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The California Healthy Building Study Phase 1: A Summary

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THE CALIFORNIA HEALTHY BUILDING STUDY PHASE 1: A SUMMARY

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Abstract

The long-term goal of the California Healthy Building Study is to increase our understanding of the building and environmental factors that result in healthy and productive office workers. The objectives of the Phase-1 study were to: (1) obtain background data on health symptom prevalences and indoor air quality in office buildings; (2) test hypotheses about associations between health symptoms and features of the buildings, indoor environments, and jobs; and (3) gain experience with this type of study. We selected three naturally ventilated (NV) office buildings; three mechanically ventilated (MV) office buildings; and six air conditioned (AC) office buildings. Information on the prevalences of work-related symptoms, demographics, and work and job factors were determined via a questionnaire completed by 880 eligible occupants. Several indoor environmental parameters were measured. Logistic regression models were used to evaluate associations between symptom prevalences and features of the buildings, indoor environments, jobs, and personal factors. Although symptom prevalences varied within each group of buildings, the occupants of the MV and AC buildings had significantly more symptoms than occupants of the NV buildings. Based on preliminary analyses of the data, none of the measured environmental parameters were clearly associated with symptom prevalence; however, increased prevalences of some symptoms were associated with several job and workspace factors including: presence of carpet, increased use of carbonless copies and photocopiers, space sharing, and distance from a window.

INTRODUCTION

In multi-building surveys, European researchers have determined that many of the occupants of typical office buildings report frequent work-related health symptoms. Prior to the California Healthy Building Study (CHBS), no comparable survey in buildings with different ventilation types had been completed in the U.S. The symptoms reported include irritation of the eyes, nose, or throat, headache, fatigue, dry or itchy skin, and difficulty breathing or chest tightness. These symptoms have many potential causes and do not generally indicate a specific disease or pollutant exposure. The same symptoms are associated with sick-building syndrome (SBS). Although not precisely defined, SBS is evident in a building when symptoms are unusually severe, frequent, or widespread. It is not known if sick buildings represent the high-symptom tail of the distribution of normal buildings or if unique factors in sick buildings are responsible for the increased health effects.

Surveys in buildings selected without regard to SBS status have been more informative about the causes of symptoms than investigations in sick buildings, in part, because the occupants of sick buildings are upset and apt to over-report symptoms. The typical survey approach includes administration of questionnaires to obtain symptom prevalences, demographic information, and job and workspace characteristics. Buildings are characterized via inspections and interviews. In some surveys, the indoor environment (e.g., air quality) is characterized

through measurements. Statistical models are used to assess relationships between symptom prevalences and factors considered likely to influence these symptoms.

Prior surveys have consistently shown that occupants of air-conditioned buildings report more symptoms than occupants of naturally-ventilated buildings (1,2). Women consistently report more symptoms than men by about a factor of two to three. Workers reporting high job stress also report more symptoms. Other factors have been associated with increased symptoms in some, but not all, studies (2). Higher concentrations of indoor air pollutants, which are often cited as the cause of SBS, have not consistently been associated with symptoms; however, the breadth and quality of pollutant measurements has generally been limited. A review of the results of prior surveys is provided by Mendell (2).

STUDY DESCRIPTION

We conducted Phase 1 of the CHBS in twelve office buildings using the basic survey approach described in the previous section. The primary research objectives were to: (a) obtain background data on health symptom prevalences and indoor air quality; (b) test several hypotheses about associations between health symptoms and features of the buildings, indoor environments, and jobs; and (c) to gain experience with this type of study and the associated monitoring techniques.

Buildings were selected from a list of all city- or county-owned buildings in a defined geographic region. Eligible buildings had more than 45 full-time workers. Three buildings were naturally ventilated via openable windows. Three buildings had mechanical supply and exhaust ventilation with operable windows and no air conditioning (henceforth "mechanical ventilation"). Six buildings had mechanical supply and exhaust ventilation with sealed windows and air conditioning (air conditioning). Buildings without one of these types of ventilation were considered ineligible. We selected all eligible buildings to which access was granted (3,4). One of the six air-conditioned buildings was a classic sick building with a long history of occupant health complaints and associated but unsuccessful investigations. Smoking was prohibited in each building except in designated, enclosed smoking rooms from which air was not mechanically circulated to other rooms.

