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Hypothesis-Based Research on the Causes of Sick Building Symptoms: A Design for Phases 2 and 3 of the California Healthy Building Study

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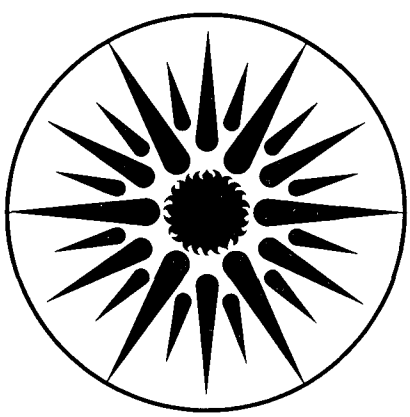

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HYPOTHESIS-BASED RESEARCH ON THE CAUSES OF SICK BUILDING SYMPTOMS: A DESIGN FOR PHASES 2 AND 3 OF THE CALIFORNIA HEALTHY BUILDING STUDY

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I. EXECUTIVE SUMMARY

A. Objectives of Research Sponsored by CIEE

The California Healthy Building Study (CHBS) is a multidisciplinary research effort, based in 12 office buildings within California. The overall goal the CHBS is to elucidate relationships between occurrences of office worker health symptoms and characteristics of the workers' buildings, ventilation systems, work spaces, jobs, and indoor environments. A Phase-1 study was completed during 1990. The California Institute for Energy Efficiency (CIEE), through its Exploratory Research Program, supported the design of research plans for two future phases of the CHBS. The intent of the CIEE-supported effort was to design research to be conducted in the Phase-1 buildings that capitalizes on the Phase-1 research findings and also on recently-published results of research from other institutions. This report describes the research plans developed with CIEE support and presents the rationale for these research plans.

B. Background

This research effort is motivated, in part, by the "sick building syndrome" (SBS). Incidents of SBS, within specific buildings (often office buildings), are characterized by an unusually high prevalence of health symptoms and health complaints from the buildings' occupants. The symptoms may include irritation to the eyes, nose and throat, dry or itchy skin, difficulty breathing, cough, headache and fatigue. These symptoms do not generally indicate a specific disease or specific pollutant exposure. The occupants believe that their symptoms are caused by the indoor environment, generally air pollutants within the building.

Recent surveys have shown that many occupants of "normal buildings," (i.e., buildings without identified sick-building problems) report that they have health symptoms that improve when they are away from the building. They report the same symptoms commonly associated with SBS. An increased prevalence of health symptoms among occupants of mechanically-ventilated buildings with air conditioning relative to the incidence of these symptoms among occupants of naturally-ventilated buildings is the strongest and most consistent association identified in these surveys.

In the summer of 1990, we completed a survey, called Phase 1 of the California Healthy Building Study, in twenty-nine study spaces within twelve city- or county-owned office buildings located in the San Francisco area. An investigation of the association between symptom prevalence and ventilation type was a primary goal (880 occupants provided information on their symptom prevalences, jobs, and workspaces, and provided personal information, e.g., sex, age, and smoking status). Building and ventilation system characteristics were determined in inspections and interviews with building operators. Several indoor environmental parameters were measured during the week that preceded questionnaire administration. The Phase-1 data indicated that occupants of the air conditioned and mechanically ventilated buildings had an increase in the prevalence of most symptoms relative to occupants of naturally-ventilated buildings, although there was a substantial variation in symptom prevalence between buildings with the same type of ventilation. The prevalences of skin symptoms (dry or itchy skin) and tight chest and difficulty breathing were more highly elevated in the buildings with mechanical ventilation with or without air conditioning than other symptoms. We know that ventilation type cannot be a direct cause of symptoms, so it must be a surrogate for one or more direct causes such as an increased pollutant exposure. Other factors that were associated with increased prevalence of one or several symptoms include female gender, high job stress (reported on the questionnaire), use of carbonless copies, any carpet in the test space, and no window within 15 feet of the workstation. Based on data analyses to date, which are nearly complete, no measured environmental parameter was clearly associated with an increase in symptom prevalence.

C. Research Plans

Two additional phases (Phase 2 and Phase 3) of research of research have been designed. For two primarily reasons, we have chosen to conduct this research in the buildings studied during Phase 1. First, the Phase-1 research findings suggest possible causes of symptoms that can most efficiently be studied in the same population of buildings. Second, studying the same set of buildings reduces research costs because contact persons have been identified, access to the buildings has been granted, and reference information on the buildings and ventilation systems has been obtained. For the same basic reasons, we will generally study the same population of individuals within each building. However, testing of some hypotheses, as described subsequently, will require special study populations to obtain statistically meaningful results.**

We expect to undertake Phase 2 in the fall of 1992. Due to limited resources and time, Phase 2 activities are limited in scope. Several of the Phase-2 activities are intended to provide information for the development of appropriate measurement or inspection protocols that will be employed during Phase-3. Other Phase-2 activities are inspections and low cost measurements which yield information that can be used to test associations with the previously-obtained Phase-1 symptom data In these cases, we must be reasonably certain that the information collected during Phase 2 is also representative of the time period when the Phase-1 symptom data were collected.

Phase 3, scheduled for the summer of 1993, is intended to be a much more intensive investigation which includes substantial measurements and administration of a questionnaire on health symptoms. The Phase 3 study should reflect the findings of Phase 2 and must be consistent with future financial resources, which are uncertain. In addition, some of the anticipated Phase 3 efforts depend on development and validation of measurement methods and sampling protocols prior to implementation of Phase 3. Consequently, the Phase 3 design described in this document is a preliminary design.

Hypotheses about the causes of work-related symptoms were generated and eleven hypotheses, some with associated sub-hypotheses, were selected for evaluation in Phases 2 and 3. The hypotheses were based on the Phase 1 findings, results of similar surveys conducted elsewhere, and judgments of biological and physical plausibility of an association between a factor and symptoms. In the remainder of this executive summary, we list the hypotheses and provide brief descriptions of the associated research plans.

Hypothesis 1: Heating, Ventilating, and Air Conditioning (HVAC) systems can be a source of pollutants that elicit symptoms. The potential pollutants are volatile organic compounds (VOCs), bioaerosols, and fibers.

Phase-2: HVAC systems will be inspected for potential sources of air pollutants including internal fibrous duct liners and fiberglass duct (potential source of fibers and VOCs), stored chemicals, and microbiological contamination (i.e., potential sources of bioaerosols). Laboratory measurements will quantify the emissions of VOCs (including aldehydes) from duct-liner samples, with and without exposure to ozone. Several methods for confirmation of microbiological contamination in HVAC systems will be evaluated and intercompared. HVAC cleaning practices (e.g., cleaning and disinfection of drain pans) will be assessed via interviews. In three study spaces, we will also evaluate a method of assessing bioaerosol entry into the study space via the HVAC supply air. The numbers and types of bioaerosols in supply airstreams will be assessed by analysis of the bioaerosols collected on membrane filters through which samples of supply air are drawn. Using a regression model, the associations of Phase-1 symptom prevalence to duct liner area and to an index of HVAC cleaning will be determined.

Phase 3: VOC and aldehyde emissions from HVAC systems will be assessed by measurements in the systems, at the outside air intakes, and in the occupied spaces just before and after starting operation of the systems. HVAC systems will be re-inspected for microbiological contamination, with confirmation of microbiological growth based on the methods determined to be suitable during Phase 2. If the Phase-2 measurements of bioaerosols in supply airstreams are successful, these measurements will be repeated in all study spaces with

mechanical ventilation or air conditioning. The results of these Phase 3 measurements will be compared to symptom prevalence using a regression model.

Hypothesis 2: Occupants are exposed to pollutants that accumulate on indoor surfaces, especially high surface area materials. The suspected pollutants are viable and non-viable microorganisms, fibers, cleaning compounds, and insecticides. The exposure route may involve direct human contact with the surfaces or resuspension and inhalation of particles.

Phase 2: Protocols for evaluating the extent and types of microbiological material on carpeted and hard-surface floors will be evaluated via field trials in five study spaces. Through inspections and physical measurements, the surface area of carpets in each study space per unit air volume will be quantified. Office cleaning and pest-control practices (e.g., use of insecticides) will be determined in interviews. The normalized area of carpet and an index of the quality of office cleaning will be compared to Phase-1 symptom data using a regression model.

Phase 3: Using a protocol based on the Phase-2 trials, the extent and types of microbiological material on carpeted and hard-surface floors will be measured in all study spaces. Regression modeling will be completed to evaluate the association of measurement results to symptoms.

Hypothesis 3: New carpets and/or other components of carpet installations emit volatile organic compounds that elicit sensory irritation and respiratory symptoms.

Phase 2: This hypothesis will not be evaluated in the Phase-2 study.

Phase 3: In advance of the Phase 3 field investigation, study locations where there are plans to install new carpeting will be identified by interviewing the building managers. These areas will be included in the Phase-3 study. The general approach will be to attempt to relate symptom prevalence to estimated concentrations and exposures to VOCs emitted by carpets and related materials. Samples of the carpet and related materials, such as pads and adhesives, will be collected at the time of installation and VOCs that are emitted by the carpets and related materials will be identified in the laboratory. The estimated emission rates will be input along with building parameters into a simple mass-balance model to obtain order-of-magnitude estimates of concentrations and of exposures of workers to the compounds of interest. Symptom reporting from the questionnaires will then be compared to these estimated concentrations and exposures.

Hypothesis 4: People who inhale certain bioaerosols may experience symptoms as a result of this exposure.

Phase 2: To evaluate sampling and sample-analysis protocols for measurement and identification of airborne viable bacteria and fungi, we will complete measurements in three of the study spaces using impactor type samplers that deposit particles directly on culture media. Samples collected at different locations will provide information on the spatial variability in airborne viable microorganisms within a test space.

Phase 3: Measurements will be performed to determine the types and concentrations of bioaerosols in each test space and results will be compared to symptom data using a regression model.

Hypothesis 5: Decreased outside air ventilation rate is associated with increased symptom prevalence.

Phase 2: A practical, non-obtrusive technique for measuring ventilation rates is not available. In another research project, we are developing a measurement technique that should be available for Phase-3 research.

Phase 3: Passive tracer gas sources that emit tracer gas continuously will be deployed throughout buildings so that they are spaced uniformly per unit floor area. The time-average concentrations of tracer gas at workstations and in exhaust air streams will be measured by analyses of samples collected on sorbent tubes. Based on the measurements, indices of ventilation efficacy (values of a new parameter called the pollutant

control index) will be computed and compared to symptom prevalence. (Implementation of these plans is subject to field validations of the measurement technique prior to Phase 3.)

Hypothesis 6: Formaldehyde and ozone elicit sensory irritation and respiratory symptoms.

Phase 2: This hypothesis will not be evaluated during Phase 2.

Phase 3: Passive sampling techniques will be used to measure: (a) formaldehyde concentrations in each study space integrated over a workday, and (b) and week-average ozone concentrations for four consecutive weeks. Correlations to symptom data will be checked with a regression model.

Hypothesis 7: Elevated sensory irritation and respiratory symptoms due to gaseous contaminants can be predicted by a mouse bioassay.

Phase 2: This hypothesis will not be evaluated during Phase 2.

Phase 3: Air samples from a minimum of four study spaces (high and low symptom spaces based on Phase-1 data) plus two outdoor locations will be collected. These samples plus samples of ultra-clean air and air spiked with formaldehyde will be submitted to a laboratory for a mouse bioassay. Measured changes in respiration patterns of mice that breathe the air samples are potential indicators of sensory irritation and pulmonary irritation in humans and will be compared to the prevalences of occupant symptoms. The samples will also be analyzed for chemical composition.

