Supply	5	24.5 ± 0.3	17.2 ± 0.2	27.4 ± 0.6	1.9 ± 4.7	n = 90
OB Recovery	6	26.2 ± 0.1	17.0 ± 0.2	22.8 ± 0.1	−4.4 ± 0.5	n = 90
Outdoor Site		27.0 ± 3 (n = 17)	25.0 ± 3 (n = 17)	9.9 ± 1.5	−5.8 ± 0.8	n = 60

TABLE 3

Comparison of Aerosols in Two Hospitals.

Functional Area	Site	Particulates (Mean + S.D.) Count (# In Millions of > 0.3 μm/m³) A	Particulates (Mean + S.D.) Count (# In Millions of > 0.3 μm/m³) B	Microbial Concentration (n = 1) (CFU/m³) A	Microbial Concentration (n = 1) (CFU/m³) B
Medical Records	1	30.0 ± 3.9 (n = 90)	10.6 ± 2.7 (n = 87)	37	53
Chemistry Lab	2	18.6 ± 5.9 (n = 90)	12.7 ± 4.1 (n = 90)	53	53
Patient Room — Oncology	3	173.5 ± 16.0 (n = 90)	10.4 ± 0.5 (n = 90)	27	106
Cystoscopic/O.R.	4	4.3 ± 0.2 (n = 90)	4.8 ± 0.9 (n = 120)	25	9
Central Sterilizing and Supply	5	68.2 ± 39.8 (n = 90)	63.4 ± 7.8 (n = 90)	42	82
OB Recovery	6	65.5 ± 7.6 (n = 90)	164.4 ± 2.3 (n = 89)	19	94
Outdoor Site		96.7 ± 14.6 (n = 76)	20.8 ± 1.1 (n = 59)	NA	88–212 (n = 6)

NA = Not Available

mer adsorbent beds which were thermally desorbed, cryofocused, and analyzed via capillary gas chromatography/mass spectrometry. Differences in VOC methods between Hospital A and Hospital B made it difficult to compare data between the two hospitals.

Ventilation rates were determined by at least one of three methods: 1) tracer gas analysis, 2) CO_2 analysis, and 3) airflow measurement. Tracer gas analysis consisted of releasing sulfur hexafluoride (SF_6) into the occupied space, measuring the tracer gas decay with an infrared analyzer or electron capture gas chromatograph, and calculating the room air exchange rates (ach) and occupant-normalized ventilation rates (L/s per person). CO_2 analysis consisted of measuring the difference between indoor and outdoor CO_2 concentrations with an infrared analyzer, determining the percent of outdoor air provided by the system by airflow measurements, and by calculating the air exchange and ventilation rates from estimates of the CO_2 generation rates by the occupants. Airflow measurements consisted of volumetric flow measurements at supply diffusers with "flow hoods" and volumetrics, and pitot transverses of duct sections.

Subjective Measures

Occupant environmental questionnaires were completed by sampling hospital staff; patients were not selected for the subjective evaluation procedure. The questionnaires, shown in Figure 1, were used to record subjective responses to the environmental stresses imposed by thermal, air quality, acoustic, and lighting factors. The validity of these questionnaires for determination of environmental acceptability has been previously reported (Rohles et al. 1987, 1989). The primary purpose for using these forms in these two hospitals was to obtain perceptions of the environmental quality which may be correlated to the objective measures.

The occupant questionnaire provided information from staff in the selected functional areas regarding individual perceptions of the indoor environment during the period that objective measures were also being acquired. Questionnaires were administered one to three times during objective data acquisition periods. Twelve components of the indoor environment were rated on a six-point scale, with one being very unacceptable and six being very acceptable. Individuals were also asked to rate the overall air quality of their work envi-

Date _____ Time _____ AM
_____ PM

ENVIRONMENTAL QUESTIONNAIRE

Listed below are 12 items related to the environment of the area in which you work. In front of each item, enter the number from the following acceptability scale that best describes the acceptability of your work area at this time.