Within each building, workers from a selected study space, or study spaces, were included in the study. Large open study spaces were selected when possible, along with the adjoining enclosed offices. When necessary, several smaller spaces, with a total occupancy of at least 45, were studied. Questionnaire data were collected from 880 occupants in 29 study spaces.

Seven research hypotheses were formulated prior to implementation of the Phase-1 study (5). Abbreviated statements of five key hypotheses are as follows:

H-2: Occupants of air-conditioned buildings will have more symptoms than occupants of naturally-ventilated buildings. Occupants of mechanically-ventilated buildings will have symptom prevalences similar to, or slightly higher than, occupants of naturally ventilated buildings.

H-4: Symptom prevalence will increase with increased temperature, or alternately, with decreased thermal comfort predicted via a comfort model based on measured data.

H-5: Symptom prevalence will not be associated with total concentrations of volatile organic compounds (TVOC).

H-6: Symptom prevalences will not be associated with total concentrations of viable bacteria or fungi.

H-7: Increased symptom prevalences will be associated with the presence of fleecy materials such as carpet and fabric.

Using a self-administered questionnaire (5), occupants were asked about the frequency of 15 health symptoms at work during the previous week and previous year and asked if symptoms changed when they were not at work. Other questions assessed health, demographic, psycho-social, and work-related parameters.

Relevant characteristics of the buildings and study spaces were determined through inspections and interviews. This information included the type of ventilation, operability of windows, building age and size, type of floor surfaces, and presence of fabric-covered partitions.

Indoor environmental parameters were measured at one to three locations in 26 of the study spaces. Measurements were completed during all or part of the work week preceding administration of the questionnaire; consequently, symptom data and environmental measurements were available for the same time period. Air temperature and humidity were measured every 15 seconds and 15-minute averages were logged. Work-week-average carbon dioxide and carbon monoxide concentrations were determined by pumping air samples at constant rates into sample bags during the 45-hour work week and subsequently analyzing the concentrations in the bags. Air samples were also drawn through multi-sorbent sample tubes for approximately an eight-hour period on a single work day. These samples were analyzed using a flame ionization detector to determine the TVOC concentration and via gas chromatography-mass spectrometry to determine the concentrations of specific volatile organic compounds (VOCs). Total airborne concentrations of viable fungi and bacteria were also measured using an impactor-type sampler. The sampling for fungi and bacteria was performed twice at each measurement location during a single work day; however, the sampling period was only a few minutes. The outdoor air at the site of each building was characterized using the same measurement techniques, except outdoor temperature and humidity were not measured. The measurement procedures are described in greater detail by Daisey et al. (5).

Two approaches were used to evaluate the temperature and humidity data. First, the number of hours during the work week with temperatures and humidities outside of the bounds of the summer thermal comfort zone defined by ASHRAE (6), and also above and below other limits, were computed. Second, the measured temperatures and humidities along with an assumed typical air velocity of 0.137 m/s were entered into a comfort model to obtain the Predicted Percentage Dissatisfied (PPD) with the thermal environment (5).

Because of the large variation in the sensory irritancy and neurotoxicity of different VOCs, we did not expect TVOC concentrations to correlate with symptom prevalence. To obtain a parameter more likely to correlate with symptoms, we computed values of an irritancy index (5) based on the concentrations of individual VOCs and estimates of the relative irritancy of each VOC.

Two definitions of work-related symptoms were used. For comparisons of symptom prevalence to permanent parameters, e.g., ventilation type, a work related symptom was defined as one that occurred often or always last year and that also improved when the respondent was away from work. For comparison of symptoms to the measured environmental parameters, a work-related symptom was one that occurred on three or more days last week and improved when the respondent was away from work. Six groups of related symptoms (see Table 2) considered likely to be related to the indoor air quality or to factors that may affect indoor air quality were formed by combining related symptoms. Reporting of one work-related symptom in a group constituted a positive response.

Associations between work-related symptom groups and various factors were determined using the SAS and BMDP software. Odds ratios (ORs) and 95% confidence intervals were calculated (3,4). For analysis of the ORs associated with environmental measurements, the measured parameters were categorized into quartiles and the lowest quartile was used as the reference category. For analysis of the ORs associated with ventilation type, natural ventilation was the reference category. Crude ORs, i.e., unadjusted for potential confounders were computed first. Unconditional logistic regression models including the significant independent variables were also used to compute ORs adjusted for confounders. These models included a variable for problem building status. The data analyses procedures are described in greater detail elsewhere (3,4).