Hypothesis 8: Increased noise is correlated with increased symptom prevalence.

Phase 2: Through measurements in each study space, we will assess the spatial and temporal variability in sound levels and the variation in the frequency distribution of sound.

Phase 3: Using a measurement protocol that reflects the Phase-2 findings, sound levels and the frequency distribution of sound will be measured in each study space. The correlation of sound level measurements and symptom data will be evaluated with a regression model.

Hypothesis 9: Flicker from lighting is associated with the prevalence of headaches in office workers.

Phase 2: The extent of lighting flicker will be measured in all study spaces. The correlation of lighting flicker to the Phase-1 symptom data will be checked via regression modeling.

Phase 3: If the Phase-2 data indicate a positive correlation, the measurements will be repeated during Phase 3.

Hypothesis 10: Skin irritation symptoms reported by office workers using photocopiers are due to skin exposures to : (1) black toner particles emitted by this equipment; and/or (2) irritant chemicals on the photocopies produced by this equipment.

Phase 2: No research related to this hypothesis will be performed in Phase 2.

Phase 3: Prior to collection of field data in the twelve buildings, laboratory-based exploratory research will assess if irritant compounds are sorbed onto toner particles, are present as vapors near photocopiers or laser printers, or are present on the pages of photocopy or print. If irritant compounds on particles or in air are detected, the emission rates of these compounds will be evaluated through experiments in an environmental chamber. Phase-3 field data collection, if any, will depend on the results of this exploratory research.

Hypothesis 11: Carbonless copy paper releases organic chemicals that cause sensory irritation and respiratory symptoms. The exposure route may be inhalation or via physical contact.

Phase 2: There will be no investigation of this hypothesis during Phase 2.

Phase 3: The relationship between use of carbonless copy paper and symptom reporting will be assessed by the questionnaire which asks respondents to report the time they spend during a typical day working with carbonless copy paper. Samples of frequently used carbonless copy forms will be collected from each building following the administration of the questionnaire. The percent of the total number of forms used in an office that are represented by each of the forms will be estimated. The collected forms will be coded and analyzed for solvent type and formaldehyde content. The frequency of carbonless copy paper use by individual workers in each building can then be corrected to reflect the handling frequency for forms of different types and formaldehyde content. If the type or formaldehyde content of the forms are important factors, the statistical significance of the relationship between the use of carbonless copy paper and symptoms should be strengthened by this categorization.

II. INTRODUCTION

A. Background

The phenomenon of "sick building syndrome" (SBS) is now widely recognized as a significant problem by public health officials, researchers, and even the media and the general public. Incidents of SBS, within specific buildings (often office buildings), are characterized by an unusually high prevalence of health symptoms and health complaints among the buildings' occupants. The symptoms may include irritation of the eyes, nose or throat, dry or itchy skin, difficulty breathing, cough, headache and fatigue. These symptoms could have many potential causes and, therefore, do not generally indicate a specific disease or specific pollutant exposure. The occupants believe that their symptoms are caused by the indoor environment, generally air pollution within the building. They report that their symptoms improve when they are not in the building, unlike the symptoms associated with typical infectious diseases. Severe cases of SBS prompt investigations by health officials and consultants and can even lead to evacuation of buildings.

The initial response to SBS was predominantly reactive. Researchers and health officials responded to severe cases of SBS by conducting investigations in the affected buildings. The investigations often included interviews of employees, measurements of indoor pollutant concentrations, and inspections of ventilation systems. In some buildings, causative factors were identified and corrected but, in many buildings, the causes of SBS were not determined. These reactive investigations in sick buildings have not elucidated the general causes of SBS. Such investigations are made more difficult by the disturbed psychological climate within sick buildings. Occupants are upset and afraid, making it very difficult to collect reliable or believable health data using subjective methods such as questionnaires and interviews. Objective assessments of health are generally unavailable or impractical.

During the past five years, researchers have started to use cross-sectional surveys conducted in multiple office buildings (chosen irrespective of the prevalence of occupant complaints) to evaluate the associations between the prevalences of health symptoms and characteristics of the individual, job, work space, building, and indoor environment. Questionnaires are used to determine the prevalences of health symptoms and to collect information on the individuals and their jobs and workspaces. Inspections and measurements are the basis for information on buildings and environmental conditions. These surveys have shown that many occupants of "normal buildings", (i.e., buildings without identified sick-building problems) report that they have health symptoms that improve when they are away from the building. They report the same symptoms commonly associated with SBS. An increased prevalence of symptoms in occupants of mechanically-ventilated buildings with air conditioning relative to the prevalence in occupants of naturally-ventilated buildings is the

strongest and most consistent association identified in these surveys. Prior to Phase 1 of the California Healthy Building Study (described below), no cross sectional survey of this type had been completed in U.S. buildings.

SBS and SBS symptoms among occupants of normal buildings are not just public health issues. Building energy use and occupant productivity are also affected. Increased ventilation, with associated increases in energy use and peak power, is one of the few options currently available to building operators seeking to prevent or reduce SBS problems; however, the efficacy of this common response to SBS has not been clearly demonstrated. The public and media associate SBS with sealed energy efficient buildings -- a perception that inhibits public acceptance of energy conservation. Severe cases of SBS clearly disrupt work and are a source of reduced productivity. In buildings with less severe problems an association between the prevalence or severity of SBS symptoms and work performance has not been proven but is plausible. An improved understanding of the causes of SBS and SBS symptoms is necessary for the development of energy efficient solutions to this problem.

B. Summary of the Phase-1 Study

In the summer of 1990, we completed a survey in twenty nine study spaces within twelve city- or county-owned office buildings located in the San Francisco area. The study methods are described in detail by Daisey et al. (1990). An investigation of the association between symptom prevalence and ventilation type was a primary goal. Six of the buildings were air conditioned (AC) and had sealed windows. Three buildings were mechanically ventilated (MV) without air conditioning and had openable windows. The remaining three buildings were naturally ventilated (NV) with openable windows. Smoking was prohibited in all buildings except in designated smoking lounges. 880 occupants provided information on their symptom prevalences, jobs, and workspaces, and provided personal information (e.g., sex, age, and smoking status). Occupants reported their symptom prevalences during the previous week and previous year and indicated if symptoms improved when they were away from the building. Building and ventilation system characteristics were determined in inspections and interviews with building operators. Several indoor environmental parameters were measured during the week that preceded questionnaire administration. The time-average indoor and outdoor concentrations of CO_2 and CO for the 45-hour work week were measured. The average indoor air temperature and humidity during each 15-minute period were recorded. Indoor and outdoor samples were collected for one work day and analyzed for determination of the total concentration of volatile organic compounds (TVOC) and to determine the concentrations of individual VOCs. Short-term (e.g., few minute) indoor and outdoor samples were also collected on a single day for a determination of the concentrations of total airborne viable fungi and bacteria. Measurements of aldehyde concentrations and ventilation rate, using new methods, were attempted but unsuccessful.

Logistic regression models were used to evaluate the associations between prevalences of work-related symptoms (i.e., symptoms that improve when away from work) and characteristics of the buildings, jobs, workspaces, individuals, and indoor environment. Each model yields odds ratios for various risk factors related to occurrence of a specific symptom. The odds ratio is defined as the odds for a symptom in the population of individuals with a hypothesized risk factor (e.g., individuals in an AC building) divided by the odds for the same symptom in a reference population of individuals without that risk factor (e.g., individuals in a NV building). The model computes odds ratios while controlling simultaneously for multiple confounding factors; for example, controlling the difference in gender distributions between two populations.

The Phase-1 data indicated that occupants of the air conditioned and mechanically ventilated buildings had an increase in the prevalence of most symptoms relative to occupants of naturally-ventilated buildings (Mendell et al. 1992), although there was substantial variation in symptom prevalence between buildings with the same type of ventilation. The odds ratios for skin symptoms (dry or itchy skin) and tight chest and difficulty breathing were more highly elevated in the buildings with AC and MV than the odds ratios for other symptoms (eye, nose, and throat irritation; headache; fatigue or sleepiness). The finding of increased symptoms in air conditioned buildings is particularly significant because it is consistent with the results of

previous European surveys (Mendell and Smith 1991). We know that ventilation type cannot be a direct cause of symptoms, so it must be a surrogate for one or more direct causes such as an increased pollutant exposure.

Several other factors were associated with increased prevalence of one or several symptoms. These factors include female gender, high job stress (reported on the questionnaire), use of carbonless copies, any carpet in the test space, and lack of a window within 15 feet of the workstation. Based on data analyses to date, which are nearly complete, no measured environmental parameter was clearly associated with an increase in symptom prevalence. An increase in the prevalence of several symptoms among occupants with the highest quartile of airborne viable fungi was suggested; however, buildings with the highest fungi concentrations were also the oldest buildings, and the proper interpretation of this association is unclear.

C. Objectives of the CIEE-Sponsored Research Effort

The California Institute for Energy Efficiency (CIEE), through its Exploratory Research Program, supported the design of research plans for future phases of the (CHBS). The intent of the CIEE-supported effort was to design research to be conducted in the Phase-1 buildings that capitalizes on the Phase-1 research findings and also on recently-published results of research from other institutions. This report describes and provides the rationale for research plans developed with CIEE support.

D. Introduction to the Design of Phases 2 and 3

Two additional phases (Phase 2 and Phase 3) of research have been designed. The main goal of the research in Phases 2 and 3 is to test hypotheses about associations between health symptom prevalences and characteristics of the buildings, ventilation systems, work spaces, and indoor environments. Using the Phase-1 building population, this research capitalizes on the Phase-1 findings and also includes investigations of hypotheses about the causes of symptoms that were not evaluated in Phase 1.

For two primarily reasons, we have chosen to conduct the Phase-2 and Phase-3 research in the same buildings studied during Phase-1. First, the Phase-1 research findings suggest possible causes of symptoms that can most efficiently be studied in the same population of buildings. The same set of factors may not be associated with increased symptom prevalences in a different set of buildings. For example, we can investigate the reasons for an association between symptom prevalences and use of carbonless copy paper in the Phase-1 buildings. In a different population of buildings, there may be no association between symptom prevalences and the use of carbonless copy paper because the occupants use different types or amounts of carbonless copy paper. Detailed and expensive investigations of carbonless copy paper use would be inappropriate in this different population of buildings. The second reason for continuing research in the Phase-1 buildings is based on a financial consideration. Studying the same set of buildings reduces research costs because contact persons have been identified, access to the buildings has been granted, and reference information on the buildings and ventilation systems has been obtained. For the same basic reasons, we will generally study the same population of individuals within each building. However, testing of some hypotheses, as described subsequently, will require special study populations to obtain statistically meaningful results.

We expect to undertake Phase 2 in the fall of 1992. Due to limited resources and time, Phase-2 activities are limited in scope. Several of the Phase-2 activities are intended to provide information for the development of appropriate measurement or inspection protocols that will be employed during Phase 3. An example is a determination of the spatial variability in sound levels within study spaces during Phase 2. This information is needed in order to determine the required number of measurement locations in the Phase-3 study. Other Phase-2 activities are inspections and low cost measurements which yield information that can be used to test associations with the previously-obtained Phase-1 symptom data In these cases, we must be reasonably

certain that the information collected during Phase 2 is also representative of the period when the Phase-1 symptom data were collected (June through September of 1990).

Phase 3, scheduled for the summer of 1993, will be a much more intensive investigation than Phase 2. Substantial measurements will be included along with the administration of a questionnaire on health symptoms experienced by the occupants during the measurement period. The Phase 3 study should reflect the findings of Phase 2 and must be consistent with future financial resources, which are uncertain. Some of the anticipated Phase 3 efforts depend on successful development and validation of measurement methods and sampling protocols prior to implementation of Phase 3. Consequently, the Phase 3 design described in this document is a preliminary design. In some cases, research plans are described in detail while in other cases we provide a more general outline.