6 = very acceptable
5 = acceptable
4 = somewhat acceptable
3 = somewhat unacceptable
2 = unacceptable
1 = very unacceptable

_____ temperature

_____ humidity

_____ air movement

_____ odor (or smell)

_____ amount of dust

_____ amount of tobacco smoke

_____ loudness of the sounds

_____ pitch (or frequency or tone) of the sounds

_____ number of noisy distractions

_____ brightness of the lighting

_____ glare

_____ shadows

_____ OVERALL QUALITY

Please answer the following questions by filling in the blank or circling the correct response:

What is your age <20 ____; 20-29 ____; 30-39 ____; 40-49 ____;
50-59 ____; 60-69 ____' >70 ____

What is your gender? Male Female

Are you currently a tobacco smoker? YES NO

Have you smoked at your workstation during the past hour?
YES NO

Please circle any of the following symptoms that you may have AT THIS POINT.

HEADACHE	UNEXPLAINED MEMORY LOSS
BACKACHE	STIFF ARM
DROWSINESS	NOISE IRRITATION
HAND CRAMPS	ITCHY SKIN OR RASH
EYE IRRITATION	NECK PAIN
DRY MUCOUS MEMBRANES	MENTAL FATIGUE
SORE THROAT	LEG CRAMPS
ITCHY FOOT	DRY SKIN

Other current symptoms that may be related to your work environment: _____

_____

_____

Figure 1 Environmental questionnaire used for subjective measures (Rohles et al. 1987, 1989; Woods et al. 1987)

TABLE 4

Comparisons of Selected Gases and Vapors in Two Hospitals.

		Carbon Dioxide (Mean + S.D.) (ppm)		Volatile Organic Compounds (ug/m^3) (n = 1)			
				A	B		
Functional Area	Site	A	B		Dichloroethane	Toluene	Limonene
Medical Records	1	639 ± 38 (n = 90)	533 ± 18 (n = 90)	NA	442	7	2
Chemistry Lab	2	422 ± 19 (n = 88)	NA	NA	147	14	2
Patient Room — Oncology	3	503 ± 45 (n = 87)	463 ± 22 (n = 89)	NA	211	134	56
Cystoscopic/OR	4	319 ± 31 (n = 85)	387 ± 9 (n = 120)	NA	101	162	2
Central Sterilizing and Supply	5	373 ± 11 (n = 87)	449 ± 34 (n = 89)	NA	584	397	2
OB Recovery	6	373 ± 25 (n = 87)	526 ± 51 (n = 92)	NA	303	87	4
Outdoor Site		290 ± 13 (n = 102)	298 ± 44 (n = 59)	NA	32	7	ND

NA = Not Available
ND = Non-Detectable

TABLE 5

Derived Occupant-Normalized Ventilation Rates in Two Hospitals.

		Occupancy Density (No. People/ $100m^2$ Floor Area)		Occupant-Normalized Ventilation Rate (1/s Per Person)			
				Reference Method		CO_2 Method	
Functional Area	Site	A	B	A (Tracer Gas)	B (Air Flow)	A	B
Medical Records	1	11	10	41	NA	21	24
Chemistry Lab	2	6	NA	NA	NA	58	NA
Patient Room — Oncology	3	14	15	43	NA	35	42
Cystoscopic/O.R.	4	14	12	133	69	106	80
Central Sterilizing and Supply	5	3	3	NA	NA	97	48
OB Recovery	6	6	8	100	NA	99	32

NA = Not Available

ronment. In addition, four personal questions were asked to obtain demographic information on age, sex, and smoking status. Occupants also were asked to select from a list of symptoms those which they were experiencing during the monitoring period. Of these symptoms, nine were intended to relate to characteristic complaints of sick building syndrome and seven were intended to be unrelated to air quality issues. Survey participants were also invited to write in other symptoms that were not on the list.

Quality Assurance/Quality Control

A quality assurance/quality control program was developed and implemented for the diagnostic procedures employed to study these hospitals. This program required the use of standard methods, qualified laboratories, stringent calibration practices, sample/data chain-of-custody procedures, and other practices to ensure reliable, accurate, and representative data.

RESULTS

Objective Results

The results of the thermal, lighting, acoustic, aerosol, gas, and vapor measures, and ventilation rates are shown in Tables 2 through 5.

