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# THE CALIFORNIA HEALTHY BUILDING STUDY, PHASE 1: A SUMMARY

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**Abstract**

Increasing our understanding of the building and environmental factors that result in healthy and productive office workers is the long-term goal of the California Healthy Building Study. The primary objectives of the Phase-1 study were to: (1) test hypotheses about associations between health symptoms and features of the buildings, indoor environments, and jobs; (2) obtain background data on health symptom prevalences and indoor air quality; and (3) gain experience with this type of study. Primary hypotheses were that symptom prevalences, after adjustment for confounders, would be: (a) higher in sealed air conditioned buildings than in naturally ventilated buildings; (b) not related to the total concentrations of volatile organic compounds (VOC), fungi, or bacteria; and (c) higher as the measured thermal comfort decreased. For the 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 occupants. Several indoor environmental parameters were measured. Logistic regression models were used to assess associations between symptom prevalences and features of the buildings, indoor environments, jobs, and occupants. 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 and Scandanavian researchers have determined that many of the occupants of typical (e.g., non-sick) office buildings report frequent work-related health symptoms. Prior to the California Healthy Building Study, no comparable survey had been completed in the U.S.. The common symptoms include irritation of the eyes, nose, or throat, headache, fatigue, dry or itchy skin, and difficulty breathing or tight chest. These symptoms have many potential causes and do not generally indicate a specific disease or pollutant exposure. The same health 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.

Obtaining reliable symptom data is particularly difficult in sick buildings because the occupants are upset and apt to over-report symptoms. This is one reason why surveys in buildings selected without regard to SBS status have been more informative about the causes of symptoms than investigations in sick buildings. 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 check for correlations between symptom prevalences and factors considered likely to influence these symptoms.

The 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). Increased 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 comprehensive review of the results of the prior surveys is provided by Mendell (2).

## STUDY DESCRIPTION

We conducted Phase 1 of the California Healthy Building Study (CHBS) in twelve office buildings using the basic survey approach described in the previous section. The primary research objectives were: (a) to test several hypotheses about associations between health symptoms and features of the buildings, indoor environments, and jobs; (b) to obtain background data on health symptom prevalences and indoor air quality; 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 and one of three types of ventilation: natural ventilation via openable windows (henceforth "natural ventilation"); mechanical supply and exhaust ventilation with operable windows and no air conditioning (mechanical ventilation); and mechanical supply and exhaust ventilation with sealed windows and air conditioning (air conditioning). As described elsewhere (3,4), we selected all eligible buildings to which access was granted. There were three mechanically- and three naturally-ventilated buildings. 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.

Workers were studied from a selected study space ,or study spaces, within each building. Large open areas 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 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 follow:

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 sample 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 and via gas chromatography-mass spectrometry to determine the TVOC concentration and the concentrations of specific VOC. 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 sample 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 (4).

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 computer model to obtain the Predicted Percentage Dissatisfied (PPD) with the thermal environment (5).

Because of the large variation in irritancy 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 VOC 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 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 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 Statistical Analysis System (SAS) software. Odds ratios (OR) 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. For analysis of the ORs associated with ventilation type, natural ventilation was the reference. Crude ORs, i.e., unadjusted for potential confounders were first computed. Unconditional logistic regression models which included the significant variables were also used to compute odds ratios adjusted for confounders. The data analyses procedures are described in greater detail elsewhere (3,4).

## RESULTS AND DISCUSSION

For each type of study space, Table 1 provides the means and standard deviations of selected measured environmental parameters. P values based on the Wilcoxon Rank Sum Test are also provided. The low p values 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 is approximately three times as high as the means in naturally-ventilated and mechanically-ventilated spaces. However, this difference in mean TVOC concentrations is not due to any factor inherently connected to ventilation type. Instead, the difference is a consequence of the emission of VOCs by wet process photocopiers in only three 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 are much lower in the air-conditioned spaces. We suspect that the lower fungi concentrations are 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 $^oC$ (the approximate upper limit of ASHRAE's comfort zone) is also much lower in the air-conditioned spaces. This is an obvious consequence of the cooling of the indoor air, which only occurs in these 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.

Concentrations of carbon monoxide, measured primarily as an indictor of a vehicle exhaust, were very low (below 2 ppm) in all buildings. Average values of relative humidity for the work week ranged from 33% to 58%.

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 |
| $\Delta CO_2$ (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 | | | | |
| Bacteria (cfu/$m^3$) | 180 (82) | 120 (47) | 180 (68) | 0.59 |
| Indoor-Outdoor Bacteria Ratio | | | | |
| Hours Temp > 26 $^oC$ | 4.3 (4.8) | 14.5 (10.8) | 0.6 (1.32) | |
| Thermal Discomfort (hrs PPD>10%) | 8.1 (2.4) | 9.9 (2.5) | 7.6 (3.7) | 0.04 |

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 was only 630 ppm. All measured pollutant concentrations, including those in the sick building, were within the normal ranges, 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 specific symptoms exceeded 20% (fatigue, stuffy nose, sleepiness, and eye irritation). The prevalences of several symptoms were highest in the sick building, but the sick 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 odds ratios for the prevalences of work-related symptoms. The associated 95% confidence intervals are included. For all symptoms except headache, the odds ratios for both mechanical ventilation and air conditioning (relative to natural ventilation) are above unity. The lower bounds of symptom prevalences were similar for all three ventilation types, but the upper bounds were higher in the mechanically ventilated and air conditioned buildings. A reanalysis, excluding data from the sick air-conditioned building, yielded odds ratios for air conditioning similar to those associated with mechanical ventilation. The association between increased symptom prevalence and air conditioning has been found consistently in European and Scandinavian 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. Ventilation type cannot be a direct cause of symptoms; thus, these findings suggest that it is a surrogate for other direct causes.

Several job-related or workspace factors that are also associated with increased prevalences of one or more symptom groups are identified in Table 2. Except for the lack of a window within 5 m of the study space, one or more previous studies have found an association between these same factors, 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) |
| Chest Tight 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 the most 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 report frequent work-related complaints. 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. Selecting measurements that more closely indicate personal exposures may also be warranted.

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