E. Structure of this Document

The structure of the remainder of this document is as follows. First, we describe the method of collecting health symptom data in Phase 3. Then, we provide background information and describe the Phase-2 and Phase-3 plans for testing several hypothesis. Finally, descriptions of some detailed measurement or sampling protocols are included in appendices.

III. COLLECTION OF SYMPTOM DATA IN PHASE 3

A. Background and Objectives

In most investigations of office worker health complaint episodes, objective measures of health effects have not been informative, and the symptoms reported have not suggested specific known diseases. On the other hand, cross-sectional multi-building studies have shown consistent increases in some of these same symptoms in association with particular building or environmental factors. This suggests the potential occurrence in office workers of illness syndromes or toxic responses not yet understood or characterized. We will assess worker health responses using a symptom questionnaire. Although measures are subjective and open to bias, it is the only type of measure to have shown consistent associations with various environmental factors in previous studies.

Our primary objective is to use individual symptom data to identify environmental factors associated with increased reporting of one or more symptoms in the buildings. We also plan to use the symptom data to formulate preliminary case definitions for indoor factor-related illness syndromes, by finding groups of symptoms either clustered with each other or jointly associated with particular environmental features. This analysis should lead to hypotheses about possible mechanisms of action, and provide information for selection or development of useful objective health measures for future studies.

B. Instrument

We will use a modification of the office worker questionnaire produced by the EPA for their Building Assessment Survey and Evaluation (BASE) Program. The EPA/BASE questionnaire, intended for use in a large survey of U.S. office buildings selected without regard to worker complaints, was the consensus product of a national group of indoor air experts convened by the EPA. This group revised a previous instrument produced by the EPA, NIOSH, and several other groups for use in two large investigations of problem buildings. The EPA/BASE questionnaire thus represents the current state of knowledge about questionnaires on health effects applicable to this type of study.

We have modified the EPA/BASE questionnaire, as it was designed to collect general descriptive information on U.S. office buildings, and we wished more specifically to assess hypotheses and to identify risk factors related to worker health effects. Because a high survey response rate is essential for study results to be representative, we have shortened the questionnaire, retaining questions most clearly related to our current hypotheses, and eliminating other more exploratory questions. Some questions were also revised for greater clarity. The revised questionnaire is provided in Appendix 1.

C. Planned Analyses

Health outcomes to be assessed will include symptoms and other health conditions such as asthma and allergies. The data that are collected will allow a variety of definitions of symptoms to be used in the analyses. For example, symptoms with varying degrees of minimum frequency can be chosen for the analyses; also, the analyses can include either all symptoms reported or only those which improve when the individual is away from work.

The analyses will compare health outcomes to a variety of other factors assessed either in the questionnaire, by inspection, or by environmental measurements. These factors will include a variety of personal, psychosocial, work-space factors, building features, and measurements of the thermal, chemical, and biological environments. Assessment of symptom clustering may allow formulation of preliminary case definitions for office environment-related syndromes.

Other analyses can be performed using data from Phases 1 and 3 simultaneously. For instance, persistence over time of symptom prevalences in buildings can be assessed. Also, if a sufficient number of Phase-3 questionnaires are received from employees who also participated in Phase 1, changes in symptom status over time for those individuals can be assessed. In addition, workers reporting particular health outcomes can be targeted for more focused additional study, along with selected control subjects.

IV. TESTS OF HYPOTHESES

A. Background

Hypotheses about the causes of work-related symptoms were generated and selected based on the Phase-1 findings, results of similar surveys conducted elsewhere, and judgments of biological and physical plausibility of an association between a factor and symptoms. In most cases, a pollutant is hypothesized to be a cause of symptoms because few other factors are plausible direct causes. However, in contrast to most previous research that focused almost entirely on inhalation of airborne pollutants, we consider pollutants deposited on indoor surfaces, and direct physical contact with surfaces or materials as a potential route of exposure. Two additional hypothesized sources of symptoms -- lighting flicker and noise -- are physical factors rather than pollutants. Finally, in a few cases, we hypothesize that a suspected pollutant source, for example new carpeting, or a factor that will affect indoor pollutant concentrations, (e.g., ventilation rate), is associated with symptom prevalence.

The subsequent subsections state our hypotheses, provide background information relevant to the hypotheses, and describe Phase 2 and Phase 3 plans.

B. Description of Hypotheses and Associated Research Plans

1. Hypothesis 1: HVAC systems can be a source of pollutants that elicit symptoms. The potential pollutants are VOCs, bioaerosols, and fibers.

a. Background

Mechanical ventilation with air conditioning, relative to natural ventilation, has been associated with an increased prevalence of work-related symptoms in British surveys (Mendell and Smith 1991), a Danish survey (Skov et al. 1987), in Phase 1 of the CHBS, and anecdotally in other surveys that have not yet been described in the literature. Mechanical ventilation without air conditioning has also been associated with an increased symptom prevalence in some of these surveys and in Phase 1 of the CHBS. Despite these consistent findings, mechanical ventilation per se with or without air conditioning cannot be a direct cause of symptoms. Instead, it must be a surrogate for other agents or environmental conditions that elicit symptoms. One possibility is that HVAC systems are sources of pollutants that are transported to the occupied spaces and then elicit symptoms. HVAC systems contain several potential sources of contaminants. Interior duct liners used for thermal insulation and sound adsorption and fiberglass ducts are present in many HVAC systems and are potential sources of fibers and VOCs. Chemicals and cleaning compounds are sometimes stored in mechanical rooms or fan rooms -- another potential source of VOCs. HVAC systems also contain many sites that microorganisms can colonize, such as wet coils, drain pans, air filters, humidifiers (although no Phase 1 building has a humidifier), and dirty duct liners or duct surfaces. Fanger et al. (1988) conducted surveys which indicated that HVAC systems are a significant source of air pollution perceived subjectively by trained panels of people.

We have generated three sub-hypotheses related to Hypothesis 1. In the following sections we state these sub-hypotheses and describe the associated research plans.

1.1. Hypothesis 1, Sub-hypothesis 1: Ventilation systems are a source of VOCs that elicit symptoms.

a. Background

In the Phase 1 investigation, eye, nose or throat symptoms were the most common symptoms among the entire study group of 880 workers (40 percent). The prevalence of fatigue or sleepiness was also quite high (33 percent). For workers in air conditioned and mechanically ventilated buildings, many building-related symptoms were elevated compared to naturally ventilated buildings, with the highest adjusted odds ratios associated with skin symptoms, chest tightness or difficulty breathing, and chill or fever (Mendell et al. 1992).

A possible explanation for the finding that symptoms, particularly eye, nose, or throat symptoms and chest tightness or difficulty breathing were elevated in air-conditioned and mechanically ventilated buildings relative to naturally ventilated buildings, is that ventilation systems are associated with increases in airborne chemical contaminants. Molhave and Thorsen (1991) used a mass-balance approach in an attempt to show that ventilation systems are a primary source of VOCs. One common material which is a potential source of VOCs in air handling systems is internal duct liner used as a thermal insulation and for noise control.

b. Objectives

The primary objective of this investigation during Phase 2 is to determine if aged duct liners obtained from the study buildings are a significant primary source of individual VOCs and low-molecular weight aldehydes.

In Phase 3, the objective will be to determine if mechanical ventilation systems result in elevated concentrations of total VOCs and individual VOCs in occupied spaces over short periods following morning start-up of the ventilation systems. These start-up concentrations will also be compared to concentrations in naturally ventilated buildings at the beginning of a work day. Logistic regression models will be used to determine if symptoms are associated with concentrations of individual compounds, groups of related compounds or total VOCs measured at these times.

c. Phase-2 Research Plans

General Approach

The general approach for Phase 2 will be to collect small samples of duct liner from the buildings with mechanical ventilation systems. This will be done in conjunction with the inspections of the ventilation systems in these buildings, which may also identify other sources of VOCs such as stored chemicals. In the laboratory, experiments will be conducted with the samples of duct liner using small-scale environmental chambers. Following an initial decay period in the chambers during which much of the surface-sorbed VOCs will be eliminated, the samples will be successively exposed to elevated concentrations of water vapor and ozone. The emissions of VOCs and low-molecular weight aldehydes under these conditions will be qualitatively and quantitatively determined.

Building Inspections

Ventilation system inspections and assessments of ventilation-system maintenance will be conducted as part of the Phase 2 investigation. (See Section IV-1.3 and Appendices 2 and 3). In addition to identifying and quantifying the various materials in the systems, such as internal duct lining, other potential sources of VOCs and low-molecular weight aldehydes will be noted. These potential sources include the storage of maintenance chemicals in fan rooms which is not an uncommon practice.

Collection of Duct Liner Samples

Nine of the twelve buildings have one or more mechanical ventilation systems. If internal duct liner is found to be present in these systems, small samples of this material will be collected. The specific locations in the systems from which the samples are obtained will be determined in the field based on the accessibility to the systems through doors or removable panels. For consistency, an attempt will be made to collect the samples downstream from supply fans. A single piece of duct liner will be obtained from each building as long as it appears that any multiple mechanical systems are of the same construction and age and the same material has been used throughout the systems. If there are obvious differences in the construction or age of the systems in a building, then a sample will be collected from each of the different systems. The inspection team will attempt to identify the types of duct liner materials and estimate their total surface areas in the various mechanical systems.

At each sampling location, a four by four inch piece of duct liner will be removed from the duct using a utility knife, scissors, or scraper. If it is glued to the duct, an attempt will be made to remove the entire thickness of the liner including the adhesive layer. Each piece will be wrapped tightly in aluminum foil which has been pre-cleaned with methanol to remove residual oils. The packaged piece will be placed in a solvent-cleaned one-pint paint can and sealed. Sample collection information will include a sample number, the building number, the duct location and the date. The samples will be stored in their containers in a refrigerator prior to analysis to preserve their chemical integrity.

Experimental Procedures

Experiments will be conducted with each of the major types of duct liner that are collected from the buildings. It is anticipated that there will be no more than four different types. If there is one dominant type, additional experiments will be conducted using samples of this type collected from several of the buildings. One experiment will be conducted in duplicate using pieces of duct liner cut from the same sample to assess the reproducibility of the experiments. A blank experiment without a sample of duct liner will be conducted prior to the other experiments to measure the levels of any background contamination. A maximum of eight individual experiments will be performed.

The experiments will be conducted at LBL using small-scale environmentally controlled chambers. The chambers will consist of 4-L glass or steel containers fitted with air inlets and outlets (Hodgson and Girman 1989). The chambers will be maintained at constant temperature and will be supplied with clean humidified air.

Aged duct liners collected from buildings are expected to be sinks for the VOCs in the air that passes through the ducts. These VOCs will be sorbed onto surfaces and perhaps diffused throughout the materials. When exposed to clean air in the chambers, the amounts of the surface-sorbed VOCs should decline rapidly. Since the purpose of these experiments is to determine if aged duct liner can be a primary source of VOCs and low-molecular weight aldehydes, the samples will first be subjected to a 48-h decay period to desorb and significantly reduce the chamber concentrations of surface-sorbed compounds.