Thermal. In Hospital A, the plane radiant temperature differences were no greater than 0.5°C and in Hospital B, the plane radiant temperature differences ranged between 0.5°C and 3.6°C in the selected areas. These differences were within acceptable limits (< 7.8°C) according to ASHRAE Standard 55-1981 (ASHRAE 1981a). Air speed measurements in Hospital A were less than 0.35 m/s at the selected sites and were less than 0.16 m/s in Hospital B. Metabolic rates and clo values (ASHRAE 1985) were normal for hospital staff and were not expected to directly influence differences in responses to the thermal conditions.

Table 2 lists thermal conditions in terms of dry-bulb and dew point temperatures in the six paired sites selected for

this comparison. Indoor dry-bulb temperatures were not substantially different between hospitals and were quite similar when compared by functional area. On the other hand, there were substantial differences in dew point temperatures between Hospital A and Hospital B. In general, dew points in Hospital A ranged from 9.6° to 17.2°C (i.e., 52% to 64% RH) and from -2.7° to 2.1°C (i.e., 14% to 23% RH) in Hospital B. Hospital A was evaluated in the summer and Hospital B was evaluated in the early spring. Humidity control was provided during the test period in Hospital A by the chilled water coils in the central air-conditioning units, but humidity control was not available during the test period in Hospital B since the steam humidifiers had been deactivated. The dew point temperatures in Hospital B, which had reported problems, were substantially lower than those in Hospital A, which did not have reported problems, and were also lower than ASHRAE 55-1981 guidelines (ASHRAE 1981a).

Acoustics and Illuminance. Both acoustic and illuminance conditions were within acceptable ranges for the hospital environment. Average sound pressure levels in Hospital A ranged from 57 ± 5 to 66 ± 4 dBA. Average sound pressure levels in Hospital B ranged from 54 ± 5 to 66 ± 6 dBA. Sound pressure levels did not vary greatly between areas within either hospital nor were there substantial differences when the paired sites were compared. Illuminance data were evaluated for each site at the two hospitals. Unfortunately, these data cannot be compared because data were not recorded from comparable work surfaces within each functional area.

Aerosols. Two types of aerosol data were acquired in the hospitals: particulate and microbial aerosols. Particulate data included particulate mass per m^3 of sampled air and number count of particulates greater than or equal to 0.3 μm diameter per m^3. Particulate mass in Hospital A ranged from 3 to 65 $\mu g/m^3$. Particulate mass in Hospital B ranged from 1 to 9 $\mu g/m^3$. Table 3 contains a list of particulate count by hospital and by paired site. Interestingly, the particulate concentrations of problem Hospital B were generally less than the particulate concentrations in non-problem Hospital A in four of the six sites.

Single samples of viable microbial concentrations (colony-forming units/m^3) are also presented in Table 3 for each site. The microbial population in each hospital was similar in taxa and concentration throughout each respective building. Furthermore, the population in Hospital B was also similar in taxa and concentration to the outdoor air concentration. Microbial aerosol problems were not apparent in either hospital, as substantial concentrations of pathogenic or opportunistic microorganisms or bioamplification sites were not detected. No substantial conclusions can be drawn by comparing interhospital microbial data because of the many confounding factors such as season, time of day, weather patterns, locale, etc.

Gases and Vapors. The results of gas and vapor sampling at the two hospitals are shown in Table 4. Carbon dioxide (CO_2) measurements in Hospital A ranged from approximately 319 ppm to 639 ppm and Hospital B concentrations ranged from about 387 ppm to 533 ppm. Both outdoor concentrations were similar at 290 and 298 ppm, respectively. CO_2 concentrations may be associated with the ventilation strategy serving the site. In Hospital A, Medical Records utilized recirculated air and the CO_2 levels were twice as high as outdoor levels and were generally higher than all other sites, which did not recirculate air. In Hospital B, this association is less distinct, as Medical Records and Central Sterilizing & Supply utilized recirculated air and had CO_2 concentrations only slightly higher or the same as the other sites without recirculated air. Obviously, source load and the degree of ventilation effectiveness in the nonrecirculating areas of the hospital influence the CO_2 concentration.