RESULTS AND DISCUSSION

Table 1 provides the means and standard deviations of selected measured environmental parameters for study spaces grouped by type of ventilation. The low p values (included in the

Table) for most parameters indicate that there are statistically significant, but not necessarily important, differences in pollutant concentrations and thermal comfort conditions between spaces with different ventilation types.

The mean TVOC concentration in the air-conditioned spaces was approximately three times as high as the means in naturally-ventilated and mechanically-ventilated spaces. However, this difference in mean TVOC concentrations was not due to any factor inherently connected to ventilation type but was a consequence of the emission of VOCs by wet-process photocopiers in only three of the air conditioned spaces. The VOCs emitted by these photocopiers are not expected to be strong irritants, thus, the VOC irritancy index is only moderately higher in the air-conditioned spaces.

Total viable fungi concentrations were much lower in the air-conditioned spaces. We suspect that the lower fungi concentrations were a consequence of reduced entry of outdoor fungi into the air-conditioned spaces which, in turn, is explained by the sealed windows and filtering of supply air. The lower ratio of indoor-to-outdoor fungi in the air conditioned spaces is consistent with this explanation.

The number of hours during the work week with an air temperature above 26 °C (the approximate upper limit of ASHRAE's comfort zone) was also much lower in the air-conditioned spaces. This is a consequence of the cooling of the indoor air in the air-conditioned spaces. However, the estimated work-week-average percentage of occupants dissatisfied with thermal conditions is only a couple of percent smaller in the air-conditioned spaces. Average values of relative humidity for the work week ranged from 33% to 58%.

Concentrations of carbon monoxide, measured primarily as an indicator of vehicle exhaust, were very low (below 2 ppm) in all buildings.

Table 1. Space-average environmental parameters as a function of ventilation type

Parameter	**Natural Ventilation** Mean (s.d.)	**Mechanical Ventilation** Mean (s.d.)	**Air Conditioning** Mean (s.d.)	**Wilcoxon Rank Sum Test** p Value
CO_2 (ppm)	420 (40)	390 (10)	440 (60)	0.07
ΔCO_2 (ppm)*	81 (35)	48 (12)	110 (72)	0.07
TVOC ($\mu g/m^3$)	340 (140)	380 (100)	1200 (1700)	0.28
VOC Irritancy Index	54 (33)	63 (16)	89 (36)	
Fungi (cfu/m^3)	72 (12)	59 (20)	12 (4.9)	0.01
Indoor-Outdoor Fungi Ratio	0.72(0.4)	0.62(0.1)	0.12(0.08)	0.0003
Bacteria (cfu/m^3)	180 (82)	120 (47)	180 (68)	0.59
Indoor-Outdoor Bacteria Ratio	3.9(3.1)	2.2(0.9)	2.2(1.3)	0.62
Hours Temp > 26 °C	4.3 (4.8)	14.5 (10.8)	0.6 (1.32)	0.01
Thermal Discomfort (hrs PPD>10%)	8.1 (2.4)	9.9 (2.5)	7.6 (3.7)	0.04

* difference between indoor and outdoor concentration

In general, there are no standards or guidelines with which to compare the measured pollutant concentrations. ASHRAE's Standard 62 "Ventilation for Acceptable Indoor Air Quality" does have a 1000 ppm guideline for carbon dioxide (7). The maximum work-week-average carbon dioxide concentration at any location was only 630 ppm. All measured pollutant concentrations, including those in the sick building, were within the ranges considered normal, based on the limited data available from office buildings.

Mendell (3,4) presents a breakdown of the prevalences of work-related symptoms. The prevalences depend on the definition selected for a work-related symptom. Using the previously described definition based on symptoms last year, the prevalence of eye, nose, or throat irritation, for the entire study population, was the highest (40.3%) and the prevalence of chills or fever was the lowest (4.5%). The prevalence of four individual symptoms exceeded 20% (fatigue, stuffy nose, sleepiness, and eye irritation). The lower limits of symptom prevalences within buildings were similar for all three ventilation types, but the upper limits were higher in the mechanically-ventilated and air-conditioned buildings. The prevalences of several symptoms were highest in the sick building, but this building was not dramatically different from others in terms of symptom prevalences. These substantial health symptom prevalences in typical office buildings suggest the existence of a widespread and significant health problem that requires further study.