For each experiment, a two by two inch (25 cm^2) piece of duct liner will be cut from a sample. The piece will be weighed and inserted into a chamber. (The remaining piece of duct liner will be repackaged and stored pending possible use in other experiments.) The chamber will then be sealed and a ventilation rate of 5.0 h^{-1} will be established. The chamber will be operated at the standard conditions given in Table 1 for a period of 52 h. The collection of samples for VOCs and aldehydes will be initiated at an elapsed time of 48 h and will continue for four hours as described below. Upon completion of this sampling, the temperature of the chamber inlet air will be increased to 35° C while maintaining the same relative humidity (absolute humidity, i.e., volume of water vapor per unit volume of air, will increase). Then, the second set of samples will be collected at these conditions over a period of four hours. The chamber will next be returned to the standard conditions for 20 hours with samples of chamber air collected over the last four hours using the same procedures. In the final stage of the experiment, ozone at a concentration of about 100 ppb will be introduced into the chamber. The fourth set of samples will be collected at these conditions over a four-hour period. At the conclusion of the experiment, the duct liner will be removed from the chamber and re-weighed.

During each experiment, the temperature of the chamber will be monitored with a thermocouple. The dew-point temperature of the outlet air will be measured with a chilled-mirror dew-point hygrometer. The ozone concentration of the outlet air will be measured with an ozone analyzer.

Air Sampling and Analysis

The sampling devices for VOCs and low-molecular weight aldehydes are described in Appendix 4. Duplicate samples of chamber air for the qualitative and quantitative analysis of VOCs will be collected over periods of four hours. Single samples will be collected over the same periods for the analysis of formaldehyde and other low-molecular weight aldehydes. The air flow rates for the VOC samples will be about 15 cm^3 min^{-1}, and the air flow rates for the formaldehyde samples will be about 300 cm^3 min^{-1}. The respective sample volumes will be approximately 3.6 and 72 L. All samples will be stored in a freezer and will be analyzed within one week of sample collection.

The samples will be analyzed using the methods described in Appendix 4. These methods will result in limits of quantitation for emission rates of approximately 10 μg m^{-2} h^{-1} for individual VOCs and 20 μg m^{-2} h^{-1} for formaldehyde.

Data Analysis

The data will first be analyzed to determine if there are qualitative differences in the emissions of VOCs and aldehydes from the duct liners that can be attributed to the elevated temperature and concentration of water vapor or to the elevated concentration of ozone. For example, if a urea-formaldehyde resin has been used as a binder in a duct liner, the increase in temperature and water vapor concentration may result in hydrolysis of the resin and the release of formaldehyde. Ozone may react with components of duct liners to produce new volatile species that are not present in the absence of ozone (Weschler et al. 1992).

Emitted compounds which have the potential to produce sensory irritation or respiratory symptoms will be selected for quantitative analysis. For each of the compounds of interest, the concentration for a measurement period will be multiplied by the time of the sampling interval (4 h). This product will be multiplied by the air flow rate through the chamber ($m^3\ h^{-1}$) and divided by the area of the duct liner (m^2) to calculate the mass of the compound that was emitted per square meter of duct liner over the sampling interval. The effects of the elevated temperature and water vapor concentration or ozone concentration will be evaluated by comparing the emission factors of the compounds of interest during the period of elevated concentration to their respective emission factors during the preceding period when the chamber was operated at the standard conditions.

The experimentally determined emission factors can be multiplied by the estimated surface areas of duct lining in the mechanical systems of the buildings to obtain rough estimates of the potential for the emissions of VOCs and aldehydes from the duct liners of the buildings under conditions of elevated temperature and water vapor concentration or elevated ozone concentration.

d. Phase-3 Research Plans

Sampling Strategy

If the materials in mechanical systems are primary sources of VOCs, the concentrations of the compounds that are emitted are expected to build up in the ducts during periods when the systems are shut down (Mechanical systems in many buildings are shut down at night and on weekends). When the mechanical systems are activated, these compounds will be quickly introduced into the occupied spaces. Concentrations in the spaces may rapidly increase and then decay at a rate which is dependent upon the ventilation rate.

The sampling strategy for Phase 3 is designed to capture any short-term changes in the concentrations of VOCs in the study locations that may be due to the morning start up of mechanical ventilation systems. In each mechanically ventilated building, samples for VOCs and low-molecular weight aldehydes will be collected from a representative air-handling unit prior to the morning start up and from the three study locations immediately prior to and immediately following the start up. To maximize the probability of detecting an effect, an attempt will be made to conduct this sampling on a Monday morning following a weekend shut down. Samples of outdoor air near the air intake for the air-handling unit will also be collected to provide assurance that the air handling unit, not outdoor air, is the source. It may be necessary to collect samples from more than one air-handling unit in buildings with multiple units if there are substantial differences among these units. This necessity will be determined based on the inspections conducted in Phase 2. Sample collection intervals will be approximately 30 minutes in duration. Sampling will be coordinated with the building operators so that the collection of the post start-up samples in the study locations will commence when the air handling units are activated.

Samples for VOCs and low-molecular weight aldehydes will also be collected from the three study locations in each of the naturally ventilated buildings. So that the data will be comparable to the data for the mechanically ventilated buildings, these samples will be obtained immediately prior to the normal work day, preferably on a Monday.

Chemical Analysis

The samples will be analyzed for total VOCs and individual compounds using the methods described in Appendix 4. The samples from each mechanically ventilated building will first be qualitatively analyzed to identify any compounds that are elevated in the air-handling unit relative to the study locations prior to system start up. It is expected that any compounds that are found to be emitted from duct liner in the Phase 2 investigation will be significantly elevated. Other materials in mechanical systems, such as filters and gaskets, may also be primary sources of VOCs. Another potential source is fungi which release a variety of complex alcohols, aldehydes and other compounds (Batterman et al. 1991).

Based on the qualitative evaluations, individual compounds will be selected for quantitative analysis. Emphasis will be placed on compounds which have the potential to produce sensory irritation or respiratory symptoms. An attempt will be made to quantify each selected compound in all of the building samples so that the entire group of buildings may be used in the data analysis. All of the building samples will also be analyzed for total VOCs.

Data Analysis

Any increases in the concentrations of total VOCs and individual VOCs that are due to the start up of the mechanical systems will be calculated simply as the difference between the concentration after start up and the concentration before start up for each affected compound. These differences will demonstrate the magnitude of the mechanical systems as sources of VOCs.

Logistic regression models will be used to determine if any symptoms are significantly related to concentrations of VOCs and low-molecular weight aldehydes that are measured following the activation of the mechanical ventilation systems in mechanically ventilated buildings and at the beginning of the work day in naturally ventilated buildings. The models will be run for individual compounds of interest, such as formaldehyde, for groups of related compounds, and for total VOCs.

Table 1. Standard conditions specified for the operation of the small-volume chambers.

PARAMETER	VALUE
Volume, m^3	4×10^{-3}
Ventilation rate, h^{-1}	5.0 ± 0.2*
Temperature, °C	23 ± 1*
Relative humidity, %	50 ± 5*
Sample area, m^2	0.025

*Uncertainties are quality-assurance objectives shown as ± one standard deviation.

1.2. Hypothesis 1, Sub-hypothesis 2: HVAC systems can be sources of bioaerosols that elicit symptoms.

a. Background

The growth of microorganisms within HVAC systems has been well documented (e.g., see Burge 1990, Morey et al. 1990, Morey and Williams 1991; Martikainen et al., 1990, Elixmann et al. 1990). Sites within HVAC systems where microbiological growth can occur include coils, drain pans of cooling coils, air filters, internal fibrous duct liner, dirty interior surfaces of ducts without an internal liner, humidifiers, and cooling towers. In some cases, microorganisms have clearly been associated with specific illnesses, such as Legionnaires disease. However, the extent to which microbiological growth in HVAC systems is a cause of the less severe and varied symptoms associated with sick building syndrome, or a cause of the same symptoms in non-sick buildings, has not been determined. Clearly, the hypothesis that HVAC systems are a source of bioaerosols that elicit symptoms is plausible. Microorganisms can multiply in HVAC systems, the flow of air in the HVAC systems provides a means of transport to the occupied space; and inhaled microorganisms, along with volatile microbiological by-products and other biologic materials can trigger hypersensitivity reactions such as allergic rhinitis (Burge 1990, Burge et al. 1987, Hood 1990, Morey et al. 1990). Even without active growth in the HVAC system, bioaerosols and other debris that have collected in an HVAC system may be resuspended when the system is disturbed vigorously or when it first is turned on after a period of non-use. The supply air then may carry this material into a building.

b. Phase-2 Research Plans

Objective

In Phase 2, we will evaluate protocols relevant for testing the hypothesis that HVAC systems can be a source of bioaerosols that elicit health symptoms. One set of protocols contains proposed methods for identifying microbiological contamination (a potential source of bioaerosols) in HVAC systems. Another protocol is a method for determining the types and quantities of bioaerosols that exit HVAC supply air diffusers which are the final component of the HVAC system (in the supply air) upstream of the occupied space. We will not assume that the results of this Phase-2 microbiological assessment are representative of the prior Phase-1 study period. However, the experience gained in Phase 2 will lead to improved protocols that can be used in the future (e.g., in a Phase 3 study), coincident with the collection of data on occupant health symptoms.

Inspection of HVAC Systems for Sources of Bioaerosols

When evaluating a building for the potential to cause illnesses related to biological contaminants, investigators usually begin with a visual inspection of the site to identify sources. Examples of clues that might lead one to suspect biological contamination within an HVAC system are musty or moldy odors, stagnant water in drain pans, evidence of past water accumulation or flooding, and visible growth on the equipment. In Phase 2, we will evaluate protocols for identification of microbiological contamination in HVAC systems. The protocols, and the procedures for evaluating these protocols, are described in Appendices 2, 3, and 5.

Sampling of the HVAC Supply Air

Microbiological contamination in HVAC systems will not cause occupant health symptoms unless bioaerosols (i.e., fungi, bacteria, fragments of arthropods and protozoa, pollen, animal debris and biological byproducts) are transported into the occupied space. The flow of air through an HVAC system and into an occupied space is a possible mode of transport. The rate of transport of bioaerosols to the occupied space could be unsteady or even episodic, consequently, short-term measurements of bioaerosol concentrations in the occupied space might not be adequate for evaluating the hypothesis, even in the hypothetical situation with no sources of bioaerosols in occupied space. Transport of bioaerosols to the occupied space could be temporally associated

with the release of fungal spores, times of high air supply rates, vibrations, or disturbances (e.g., by maintenance activities) to the section of the HVAC system that is contaminated.

One potential (but experimental) method of distinguishing between HVAC systems that are or are not sources of bioaerosols in the occupied space is to draw samples of the air exiting supply diffusers through filters and subsequently perform analyses to determine the quantity and types of bioaerosols on the filter. By simultaneously sampling the supply air, the outdoor air, and air in the occupied space (or at HVAC return grilles), bioaerosol release by HVAC systems should be quantifiable. Flannigan (1992) has recommended the collection of bioaerosol samples on polycarbonate membrane filters with 0.4 μm pores for a period of several hours at low air flow rates (e.g., 1 LPM). The low flow rates are intended to reduce the desiccation and death of organisms on the filters. Even at the low sample flow rates, death of some bacteria is considered likely while the death of fungi is considered to be less likely. However, no data are actually available on which to assess the survival rates of bacteria or fungi.

We will evaluate this basic sampling method in Phase 2. To obtain statistically significant numbers of bioaerosols, a larger sample volume is required than can be obtained at a 1 LPM sample flow rate. Consequently, samples will be collected at a flow rate of 3 LPM for an eight-hour workday. To permit collection of bioaerosols emitted at the time of HVAC system start-up, sampling will commence when the HVAC fans start operating in the morning. For unbiased sampling of bioaerosols, the sample stream velocity must equal the velocity of air in the supply airstream (i.e., the sampling process must be isokinetic); otherwise, aerosols of certain sizes will be over- or under-sampled To obtain an approximately isokinetic sample, a short straight section of sample tube will be installed upstream of the membrane filter and the internal diameter of the sample tube will be chosen to yield an approximate match between the sample stream velocity and the HVAC supply air velocity. The axis of the sample tube will be oriented parallel to the direction of supply air flow, with the direction determined visually using a smoke tube. Because the sampling procedure is expected to desiccate and, thus, kill bacteria, the samples will be analyzed only for fungi and total cell count.