Selected volatile organic compounds for Hospital B are reported in Table 4 also. The three compounds listed were chosen because in Hospital B they were the three "most significant" concentrations of 21 VOC measured. These concentrations were higher than outdoor concentrations.

Ventilation Rates. The derived values of occupant-normalized ventilation rates (i.e., L/s person) are shown in Table 5, together with the occupant densities observed during the data acquisition periods. The occupancy densities for the functional areas in both hospitals were surprisingly similar. With the exception of the Medical Records area in Hospital A, the ventilation rates derived by the CO_2 method were within 20% of those derived by the reference (i.e., tracer gas or airflow) methods at four of the five sites where comparisons could be made. It is significant to note that all of the derived ventilation rates were 2 to 6 times higher than the minimum values required in ASHRAE Standard 62-1981 or proposed in 62-1981R (ASHRAE 1981b, 1981c). It is particularly important to note in Table 5 that the ventilation rates, derived from CO_2 data, were similar for three of the five sites compared in Hospitals A and B.

Subjective Results

The subjective results are data provided by employees who agreed to participate in the subjective evaluations. These results include a report of SBS symptoms and scoring—on a one to six scale—of the acceptability of various environmental parameters related to the building.

Symptoms. Table 6 contains a comparison of the number of SBS-associated symptoms which were reported by occupants within selected sites of Hospitals A and B. Generally, a building or occupied space is suspected of having an SBS problem if more than 20% of the occupants report two or more of these symptoms. Note that in Hospital A, which was considered the non-problem building, occupants in three sites reported an average of two symptoms.

Hospital B, with known SBS complaints, had higher average numbers of SBS symptoms—three out of six sites reported an average of more than two SBS symptoms.

Perceptions. The results of the perceived responses by employees in Hospital A and Hospital B are shown in Table 7. Perceptions of the environment for each of the six sites are shown for the thermal, air quality, acoustic, and lighting parameters. Note that the scores are reported as means of the six-point scale plus or minus the standard error for the replicates of the given sample size. The rating given each score is as follows: 1 = very unacceptable; 2 = unacceptable; 3 = somewhat unacceptable; 4 = somewhat acceptable; 5 = acceptable; and 6 = very acceptable.

There are substantial differences in occupant perceptions between Hospital A (non-problem) and Hospital B (problem). Generally, Hospital A reported a higher overall level of acceptability than Hospital B (i.e., three of five sites evaluated in Hospital A had an average overall score of 5, while only one of six in Hospital B had a score of 5). Hospital B consistently had the lowest scores of thermal and air quality perceptions, with the exception of the operating room. The chemistry labs, oncology patient rooms, and central sterilization areas had the largest reported differences for specific parameters between hospitals. It is probable that dissatisfac-

TABLE 6

Comparisons of the Number of SBS Symptoms Reported in Two Hospitals.

Functional Area	Site	Hospital A (Average Number of SBS Symptoms)	Hospital B Average Number of SBS Symptoms)
Medical Records	1	2.0 (n = 8)	3.5 (n = 24)
Chemistry Lab	2	0 (n = 4)	2.5 (n = 8)
Patient Room — Oncology	3	2.0 (n = 2)	6.3 (n = 9)
Cystoscopic/OR	4	NA	1.8 (n = 8)
Central Sterilizing and Supply	5	2.0 (n = 1)	2.0 (n = 4)
OB Recovery	6	1.0 (n = 5)	1.0 (n = 3)

SBS symptoms (from Figure 1) include: Headache, drowsiness, eye irritation, dry mucous membranes, sore throat, unexplained memory loss, itchy skin or rash, mental fatigue, and dry skin.

NA = Not Available

tion with one or two parameters such as thermal and air quality conditions may have adversely influenced occupants' perceptions of the lighting or acoustic conditions. It is also probable that occupants who were stressed by one or more environmental stressors may have been more susceptible to other stressors.