Table 2 contains selected values of adjusted ORs for the prevalences of work-related symptoms. The associated 95% confidence intervals are included. For all symptoms except headache, the ORs for both mechanical ventilation and air conditioning (relative to natural ventilation) are above unity. A reanalysis, excluding data from the sick air-conditioned building, rather than including the sick-building variable in the statistical model, yielded ORs similar to those in Table 2. The association between increased symptom prevalence and air conditioning is consistent with the results of prior European surveys (2,3,4). This is the first study to include a group of buildings with mechanical supply and exhaust ventilation but operable windows and no air conditioning. This type of building is not commonly associated with SBS or health complaints, yet the symptoms in the mechanically ventilated buildings were still elevated. Recently, a similar finding was reported by Zweers et al. (8);however, they did not include operability of windows in the ventilation type criteria. Since ventilation type cannot be a direct cause of symptoms, these findings suggest that it is a surrogate for other direct causes.

Several job-related or workspace factors were also associated with increased prevalences of one or more symptom groups as shown in Table 2. Except for the association of symptoms with the absence of a nearby window, one or more previous studies have found associations between the same, or very similar factors, and symptoms (2). The use of computers was not associated with increased symptoms in this study (4) although use of video display terminals has been associated with symptoms in several other studies (2).

Table 2. Adjusted Odds Ratios and 95% Confidence Intervals for Selected Risk Factors

	Risk Factor						
Work-Related Symptom Group	Mechanical Versus Natural Ventilation	Air Conditioning Versus Natural Ventilation	Carbonless Copy Paper Use (> 1 hr/day)	Photocopy Machine Use (> 1 hr/day)	Space Sharing (with 2 or more)	Any Carpet in Study Space	No Window Within 5m
Eye, Nose, or Throat	1.7 (0.9-3.0)	1.3 (0.7-2.4)	1.6 (1.0-2.6)	1.6 (0.8-3.1)	1.3 (0.9-1.9)	1.7 (1.1-2.6)	1.6 (1.1-2.3)
Tight Chest or Difficulty Breathing	3.6 (0.9-15)	4.3 (1.1-16)	2.3 (1.1-4.9)	1.7 (0.6-4.7)	2.0 (1.0-3.9)	2.5 (1.0-6.2)	1.6 (0.8-3.2)
Chills or Fever	2.3 (0.4-14)	2.3 (0.5-12)	1.7 (0.7-4.6)	0.4 (0.1-2.1)	1.3 (0.6-2.9)	1.4 (0.5-3.7)	2.4 (1.1-5.6)
Fatigue or Sleepiness	1.9 (1.0-3.6)	2.2 (1.2-3.9)	2.1 (1.3-3.5)	1.4 (0.7-2.8)	1.6 (1.1-2.3)	1.1 (0 7-1.7)	1.5 (1.0-2.5)
Headache	1.0 (0.5-2.2)	0.9 (0.4-1.9)	1.4 (0.8-2.4)	1.5 (0.7-3.1)	1.8 (1.2-2.7)	2.0 (1.1-3.4)	2.1 (1.3-3.3)
Dry or Itchy Skin	5.8 (1.5-22)	5.6 (1.6-20)	0.9 (0.5-1.9)	3.1 (1.4-6.9)	1.6 (0.9-2.8)	0.9 (0.5-1.8)	1.6 (0.9-2.7)

Our analyses of associations between symptoms and the measured environmental parameters have been less intensive. To date, however, no definite associations have been identified. Most other surveys have also failed to verify a connection between symptoms and indoor air pollutants, but several studies indicate that symptoms increase with temperature (2). From a physiological perspective, pollutants exposures are a logical causes of symptoms. Possibly, we have failed to identify the connection between pollutants and symptoms because we have measured the wrong pollutants or because our measurements are not at the appropriate times and locations to adequately represent exposures. Consequently, we are planning followup studies with different types of pollutant measurements in the same set of buildings.

In summary, the most important findings and conclusions of this study are as follows:

1. A substantial fraction of the occupants in these typical office buildings reported frequent work-related symptoms. This finding, together with similar previous findings, suggests the existence of a widespread and significant health problem that requires further study.
2. Consistent with other surveys, ventilation type was associated with symptom prevalence. There is a need to confirm this finding in additional U.S. buildings and to identify the factors associated with ventilation type that are more direct causes of symptoms.
3. Based on a preliminary analysis, the measured pollutant concentrations were not associated with symptoms. In future surveys, measurements should be closely tied to specific hypotheses. Selection of measurements that are better indicators of personal exposures may also be warranted.

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