Samples will be collected in three study spaces from the air exiting three supply diffusers per study space. Four samples will be collected simultaneously from each diffuser. Two of the samples will be used for cultures of fungi (on different culture media) and a third sample will be analyzed for total cell count. The fourth sample from each supply diffuser will be analyzed as a duplicate of one of the three other samples; providing a check of measurement precision. The sample analysis methods are described in Appendix 5.

The data analysis will include a comparison of the types and abundance of microorganisms in the different filter samples from the same supply diffuser, from different diffusers in the same test space, and between diffusers in different test spaces. In addition, these results will be compared to the results of the assessment of microbiological contamination in HVAC systems (described above) and to the results of sampling for microbiological material in the air and on the floor of the same test space as described in Sections IV-2.1 and IV-4.

To complement the Phase-2 field tests, laboratory-based experiments will be conducted to assess survival rates of bacteria and fungi during sampling on membrane filters.

c. Phase-3 Research Plans

In Phase 3, we will repeat the inspections of HVAC systems for sources of bioaerosols using the method(s) determined to be most appropriate during Phase 2. In addition, if the Phase-2 sampling of bioaerosols in supply airstreams are successful and indicate that there is substantial variation in the bioaerosols in the supply airstreams of different study spaces, the measurements will be repeated in all study spaces with mechanical ventilation or air conditioning. To complement the supply air samples, filter samples of bioaerosols will also be collected from the outside air and from air within the occupied space. Comparison of the abundance and types of bioaerosols in supply air, outside air, and return air will indicate if the HVAC systems emit

bioaerosols. The results of these Phase-3 measurements will be compared to symptom prevalences using a regression model.

1.3. Hypothesis 1, Sub-hypothesis 3: HVAC systems are a source of fibers that elicit skin and mucus-membrane symptoms. Consequently, the area of potential fiber sources in HVAC systems is also related to symptom prevalence.

a. Background

In the Phase 1 study, occupants of mechanically-ventilated (MV) and air conditioned (AC) buildings had a much higher prevalence of dry or itchy skin than occupants of naturally-ventilated buildings. The associated odds ratios and 95% confidence intervals were 5.8 (1.9 - 18) and 5.6 (1.9 - 16) for the MV and AC buildings, respectively. Low humidities, below roughly 30% relative humidity, are considered a source of skin symptoms, but the measured humidities were well within the range considered acceptable (week-average relative humidity ranged between 42% and 56%). Most air pollutants are not known to be a source of skin symptoms. However, fibers are a known source of skin irritation and could be emitted by the HVAC systems present in the MV and AC buildings. Two potential sources of fibers inside HVAC systems are internal fibrous duct liners (used for thermal insulation and sound adsorption) and fiberglass ductwork. In both cases, fibers may contact the moving air if there is not a continuous membrane between the fibers and the air stream. The moving air is a means of transport of fibers to the occupied space. In addition, the ductwork of many HVAC systems is insulated with external fiberglass insulation. This external insulation is generally surrounded by a layer (vapor barrier) of foil, paper, or plastic that should help to contain the fibers. However, fiberglass could escape into the indoor environment where the vapor barrier is broken and at the edges of fiberglass batts. In addition, fibers that are released during initial installation of the insulation could have accumulated on surfaces (e.g., in ceiling plenums) and, upon disturbance or vibration, enter the occupied space.

We are unaware of attempts to evaluate the association between these potential sources of fibers and symptom prevalence. Some data exists on fiber emission rates from these sources. Gamboa et al. (1988) conducted laboratory tests to evaluate the emissions of fiberglass fibers from fiberglass duct liner and fiberglass duct board. The new fiberglass materials assembled in accordance with an industry standard were not a significant source of airborne fibers; however, the implications for fiber emissions in older field settings are unclear. Laboratory and field tests by Shumate and Wilhelm (1991) of fiber emissions from fiberglass air filters indicated that emissions from the filters were negligible. Data on concentrations of fibers in air and on surfaces in Danish buildings is provided by Schneider (1985) and Schneider et al. (1990). These references indicate the airborne concentrations of fibers are low compared to accepted standards and indicate that measurements of fibers on surfaces may be more relevant. The low airborne concentrations may be attributed to the rapid setting of the fibers and the episodic release of fibers that are not reflected in air samples. Because HVAC systems are not the only possible fiber sources in buildings (ceiling tiles, wall insulation, and fireproofing are other potential sources), an evaluation of the correlation between symptoms and the concentrations of fibers on surfaces (a proposed Phase 3 effort) is relevant but not a direct test of this hypothesis.

b. Phase-2 Research Plans

During Phase 2, we will inspect HVAC systems to determine if internal duct lining with fibers is present and, when possible, determine the surface area of duct lining. We will also check for the presence of fiberglass duct and external fiberglass insulation of ducts in the study spaces or ceiling plenums above these study spaces. The inspection procedures and questions to be asked of facilities managers are described in Appendices 2 and 3. Building managers will be asked if these sources have been added or removed since the Phase 1 study was completed. If sufficient data are obtained, the association between the presence of sources and symptom prevalence (based on the Phase-1 questionnaire) will be evaluated using a regression model.

c. Phase-3 Research Plans

Measurement of fiber counts in samples collected from horizontal surfaces, identification of the types of fibers in these samples, and assessments of the types of fibers in potential source materials is being considered for Phase 3. Detailed research plans have not been developed. The concern of occupants regarding asbestos exposure complicates the planning process. We expect that asbestos fibers will be present in many samples, even when airborne concentrations of asbestos are typical and when the building does not contain asbestos sources. However, reporting our finding of asbestos fibers to building occupants could cause increased occupant concerns about asbestos and even be a source of conflicts between workers and building owners or managers.

2. Hypothesis 2: Occupants are exposed to pollutants that accumulate on indoor surfaces, especially high surface area materials. The suspected pollutants are viable and non-viable microorganisms and fibers. The exposure route may involve direct human contact with the surfaces or resuspension and inhalation of particles.

a. Background

Based on physiology, exposure to pollutants is a logical cause of the health symptoms associated with SBS. However, the prior surveys that included air pollutant measurements and assessments of symptom prevalence have identified no consistent statistically-significant associations between air pollutant concentrations and symptom prevalence. The prior surveys do provide some direct and indirect evidence for an association between pollutants on surfaces and symptoms as described in the discussion of Sub-hypotheses 2.1 - 2.3.

We have generated three sub-hypotheses related to Hypothesis 2. In Sections 2.1 through 2.3, we state these sub-hypotheses and describe the associated research plans.

2.1. Hypothesis 2, Sub-hypothesis 1 : Occupants are exposed to viable and non-viable microorganisms that accumulate on floors or chairs. The exposure route may involve episodic resuspension and inhalation or direct contact with skin and transport via hands to mucus membranes. These exposures may elicit symptoms in some individuals.

a. Background

Dust that has accumulated on horizontal surfaces (such as floors) within a building may reflect better than air samples the bioaerosols that have been in the building in the past. Horizontal surfaces, especially those with a high surface area, such as carpeted floors, may be reservoirs of viable and non-viable microorganisms and microbiological matter that elicit health symptoms. Prior research provides some support for this hypothesis, at least for an association between biological material on carpeting and symptoms. Dust mites, usually considered a problem in residences, have been found on surfaces in offices (Tharr 1991) and could be a source of symptoms in some individuals. In a Danish study of 14 town halls, the concentration of macromolecular organic dust of biological origin correlated strongly with the prevalences of mucosal and "general" symptoms (Gravesen et al. 1990) and the authors reported finding a similar correlation from a study in schools. The weight of floor dust and the quantity of high-surface-area materials, such as carpets and open shelves, was also correlated with symptom prevalence (Valbjorn and Skov 1987). In a follow-up study of four town halls, the quality of building cleaning and the quantity of high-surface-area materials was related to symptoms (Skov et al. 1990). The presence of carpets also correlated to symptoms with a Swiss study (Norback and Torgen 1989) and in Phase 1 of the CHBS. In the Swiss study, symptoms decreased when carpets were removed. We suspect that these associations between symptom prevalence and carpeting could be related to biological contaminants, rather than to emissions of chemicals from carpets, because existing

data indicate that the emission rates of chemicals declines rapidly (Hodgson et al. 1992) and is probably insignificant after approximately six months or more after installation of the carpet.

We are unaware of data connecting biological matter on hard-surface floors to symptoms or of any efforts to check for an association except for the study by Gravesen et al. 1990. Because dust accumulates on hard-surface floors, biological matter is likely to be present and an association with symptoms is plausible.

To the best of our knowledge, no previous research has been conducted on microbiological contamination on upholstered chairs. However, there are several reasons to suspect that microbiological contamination on these chairs is at least as important as contamination on floors. Chairs are infrequently cleaned. Occupants have extensive direct contact with the chairs. Hand contact with chairs followed by hand contact with the eyes or nose could be a route of exposure to microorganisms. The extensive human contact with chairs also increases the temperature and moisture content of the chair's surface, thus, improving the conditions for growth of microorganisms. Finally, the large expected number of skin flakes on chairs may result in a suitable environment for house dust mites (which feed on skin flakes). These reasons, together with the previously-described connection between symptoms and carpets, are considered adequate justification for research on the association between health symptoms and microbiological contamination on upholstered chairs.

b. Phase-2 Research Plans

Objectives

In Phase 2, we will evaluate measurement protocols for assessing the extent of biological contamination on both carpeted and hard-surface floors and on upholstered chairs. We will not assume that the measurement results are representative of the prior Phase-1 study period. However, the experience gained in Phase 2 will lead to improved protocols that can be used in the future (e.g., in a Phase 3 study) coincident with the collection of data on occupant health symptoms.

Measurements on Carpeted Floors

On the carpeted floors of two study spaces, we will collect dust samples using the vacuum technique described in Appendix 6. Independent dust samples will be collected from three different areas of carpet within each test space, each area located near a specific worker. To permit a check of measurement precision, a duplicate sample will be collected near one worker. Two additional samples, one as a duplicate of the other, will be composited from 35 locations spaced evenly throughout the carpeted area. Each sample will be analyzed for viable fungi and bacteria using the procedures described in Appendix 5. We also will stain portions of the sample suspensions to determine the total cell counts by microscope (American Public Health Association 1984, American Public Health Association 1989). The entire sampling process, including the collection of duplicates, will be repeated yielding samples for analyses of dust-mite concentrations. The concentrations of dust mites will be determined by microscopically examining weighed portions of dust samples.

Measurements on Hard-Surface Floors

On the hard-surface floors of a single study space, we will repeat the sampling process described above for carpeted floors. However, we will not collect the second set of samples for determination of dust-mite concentrations, because the amount of dust collected is not adequate for the dust-mite analysis.

Measurements on Upholstered Chairs

A vacuum procedure, very similar to that used on floors and described in Appendix 6, will be employed to collect dust samples from upholstered chairs in three test spaces. Samples will be collected from four chairs in each test space and used to prepare cultures of fungi and bacteria. Duplicate samples from one of the

chairs in each test space will be analyzed to indicate measurement precision. The entire sampling process will be repeated to obtain dust samples for microscopic analysis of dust-mite concentrations.