DISCUSSION

Comparison of the subjective data with the objective data ideally would be expected to illustrate correlations and would lend power to the conclusions about SBS. Results analyzed in this study indicate that objective and subjective findings may not always support each other in the determination of SBS. In comparing the objective and subjective data, it is important to recognize the many confounding factors and differences between functional categories. Figures 2 through 5 illustrate a site-by-site comparison of objective data and an associated perceived response. In these figures, dry-bulb and dew point temperatures (Table 2), particulate data (Table 3), and CO_2 data (Table 4) were used in comparison with perceived responses (Table 7).

Dry-Bulb Temperature. As shown in Figure 2, the mean dry-bulb temperatures for the Medical Records sites in Hospitals A and B were 24.2° and 25.9°C, respectively. The mean perceived responses to the temperatures in Hospitals A and B Medical Records were 4.6 and 2.6, respectively. Thus, occupants in Hospital A Medical Records found the temperature (24.2°C) nearly "acceptable," while Hospital B occupants perceived the temperature (25.9°C) as less than "somewhat acceptable." Hospital B's Medical Records area

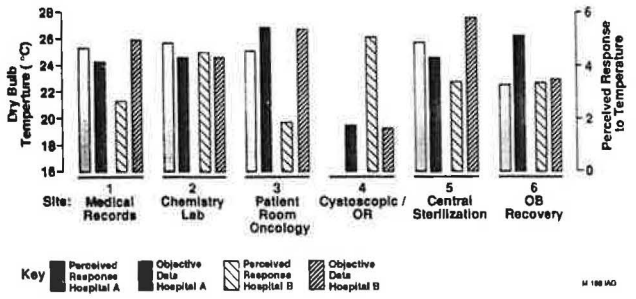

Figure 2 Comparative values between dry-bulb temperatures and perceived responses to temperature at six sites of two hospitals

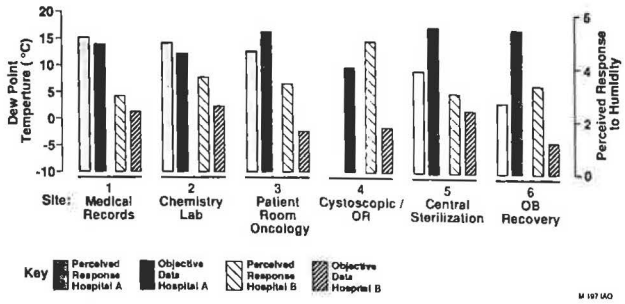

Figure 3 Comparative values between dew point temperatures and perceived responses at six sites of two hospitals

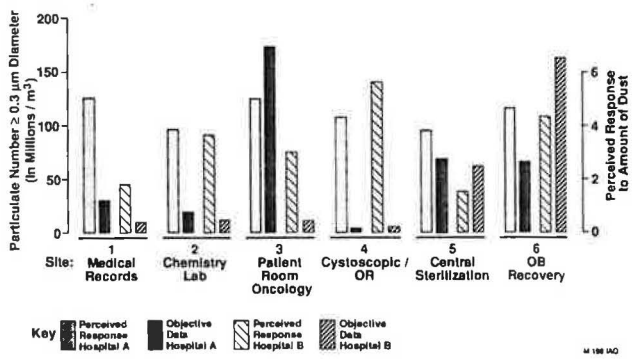

Figure 4 Comparative values between particulate numbers and perceived responses to amount of dust at six sites of two hospitals

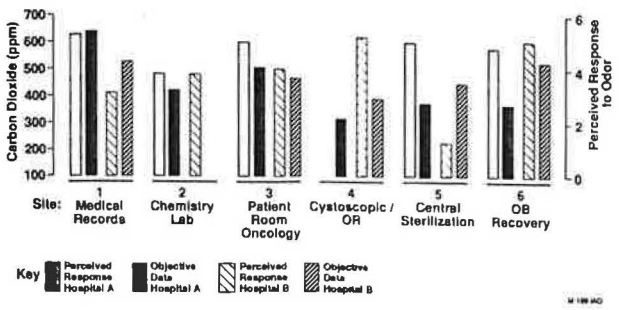

Figure 5 Comparative values between carbon dioxide concentrations and perceived responses to odor at six sites of two hospitals

TABLE 7

Comparison of Perceived Responses in Two Hospitals (Mean ± S.E.)