Data Analysis

The analysis of data from the carpeted floors, the hard-surface floors, and the chairs will include a comparison of the types and abundance of microorganisms on different floor locations (or different chairs) in the same study space. Measurement precision will be determined from the duplicate samples. The microorganisms on the carpeted floors (and chairs) of the different study spaces will be compared. The types of fungi and bacteria on floors and chairs will be compared to the types in the indoor air and HVAC supply air of the same study spaces as described in Sections IV-1.2 and IV-4. The dust-mite data will indicate if significant dust mites are present in San Francisco-area buildings and if chairs are a more or less important source of mites than carpets.. Through the Phase-2 effort, we will gain general experience in the sampling and sample analysis procedures. This experience will permit optimization of sampling and sample analysis methods for Phase 3 including the determination of the required number of samples per study space.

c. Phase-3 Research Plans

During Phase 3, the measurement of microbiological material on floors, both carpeted and hard-surface floors, will be completed in all study spaces. Chair dust samples will be collected and analyzed from all test spaces with upholstered chairs. The detailed methods will be developed after a review of the Phase-2 data. Using a regression model, the results of the Phase-3 measurements will be compared to the occupant symptom data collected in Phase 3.

2.2. Hypothesis 2, Sub-hypothesis 2: The surface area of carpet per unit volume of indoor air correlates positively with occupant symptom prevalence.

a. Background and Objectives

The presence of carpet has been associated with office worker symptoms in European studies (Skov et al. 1987, Norback and Torgen 1989) and in Phase 1 of the CHBS, presumably due to exposures to as-yet-unidentified contaminants: These contaminants could include physical or chemical components of the carpet, physical, chemical, or biological contaminants held by the carpet and re-released, biological contaminants amplified in the carpet, or chemicals added during carpet-cleaning procedures. The association between office worker symptoms and presence of carpet found in the European studies and in Phase 1 of this study has not been confirmed by other studies in the U.S.

One of the European studies (Skov et al. 1987) did not assess symptom associations with carpets specifically, but with total square feet of fabric surfaces (carpets, fabric-covered walls, seat covers, etc.) per volume of the office; they reported that this measure was associated with increased work-related symptoms. The other European study (Norback and Torgen 1989) found workers in buildings without carpet to have lower prevalences of symptoms than those in buildings with carpet, and also found that symptom prevalences decreased in one building after carpet was removed.

Assessment of carpets in Phase 1 of this study involved the determination, by inspection, of whether each respondent's workstation was within 15 feet of carpeting. As carpet-related exposures might occur not at an individual level but at a space level, an additional variable was constructed from the individual variable, reflecting the proportion of respondents in each study space whose workstations were near carpet. The space-level carpet variable was associated with increases in a number of work-related symptoms, but the individual carpet measure was not. On the other hand, symptom prevalences in Phase 1 workers were slightly reduced among those in spaces with fabric partitions, although these fabric partitions were not common in our study.

We wish to gather more accurate quantitative information on carpets in the study spaces to check our initial findings. (Partitions in our study spaces were not common enough to warrant restudy.)

The objective of this protocol is to quantify the amount of carpet within each study space volume in order to allow an improved assessment of correlations with worker symptoms. We will also assess the approximate age of all carpets.

b. Phase-2 Research Plans

Information on carpets will be collected by inspection of the study spaces. As the goal is to estimate the amount of carpet at the time of the Phase 1 questionnaire, any changes in carpeting since then will be determined in interviews with appropriate building personnel. Findings will be recorded on the "California Healthy Building Study-Phase 2 Carpet Area Assessment Sheet" provided in Appendix 7. Information on each study space will be recorded on a separate answer sheet.

The estimated square feet of carpet per study space will be divided by the estimated volume in square feet of the study space, to produce a carpet index. The resulting parameter will be used in bivariate and adjusted analyses, in conjunction with prior Phase 1 symptom data.

c. Phase-3 Research Plans

We have no plans for additional testing of this hypothesis during Phase 3.

2.3. Hypothesis 2, Sub-hypothesis 3: The quality of office cleaning and the nature of office pest-control practices is associated with occupant symptom prevalence.

a. Background and Objectives

Although evidence suggests that environmental contaminants may contribute to high symptom levels in offices, specific contaminants have not been identified. General environmental indicators, if found to be associated with worker symptoms, would help target more specific exposures. Office cleaning practices may affect levels of certain indoor contaminants, and thus indirectly affect exposures.

An associations of symptom increases with poor office cleaning practices has been reported from a follow-up study to the Danish Town Hall study (Skov et al. 1990). The initial study of 14 buildings found no association between symptoms and a cleaning index, in either unadjusted or multivariate adjusted analyses (Skov et al. 1987). However, the follow-up study of four high or low symptom buildings found a possible association of mucosal irritation symptoms with quality of cleaning (Skov et al. 1990).

The follow-up study involved a "semi-quantitative estimation of the quality of cleaning according to cleaning methods, materials, frequency, and ability of carrying through the cleaning," in 8-10 offices in each of the four buildings. It is implied that this same procedure was used in the initial study, and it is not clear why findings should have differed between the two studies.

We have not been able to obtain detailed information on the Danish group's protocol. Another forthcoming protocol, under development for the EPA, will not be available in time for our Phase 2 planning process, but may be of use in our Phase 3 design.

The objective of this protocol is to identify aspects of cleaning practices which correlate with worker symptom reports. These relationships might be due to insufficient removal of particular contaminants, or addition of chemical compounds (for cleaning, disinfection, or pest control) into the indoor environment. The assessment of office cleaning practices ascertains: types of cleaning procedures and materials used, schedules

for those procedures, records of past performance, and evidence of past performance. In addition, schedules of pesticide use and the specific substances used are determined.

b. Phase-2 Research Plans

Information for this protocol will be collected by interviews with appropriate personnel (from building management or maintenance staff, or outside contractors), and by inspection of indoor spaces. Information gathered will include: methods and frequency of cleaning floor surfaces, both with and without carpets, and other furniture or interior surfaces; description, frequency, and methods of using chemical cleaners, rug shampoos, or disinfectants. Any changes in practices, or in cleaning contractors, between the study periods will also be assessed. Findings will be recorded on the "California Healthy Building Study-Phase 2 Office Cleaning/Pest Control Practices Assessment Sheet" (see Appendix 8). Information on each study space will be recorded on a separate answer sheet. Information from separate study spaces within a single building will be combined on a single answer sheet only if it is ascertained beforehand that cleaning practices are uniform.

c. Phase-3 Research Plans

We have no plans for additional testing of this hypothesis during Phase 3.

3. Hypothesis 3: New carpets and/or other components of carpet installations emit VOCs that elicit sensory irritation and respiratory symptoms.

a. Background

The potential impacts of newly installed carpets on human health and comfort are of concern. The U.S. Consumer Product Safety Commission (CPSC) has compiled data on health complaints related to carpets (Schachter 1990) Complaints from 335 residents from 206 households were received from 1988 through early 1990 after the CPSC issued a news release about their interest in studying carpet-related health problems. About two thirds of the complainants reported that symptoms started immediately, or within a few days, following carpet installation. Most people reported upper respiratory problems in combination with other symptoms such as eye irritation, headache, rashes, and fatigue. Twenty-five of the complainants were hospitalized. Due to the limited scope of the CPSC study, no attempt was made to directly relate these symptoms to the emissions of contaminants from carpets.

Remodeling of the Washington headquarters of the U.S. EPA focused attention on emissions of VOCs from carpets. Many of the EPA employees complained of health and odor problems after new carpeting was installed in part of the building. Testing identified an individual compound, 4-phenylcyclohexene (4-PCH), as the predominant source of the "new carpet" odor (Van Ert et al. 1987). This compound is a manufacturing by-product present in the styrene-butadiene rubber (SBR) latex which is frequently used to bind the secondary backing of a carpet. The National Federation of Federal Employees petitioned the EPA to regulate 4-PCH, which the union alleged was the cause of health problems suffered by the EPA employees. The petition was denied; however, the EPA initiated a one-year dialogue with carpet manufacturers to develop standard methodologies for measuring emissions of total VOCs (TVOC) from carpets and to obtain commitments from industry for carpet testing (Federal Register 1990). A Carpet Policy Dialogue Group consisting of representatives from industry, the EPA, the CPSC, labor, public interest groups, and members of the scientific and research communities was formed to address these issues (Carpet Policy Dialogue 1991).

Carpets have been shown to emit a variety of VOCs including 4-PCH (Seifert et al. 1989, Bayer and Papanicolopoulos 1990, Black 1990, Pleil and Whiton 1990, Schröder 1990, Davidson et al. 1991, Hodgson et al. 1992). A recent CPSC-sponsored study at LBL measured the emission rates of VOCs released by four different new carpets that are typical of the major types of carpets used in residences, schools and offices (Hodgson et al. 1992). Concentrations and emission rates of a number of VOCs, including 4-PCH, were measured under simulated indoor conditions in a 20-m^3 environmental chamber over a period of one week

following the installation of a carpet sample in the chamber. Other investigators have also reported the quantitative emissions of 4-PCH from carpets (Seifert et al. 1989, Black, 1990, Black et al. 1991). It is suspected that 4-PCH or some other component(s) of these volatile emissions is the source of carpet-related health and comfort complaints. However, the effects of these compounds at low concentrations have generally not been investigated. New carpeting also contains significant amounts of loose fiber particles which can become suspended in air.

b. Objectives

A Phase-2 investigation of this hypothesis is not planned. The objective of Phase-3 effort is examine the relationships between new carpets and symptom prevalences using procedures that are designed to help identify the causal agent(s). This will involve collecting samples of the materials used in the carpet installations that occur during and immediately proceeding the study period. Emission rates of VOCs from these materials will be measured in the laboratory using small-scale environmental chambers and will be used to make projections about VOC concentrations and exposures in the buildings.

c. Phase-3 Research Plans

In advance of the Phase 3 field investigation, study locations where there are plans to install new carpeting will be identified by interviewing the building mangers. This information will be obtained at least three months in advance of the planned investigation. Since the questionnaire to be used in Phase 3 will ask workers about their symptoms over the previous month, any study locations in which emissions of VOCs from new carpeting could be affecting workers during this period will be targeted for more detailed investigation. In general, this will be locations in which carpeting is to be installed within two months of the administration of the questionnaire.

The general approach will be to attempt to relate symptom reporting to estimated concentrations and exposures to VOCs emitted by carpets and related materials. The supplemental information in Table 2 will be obtained for each installation. Samples of the carpet and related materials, such as pads and adhesives, will be collected at the time of installation from each targeted building and area. The individual VOCs that are emitted by the carpets and related materials will be identified in laboratory screening measurements (Hodgson et al. 1992). In addition, the emission rates of individual VOCs from the materials will be measured in the laboratory over a period of at least five days in small-volume chambers. Emphasis will be placed on those compounds which are likely to be sensory irritants or which may cause respiratory symptoms. The temporal decays in the emission rates of the compounds that are observed in the chambers will be used to project emission rates during the one-month study period. Existing data for similar carpets may be utilized in making these projections (e.g., Hodgson et al. 1992). The estimated emission rates will be input along with building parameters into a simple mass-balance model to obtain order-of-magnitude estimates of concentrations and of exposures of workers to the compounds of interest. Symptom reporting from the questionnaires will then be compared to these estimated concentrations and exposures.

It is difficult at this time to assess the potential for compounds emitted by carpets to cause sensory irritation and respiratory symptoms among office workers since the low-level effects of many of these compounds have not been investigated. Human health studies are complicated and expensive to perform. However, there is a mouse bioassay that uses reduction in respiratory rate as a measure of the irritancy of VOCs (ASTM standard method E981-84, ASTM 1984). A number of compounds have been assessed using this method. Concentrations which result in a 50 percent reduction in the respiratory rate of mice (RD_{50}) range over approximately five orders of magnitude with toluene diisocyanate being the most irritating compound tested and compounds such as acetone and benzene having little or no effect (Alarie 1981). The RD_{50}s are generally correlated to industrial exposure Threshold Limit Values (TLVs) for compounds whose limits are based on irritancy (*ibid.*).