Parameter	Site 1 Medical Records		Site 2 Chemistry Lab		Site 3 Patient Room — Oncology	
	A	B	A	B	A	B
Temperature	4.6 ± 0.2	2.6 ± 0.2	4.8 ± 0.2	4.4 ± 0.2	4.5 ± 0.4	1.8 ± 0.1
Humidity	5.0 ± 0.0	2.8 ± 0.2	4.8 ± 0.2	3.5 ± 0.4	4.5 ± 0.4	3.3 ± 0.3
Air Movement	4.5 ± 0.3	2.0 ± 0.2	4.8 ± 0.2	3.4 ± 0.4	4.0 + 0.0	1.9 ± 0.2
Odor	5.25 ± 0.2	3.1 ± 0.3	3.8 ± 0.8	3.8 ± 0.4	5.0 ± 0.0	4.0 ± 0.2
Amount of Dust	5.0 ± 0.0	1.8 ± 0.2	3.8 ± 0.5	3.6 ± 0.6	5.0 ± 0.0	3.0 ± 0.5
Amount of Tobacco Smoke	6.0 ± 0.0	5.7 ± 0.1	4.5 ± 0.4	6.0 ± 0.0	5.0 ± 0.0	5.2 ± 0.1
Loudness of Sounds	4.5 ± 0.3	4.4 ± 0.2	4.0 ± 0.5	4.6 ± 0.6	4.5 ± 0.4	2.7 ± 0.4
Pitch	4.5 ± 0.3	4.4 ± 0.1	3.8 ± 0.4	5.0 ± 0.3	5.0 ± 0.0	3.1 ± 0.4
Number of Noisy Distractions	4.3 ± 0.2	4.5 ± 0.1	4.0 ± 0.3	4.3 ± 0.4	4.0 ± 0.0	2.2 ± 0.3
Brightness of Lighting	4.3 ± 0.2	3.9 ± 0.3	4.3 ± 0.4	5.3 ± 0.3	5.0 ± 0.0	4.4 ± 0.3
Glare	4.0 ± 0.0	3.7 ± 0.3	4.8 ± 0.2	4.9 ± 0.4	4.0 ± 0.0	4.3 ± 0.3
Shadows	4.3 ± 0.2	4.0 ± 0.2	5.3 ± 0.2	4.6 ± 0.4	5.0 ± 0.0	4.9 ± 0.1
Overall	4.8 ± 0.2	2.8 ± 0.2	4.3 ± 0.4	4.3 ± 0.2	5.0 ± 0.0	3.1 ± 0.1
	S = 2 N = 8	S = 8 N = 24	S = 1 N = 4	S = 4 N = 8	S = 1 N = 2	S = 3 N = 9

S = # of Subjects
N = # of Responses (i.e., subjects × replicates)

Parmeter	Site 4 Cystoscopic/OR		Site 5 Central Sterilization & Supply		Site 6 OB Recovery	
	A	B	A	B	A	B
Temperature	NA	4.5 ± 0.3	4.8 ± 0.2	3.3 ± 0.2	3.6 ± 0.5	3.7 ± 0.3
Humidity	NA	4.9 ± 0.1	3.8 ± 0.2	3.0 ± 0.6	2.6 ± 0.7	3.3 ± 0.5
Air Movement	NA	4.8 ± 0.2	4.3 ± 0.2	2.8 ± 0.4	4.2 ± 0.3	3.3 ± 0.3
Odor	NA	4.6 ± 0.3	4.5 ± 0.2	1.3 ± 0.2	4.8 ± 0.2	5.0 ± 0.0
Amount of Dust	NA	4.8 ± 0.3	4.8 ± 0.2	1.5 ± 0.3	4.6 ± 0.4	4.3 ± 0.3
Amount of Tobacco Smoke	NA	5.9 ± 0.1	5.0 ± 0.0	6.0 ± 0.0	5.4 ± 0.4	6.0 ± 0.0
Loudness of Sounds	NA	5.1 ± 0.1	5.0 ± 0.0	4.0 ± 0.6	4.2 ± 0.3	4.3 ± 0.3
Pitch	NA	5.1 ± 0.1	5.0 ± 0.0	3.8 ± 0.8	4.4 ± 0.2	4.3 ± 0.3
Number of Noisy Distractions	NA	5.1 ± 0.1	4.0 ± 0.0	3.5 ± 0.8	4.2 ± 0.2	4.7 ± 0.3
Brightness of Lighting	NA	5.3 ± 0.2	5.0 ± 0.0	5.5 ± 0.3	5.0 ± 0.0	5.0 ± 0.5
Glare	NA	5.1 ± 0.1	4.3 ± 0.4	5.0 ± 0.4	4.6 ± 0.2	4.7 ± 0.3
Shadows	NA	5.1 ± 0.1	4.8 ± 0.2	4.5 ± 0.3	4.4 ± 0.2	4.7 ± 0.3
Overall	NA	5.1 ± 0.1	4.8 ± 0.2	4.3 ± 0.3	4.6 ± 0.2	4.0 ± 0.0
	S = 0	S = 4 N = 8	S = 1 N = 4	S = 2 N = 4	S = 4 N = 5	S = 1 N = 3

S = # of Subjects
N = # of Responses (i.e., subjects × replicates)
NA = Not Available

was too warm for its occupants.

In the chemistry labs, there was close agreement between nearly identical temperatures and perceived responses. However, in the patient room-oncology sites there were larger differences in perceived response to similar temperatures.

Differences in acceptability of temperature between functional sites are also shown in Figure 2. In the operating room of Hospital B, the temperature of 19.1°C received nearly "acceptable" perceived scores compared to the chemistry lab, which had a similar perceived score but a higher temperature of 24.4°C. This suggests there may be a range of acceptable temperatures within a hospital and the acceptable temperature is probably associated with, but not limited to, the occupants, their activities, their expectations, and the space's processes.

Dew Point Temperature. As shown in Figure 3, the nonproblem Hospital A demonstrated nearly acceptable dew point conditions in three sites (Medical Records, chemistry labs, and patient room-oncology). However, mean dew point temperatures in Central Supply (17.2°C) and the OB recovery room (17.0°C) were perceived as less than "somewhat acceptable" (3.8) and less than "somewhat unacceptable" (2.6), respectively. These dew point temperatures (i.e., relative humidities of 64% and 57%, respectively) were the highest recorded in Hospital A and may reflect perceptions bordering on unacceptable conditions within Hospital A, especially in conjunction with the higher temperatures found in these areas.

In Hospital B, the comparisons between dew point temperatures were not so clear. Dew point temperatures were below 2.1°C for all functional areas and perceived responses of these dew point temperatures ranged from "somewhat unacceptable" (2.6) to "acceptable" (4.9). "Acceptable" conditions for dew point temperature were reported in the operating room of Hospital B; similar dew point conditions were found at the other sites of Hospital B, but were perceived as approaching "somewhat unacceptable." Again, the occupants, their activities, their expectations, and the processes in the area may have influenced the occupant responses.

Particulates. As seen in Figure 4, there is a trend for an inverse relationship between the number of particulates $\geq$ 0.3 μm diameter/m³ of air sampled and the perceived amount of airborne dust in occupied spaces. In other words, the lower the particle count at a functional site, the higher the acceptability. However, an interhospital comparison between objective and subjective measures is not as clear. Data from four of the five sites where comparisons could be made indicate that the particle counts were lower at Hospital B than at Hospital A, yet the responses at three of the sites at Hospital B were lower than the corresponding responses at Hospital A. These findings illustrate that within paired functional sites discrepancies between objective and subjective evaluation of airborne particulates are likely. At this time, it is not clear why these discrepancies exist: they may be due to imprecise measurement techniques, or they may be due to factors such as different standards of acceptability or to increased sensitivities from exposure to one or more other stressors.