If a significant relationship between irritation effects and new carpeting with SBR latex adhesive is obtained in the Phase 3 investigation, it is proposed that the mouse irritancy test be performed to assess whether 4-PCH is the likely etiological agent. This can be done at a commercial testing laboratory that specializes in the mouse bioassay. Measuring the irritancy of 4-PCH would place the compound on a common scale with the other compounds that have been tested. It is of particular interest to compare the irritancies of 4-PCH and formaldehyde, since there is information about the effects of formaldehyde on humans at low concentrations (e.g., Gupta et al. 1982, Liu et al. 1991). In this manner, it may be possible to determine if the observed irritation symptoms could reasonably be due to exposure to this single compound.

Table 2. Supplemental information for installations of new carpeting.

PARAMETER	DATA
Installation date	Month and year
Location of carpeting within study area	Indicate on floor plan
Installed area	Approximate square yards
Carpet specifications	
Construction	Pile/Loop
Fiber type	Nylon/Polypropylene/Other
Form	Roll/Tiles
Secondary backing type	Soft/Hard polyvinyl chloride
Backing adhesive	Styrene-butadiene latex/Other
Separate pad	Yes/No
Installation method	Tack strips/Glue down
Other components	
Type of pad, if used	Polyurethane/Latex/Other
Type of adhesive, if used	Product designation

4. Hypothesis 4: People who inhale certain bioaerosols may experience symptoms as a result of this exposure.

a. Background

The frequency with which people report various health symptoms has been associated with the concentrations of specific bioaerosols, e.g., actinomycetes, other bacteria and bacterial by-products, fungi and fungal metabolites, and dust mites (Burge 1990, Hood 1990, Jarvis 1990, Lundblad 1991, Morey et al. 1990, Morey and Singh 1991, Morey et al. 1986, Olenchock 1990, WHO 1990). Researchers have studied these associations by collecting air samples to assess the amounts of airborne biological material that is present and by noting the responses of the exposed people.

b. Phase-2 Research Plans

Objective

The objectives of the Phase 2 measurements are to gain experience with the protocols for sampling and sample analysis for airborne microorganisms at breathing level in the occupied spaces, to obtain information

on the spatial and temporal variability in airborne bioaerosol concentrations, and to permit a comparison of the types and abundance of microorganisms in air samples and samples collected from surfaces. We will not assume that the measurement results are representative of the prior Phase-1 study period. However, the experience gained in Phase 2 will lead to improved protocols that can be used in a Phase 3 study coincident with the collection of data on occupant health symptoms.

Sample Locations

We will collect samples for viable airborne bacteria and fungi in the same three study spaces where samples from carpets and HVAC supply air are collected. This strategy permits a comparison of the types of microorganisms in the different types of samples. Sample collection will take place near the three workers in each space selected for floor and chair-dust sampling.

Air-Sampling Methods

Detailed plans for air sampling of bioaerosols during Phase 2 will be developed after completing laboratory-based experiments. In general, we plan to employ two methods of sampling. The first method is the traditional collection of short-term samples (two or ten minute) with an impactor-type sampler that deposits bioaerosols directly onto culture media. As was done in the Phase-1 study, we will collect air samples with a single-stage impactor, but in this case we will use the N-6 Andersen sampler (Burge et al. 1989). Because the concentrations of bioaerosols in the test buildings and outdoors are unknown, we will collect samples from two volumes of air at each sampling site. A sample volume of 0.3 m^3 will permit determination of air concentrations in the range of 30 to 600 cfu/m^3, while a volume of 0.06 m^3 will cover the range from 150 to 3000 cfu/m^3. Except in unoccupied areas, concentrations below 10 cfu/m^3 seldom are encountered in office buildings, whereas outdoor concentrations may exceed 1000 cfu/m^3. The second sampling method is the collection of samples on polycarbonate membrane filters using the same basic procedure described previously for sampling of bioaerosols from HVAC supply airstreams. However, the provisions for isokinetic sampling of supply airstreams are not required for these samples. The major advantage of the filter sampling method is that it yields a time-integrated sample for the work day. Time integrated sampling is highly desirable because of the high degree of temporal variability in the concentration of indoor bioaerosols (Miller 1992).

Sample Analysis

The methods of sample analyses are described in Appendix 5.

c. Phase-3 Research Plans

In Phase 3, the measurements of bioaerosols in air will be performed in each study space. The specific measurement procedure may be refined based on the experience gained in Phase 2 . The relationship between airborne biological material and symptom data collected during Phase 3 will be evaluated using a regression model.

5. Hypothesis 5: Decreased outside air ventilation rate is associated with increased symptom prevalence.

a. Background

Several recent studies show a correlation between outside air ventilation rate, and symptoms. Nagda et al. (1991) found a significant ($p < 0.05$) decrease of 10 to 30%, in the percent of occupants experiencing symptoms, with increased outside air ventilation rate. Data were collected with only two ventilation rates in a

single building and the symptom questionnaire was limited in scope compared to the CHBS Phase 1 questionnaire. In a similar study by Jaakkola et al. (1991), decreasing the ventilation rate in sections of a building was associated with small but statistically significant ($p < 0.05$) increases in symptoms.

Sundell et al. (1991) found that rates of reporting of some symptoms were inversely correlated with outside air ventilation rate. In some cases the slope of the correlation is great, such as a decrease from 40% prevalence of general symptoms in females at a ventilation rate of 10 Liter/sec per person to a 20% prevalence at 40 Liter/sec. per person.

Menzies et al. (1991) conducted yet another study with manipulation of ventilation rates and repeated administration of a questionnaire. There was no correlation between symptom prevalence and ventilation rates, but the data are complicated by decreases in symptom prevalence each time the questionnaire was administered. In several other studies involving multiple buildings, and in Phase 1 of the CHBS, indoor carbon dioxide concentrations (which are an indicator of the rate of ventilation per occupant) were not correlated with symptom prevalence.

One of the difficult aspects of answering this hypothesis is the measurement of the outside air ventilation rates, especially in naturally ventilated buildings. Ventilation rates vary with time; thus, symptoms reported for an extended time period should not be correlated with an instantaneous measurement of ventilation rate. A procedure for measuring the average ventilation rate for an extended period of time is required. The measurement should represent the ventilation rate during the period of occupancy. Ventilation rates at night, when the buildings are usually unoccupied and ventilation systems do not operate should not be included. Ideally, the measurement procedure should yield multiple local ventilation rates in each study area in contrast to a building-average rate, because multiple data points decrease misclassification bias in the assignment of ventilation rates to individuals.

Existing methods of measuring ventilation rates with tracer gases are not appropriate because they are expensive, inaccurate, or not applicable in some buildings, and require a constant ventilation rate (Fisk and Faulkner 1992). Determination of ventilation rates based on measurement of indoor and outdoor carbon dioxide concentrations plus estimations of carbon dioxide emissions from occupants and use of steady state mass balance calculations are generally inaccurate because of uncertainties in occupancies and carbon dioxide generation rates by occupants, and because conditions are often not at steady state (Persily and Dols 1990). Determinations of ventilation rates from direct measurements of air velocities with devices like pitot tubes or hot wire anemometers are often inaccurate, and these methods do not provide a time-average ventilation rate for an extended period.

b. Phase-2 and Phase-3 Research Plans

This hypothesis will not be tested in Phase 2 because we have no suitable and practical method to measure the ventilation rates at the present time. In addition, ventilation rates are variable; consequently the measurements must coincident with the collection of symptom data.

We are currently developing a method to measure the effectiveness of building ventilation and infiltration in controlling the concentrations of a simulated pollutant during the period of occupancy (Daisey et al. 1990). Passive sources of tracer gas are distributed throughout the building, spaced uniformly per unit floor area. These sources emit tracer gas continuously and uniformly, much like the emissions from some real pollutant sources such as floor coverings. The time-average concentrations of tracer gas during the period of occupancy (e.g., a 40-hour work week) are measured at workstations and in return airstreams. Values of "Pollutant Control Index" (PCI), a new parameter described in Daisey et al. (1990) are computed. At this time, we are reasonably confident that the method can be used to measure building-average values of PCI in the sealed air-conditioned buildings. At a minimum, we will complete these measurements in the Phase-3 study. If possible, we will include measurements in all buildings and measure both a building-average PCI and local values of PCI at workstations. However, measurement of building-average values in buildings with

openable windows and measurements of local values are contingent on validation of the measurement techniques prior to the Phase-3 research effort.

The data will be analyzed by using a regression model to evaluate the association between PCI and symptom prevalences, while correcting for potential confounders.

6. Hypothesis 6: Formaldehyde and ozone elicit sensory irritation and respiratory symptoms.

a. Background

Eye, nose or throat symptoms were the most common symptoms in the Phase-1 investigation. The prevalence for these symptoms was 40 percent among the study group of 880 workers. Although the etiological agents are not known, such symptoms can be caused by gaseous chemical irritants, of which formaldehyde and ozone are examples.

Formaldehyde is by far the most irritating of the volatile organic compounds VOCs that are commonly present in indoor air (Gupta et al. 1982). By a mouse irritancy test that measures reduction in respiratory rate, formaldehyde is over three orders of magnitude more irritating than toluene (Alarie 1981). In a study of acute health problems caused by formaldehyde among occupants of mobile homes, significant irritant effects were shown at weekly-average exposure levels as low as 7 ppm-h (Liu et al. 1991). This is equivalent to an average concentration of 70 ppb assuming that 60 percent of the occupants' time was spent at home. Concentrations of formaldehyde in office buildings are typically low, For example, the median formaldehyde concentration in 38 office buildings in the Pacific Northwest was less than 20 ppb (Turk et al. 1987). However, sources of formaldehyde are sometimes present which can result in elevated concentrations. Potential sources include particle board underlayment used for subfloor construction in wood-frame buildings, medium density fiberboard used for furnishings and shelving, hardwood plywood paneling, some types of carpets, and fiberglass insulation used as a liner in air-handling systems.

In Phase 1, an attempt was made to measure formaldehyde in each of the 12 buildings. The samples were collected on dinitrophenylhydrazine (DNPH) coated Sep-Pak cartridges at a low air flow rate over a period of one work week. The concentrations were lower than expected. The data were not used because it was suspected that there was a negative interference presumably due to the instability of the hydrazone derivative of formaldehyde when exposed for long periods to oxidants such as ozone.

Ozone is another highly irritating gas that may contribute directly to complaints of eye, nose, and throat irritation and difficulty in breathing. The current outdoor air quality standard was set at 120 ppb (one-hour peak concentration) to protect the population from transient effects of ozone exposures. However, there is now some evidence that indicates that effects on lung function in healthy people are more closely related to the cumulative daily exposures to ozone than to one-hour peak concentrations (Lippmann 1991).

Ozone has not commonly been measured in indoor environments because of its identification as an outdoor pollutant and the general perception that indoor concentrations are quite low relative to outdoors. This assumption is not always correct. Weschler et al. (1989) have shown that indoor levels of ozone can approach outdoor levels when building air exchange rates are high. These investigators found an indoor-outdoor ozone ratio of 0.71 for a building ventilation rate of 8.2 h^{-1}, a ratio of 0.54 for 4 h^{-1} and a ratio of 0.22 for 0.22 h^{-1} for three commercial buildings in New Jersey. Thus, during a smog episode when outdoor levels are high, indoor concentrations could reach or exceed the 120 ppb standard under some circumstances. Workers exposures away from their building could be generally lower due to the high temporal variability of ozone concentrations with peak concentrations typically occurring in the afternoon.