Carbon Dioxide. Carbon dioxide concentrations were compared with perceptions of odor, as shown in Figure 5. In the four paired sites with complete CO_2 data, no association between CO_2 concentrations ranging from approximately 319 to 639 ppm and occupant perception of odor was apparent. If CO_2 were used as a surrogate to indicate the presence of human occupancy odors (primarily body odors) and no other sources of odor were present, then it would be expected that low CO_2 concentrations would be related to acceptable air quality in terms of odor. The CO_2 data compared with occupant perceptions do not confirm this hypothesis. CO_2 was not a reliable objective measure for comparison with the perception of odors at the relatively low concentrations observed in these two hospitals.

VOC. A comparison of VOC by matched site with occupant response to odor was not attempted due to lack of VOC data from Hospital A. Interestingly, results from targeted VOC indicated concentrations below documented odor recognition threshold concentrations, with the exception of limonene.

Overall Comparison. With the exception of Hospital B's dew point temperatures, all of the objective measures met accepted environmental and health evaluation criteria. However, results indicated that employees of Hospital A perceived environmental conditions to be more acceptable than did employees of Hospital B, and that SBS symptoms were reported with less frequency in Hospital A. The smaller deviation in Hospital A of objective measures from acceptable performance criteria (e.g., ASHRAE Standard 55-1981) tended to result in more acceptable overall subjective responses from the staff.

The differences in objective measures between the two hospitals were less than had been expected. In some functional categories of Hospital A, problems associated with SBS were identified, whereas several functional categories of Hospital B operated without obvious problems. The most notable differences between the two hospitals were in overall management and organization. In Hospital A, the importance of maintaining the physical plant was recognized by investing in a strong engineering staff. The competency of this staff was respected by the administrative and medical staffs and problems were effectively dealt with in a cooperative manner. Conversely, in Hospital B, the importance of the physical plant was overlooked, investment in the physical plant was minimized, competence of internal engineering staff was not emphasized, and outside service contracts were relied upon to an excessive extent. The competency of this staff was questioned by the medical and administrative staffs and environmental problems often persisted for months, resulting in adversarial relationships.

CONCLUSIONS

The results from these two field investigations and other studies reported in the literature lead us to the following conclusions:

1. Perceived responses of occupants are frequently more sensitive indicators of indoor air quality problems than are the objective measures conventionally relied upon for exposure evaluation. Reliance on objective data alone may not adequately identify the scope of the indoor air quality problem.
2. Problem areas may be found in "healthy buildings," while acceptable areas may be found in "sick buildings."
3. The management procedures selected to operate and maintain physical facilities are important not only in ensuring acceptable and economical performance of the systems, but in providing for a sense of confidence and well-being among those who are exposed to the environmental conditions.
4. Effective diagnostic protocols for buildings should incorporate observations, investigation of management strate-

gies, measurement of environmental variables, and perceived responses to the environmental conditions as a basis for system evaluation, predictions of future system performance, and recommendations for improvements.

5. Scientifically designed experimental studies should be conducted to test the relationship between objective and subjective measures in "sick" and "healthy" buildings.

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DISCUSSION

Gyan Rajhans, Health and Safety Support Services Branch, Ontario Ministry of Labour, Ottawa, Ontario, Canada: What were the ventilation rates in the various rooms of the hospitals? Were the operating rooms equipped with scavengers?

V.L. Putnam, Honeywell Indoor Air Quality Diagnostics, Golden Valley, MN: The derived occupant-normalized ventilation rates are provided in Table 5 of the paper. All of the derived ventilation rates were two to six times higher than the minimum values required in ASHRAE Standard 62-1981 or proposed in 62-1981R. Both hospitals were equipped with scavenger systems in the operating rooms.

Carl Lawson, LRW Engineers Inc., Tampa, FL: In the operating rooms, were there any problems with air and ventilation controls and in maintaining the operational guidelines?

Putnam: Briefly, Hospital A met the objective performance criteria established by IAQD; unfortunately, we were not able to obtain data on the occupant perceptions of the cystoscopic site. Hospital B did not meet the thermal evaluation criteria (the dry-bulb and dew point temperatures were too low); however, the staff found the thermal conditions to be acceptable. The systems serving the operating rooms of Hospital B were operating very close to their design flow capacities and the operating room site was operating with slightly less than the design value of 15 air changes per hour.