Photocopiers and laser printers are an indoor source of ozone which will add to any ozone which enters the building from outdoors (Allen et al. 1978; Selway et al. 1980; Hansen and Andersen 1986). In small rooms with low air exchange rates, it is possible for ozone to reach levels exceeding 100 ppb with a single copier working. Selway et al. (1980) reported emission rates ranging from <1-54 µg per copy for ten copiers that were tested. These investigators found that most of the copiers produced sufficient ozone to affect the work room air quality with levels as high as 150 ppb produced under conditions of continuous use in a room with minimal ventilation. Servicing reduced the emission rates but only temporarily. Similar results have been reported by Danish investigators for 69 copying machines (Hansen and Andersen 1986).

Ozone's high chemical reactivity contributes to its potential significance as a gaseous contaminant. Weschler et al. (1992) have recently found that ozone can react with compounds on carpet fibers to produce C_5 - C_{10} volatile organic aldehydes, which are likely to be irritants. The extent of such reactions on other typical indoor surfaces and on components of mechanical ventilation systems is not yet known.

b. Objectives

There will be no investigation of this hypothesis in Phase 2. During Phase 3, the objective of the investigation will be to measure concentrations of formaldehyde and ozone in the study buildings. Separate sampling strategies are required for formaldehyde and ozone because the temporal variabilities of their concentrations are expected to be considerably different. Concentrations of these contaminants will be related to reported sensory irritation and respiratory symptoms using logistic regression models.

c. Phase-3 Investigation of Formaldehyde

Diffusive samplers that utilize the DNPH chemistry will be used to collect samples for formaldehyde in the study locations. They have been selected because they do not require a sampling pump and are, therefore, inherently simple to use. These devices and the methods for their deployment and analysis are described in Appendix 4.

The emission rates of formaldehyde from potential material sources are expected to be relatively constant over time intervals of several months and longer. For example, the emissions of formaldehyde from wood-fiber products may decay slowly over periods of up to approximately five years (Anderson et al. 1975, Hawthrone and Matthews 1987). Therefore, building concentrations measured on a single day under typical ventilation conditions are likely to be representative of concentrations over longer periods.

The diffusive samplers will be used in all of the study buildings to measure concentrations of formaldehyde integrated over an 8-9 h work day. The measurements will be made on a single day in the middle of the week (i. e., Tuesday-Thursday) in conjunction with the other measurements and observations that are being made in the buildings. In each building, the samplers will be deployed at three indoor locations and one outdoor location. At least ten percent of the indoor samples will be collected in duplicate and there will be ten percent field blanks. The details of the sampling procedures are described in Appendix 4.

Associations between the formaldehyde concentrations in the study spaces and sensory irritation and respiratory symptoms reported on the Phase 3 questionnaires will be examined with logistic regression models.

d. Phase-3 Investigation of Ozone

Several diffusive time-integrated samplers have recently been developed for ozone (Surgi and Hodgeson 1985, Monn and Hangartner 1990, Kanno et al. 1990, Grosjean and Hisham 1992) Two of these samplers are appropriate for the concentration range of interest in this study. Only one has been tested and validated in the field.

Surgi and Hodgeson (1985) reported on the laboratory validation of a diffusive monitor that is based on a filter impregnated with 10,10' dimethyl-9,9'-biacridylidine. This dimeric compound is oxidized by ozone and there is a reduction in the absorbance of the filter. The linear range was determined to be 10 - 700 ppb-h. Interferences from NO_2 and SO_2 were less than one percent at exposure concentrations as high as 10 ppm. Although this monitor looks promising, it has not been field tested.

The most highly developed and tested diffusive monitor for ozone is the device developed by Grosjean and Hisham (1992). These researchers investigated several reagents that react with ozone and determined that indigo carmine was the most suitable in terms of the stability of the product and limited interferences from other species, e.g., NO_2, PAN, and formaldehyde.

The sampler in its basic configuration consists of a Whatman filter paper impregnated with indigo carmine and mounted in a polycarbonate dual filter holder. A diffusion barrier (e.g., Teflon filter or grid), placed upstream of the impregnated filter is used to control the sampling rate. Reaction of the indigo carmine dye with ozone causes a decrease in the color and reflectance of the filter. The detection limit for this sampler is 120 ppb-day (5 ppb-h). The sampler is linear up to 600 ppb-day (300 ppb for 2 days). The sampling rate can be slowed by using a 0.2-μm Teflon filter as a diffusion barrier.

The reflectance of the impregnated filter is measured before and after sampling, relative to an uncoated reference filter using a portable color analyzer (Minolta Chroma Meter, Model CR-121). Samples can be stored in the laboratory for extended periods.

The sampler has been field tested for periods of 3-30 days at five outdoor locations where the results were compared to the results obtained with continuous analyzers (Grosjean and Williams, In press). The average precision of the sampler, calculated from 42 sets of collocated passive samplers, was 12 percent. The sampler showed no dependence on changes in ambient temperature and humidity in these tests. Interferences from other air pollutants contributed a total bias of less than five percent to the measured ozone concentrations.

Because ozone concentrations are expected to vary considerably throughout each day and from day to day, it will be necessary to make measurements over an extended period to obtain realistic estimates of exposures. The month about which the workers are asked to report their symptoms has been selected as the most appropriate measurement period. This will ensure optimal correspondence between the measurements and symptom reporting.

Diffusive samplers will be used in all of the study buildings to measure concentrations of ozone integrated over periods of one work week (Monday-Friday). It is anticipated at this time that the Grosjean and Hisham device will be used. The samplers will be left uncapped throughout the entire five days (i.e., they will not be capped during non-work hours). The samplers will deployed on four consecutive weeks. There will be three indoor sampling locations and one outdoor location in each building. At least ten percent of the indoor samples will be collected in duplicate and there will be ten percent field blanks.

Two continuous ozone analyzers (Model 1003-Ah, Dasibi Environmental Corp.) that are available in the Indoor Environment Program at LBL will be deployed with the diffusive samplers in two buildings at one indoor sampling location each. Each real-time monitor will be equipped with a data logger for continuous recording of the ozone concentration. Average concentrations over the deployment periods for the diffusive samplers will be calculated from the real-time profiles and will be compared to the diffusive sampler results. This will provide a quality assurance check on the validity of the diffusive sampler data.

Associations between four-week average ozone concentrations in the study spaces and the sensory irritation and respiratory symptoms reported on the questionnaires will be examined with logistic regression models.

7. Hypothesis 7: Elevated sensory irritation and respiratory symptoms due to gaseous contaminants can be predicted by a mouse bioassay.

a. Background

Exposure to a number of VOCs and inorganic gases can produce a sensation in humans of burning or irritation in the eyes and upper airway due to stimulation of the nerve endings of the primitive trigeminal system (Alarie 1973). The magnitude of the sensation depends very much on the compound and its concentration. The mechanisms involved in the activation of the trigeminal nerve receptors by VOCs has recently been reviewed by Nielsen (1991).

Sensory irritation in mice elicits a decrease in the respiratory rate that is mediated by the trigeminal nerve system. The decrease is due to a reflex introduced pause between the end of the inspiratory phase and the initiation of the expiratory phase (Alarie 1973). This pattern of reduced respiratory rate forms the basis for a mouse bioassay that is used as a measure of irritancy (ASTM standard method E981-84, ASTM 1984). The primary application for the standard method has been to assess the irritancy of individual compounds for industrial hygiene applications. A number of compounds have been tested. Concentrations which result in a 50 percent reduction in the respiratory rate of mice (RD_{50}) range over approximately five orders of magnitude with toluene diisocyanate being the most irritating compound tested and compounds such as acetone and benzene having little or no effect (Alarie 1981). The RD_{50}s have been shown to be generally correlated to industrial exposure Threshold Limit Values (TLVs) for compounds whose limits are based on irritancy (*ibid.*).

Pulmonary symptoms can also be detected by the mouse bioassay. In humans, pulmonary irritation produces symptoms of tightness of chest and difficulty in breathing. In mice, the effect is detected as a decrease in the respiratory rate that has a different pattern than the response due to the effect on the trigeminal nerves; a pause is introduced between the end of the expiratory phase and the following inspiratory phase (Alarie 1973).

An adaptation of ASTM standard method E981-84 is now being marketed for the direct measurement of the potency of airborne sensory and pulmonary irritation in buildings (Andersen Laboratories, Inc. 1991). Air is collected from buildings in large Tedlar gas-sampling bags which are immediately shipped back to the laboratory for testing. Mice are exposed to the air and their respiratory rates are recorded. In some cases, VOCs in the air are concentrated by passing the air through a liquid argon trap and re-volatilizing the condensate into a smaller volume of air which is then tested. It was claimed that air collected in four buildings in which there were elevated worker symptoms produced a significant response in the mice while air collected from outside the buildings did not. For one building at least, pulmonary irritation was judged to be severe and sensory irritation was judged to be moderate by the mouse test. It should be noted, however, that only known problem buildings have been tested; no control buildings have been tested; and no detailed chemical analyses of the air in the buildings or bags have been performed. The reported results are surprising since the standard method E981-84 is conducted at concentrations that are similar to, or higher than, TLVs which are typically two to four orders of magnitude higher than concentrations measured in indoor air, even in problem buildings. An example is formaldehyde which has a mouse RD_{50} of 3 ppm, a TLV of 1 ppm, and a probable median concentration in office buildings of less than 50 ppb. It is suspected, then, that the individual compounds or combinations of compounds that are eliciting the response must be potent irritants.

b. Objectives

There will be no investigation of this hypothesis in Phase 2. During Phase 3, the objective of the investigation will be to determine if mouse bioassay results for tests conducted with air collected from selected buildings are correlated with eye, nose or throat irritation and respiratory symptoms reported by the questionnaires. In addition, an attempt will be made to identify possible causal agents by detailed chemical analysis of the air that is submitted for testing.

c. Phase-3 Research Plans

A minimum of four study locations will be selected. Additional locations may be included depending upon the costs of the bioassay and the availability of resources. The study locations will be selected based on the symptom data from the Phase 1 investigation. The locations will encompass those with high and low symptoms of eye, nose, or throat irritation and high and low respiratory symptoms.

The investigation will be conducted during the month about which the workers are asked to report their symptoms. Air samples will be collected over a period of several hours in the afternoon on a day in the middle of the work week (i.e., Tuesday-Thursday). In each location, a large (100-L), clean, Tedlar gas-sampling bag will be filled using a non-contaminating pump and tubing. Air samples for VOCs and low-molecular weight aldehydes will be simultaneously collected from room air using the samplers and procedures described in Appendix 4. An additional air sample for VOCs will be drawn from the Tedlar bag after it has been filled so that the VOC composition of the room air and bag air can be compared. The bag will be shipped by air freight on the day it is collected for delivery at the testing laboratory on the morning of the following day.

One sample of indoor air from a location with elevated symptoms during Phase 1 will be collected in duplicate. Analysis of duplicate samples may give an indication of the precision of the test. Samples of outdoor air will be collected at two buildings to serve as negative controls. A sample of humidified, ultra-pure, zero air will also be used as a negative control. Positive control samples will be prepared by spiking two outdoor air samples with formaldehyde to concentrations of approximately 50 and 500 ppb. At least the higher formaldehye concentration should elicit a positive sensory response. If possible, a sample of outdoor air will be spiked with a known pulmonary irritant at a concentration that is expected to elicit a moderate response. All of the samples and controls will be submitted to the testing laboratory "blind" so that the personnel performing the tests do not know their origin.

The testing laboratory will measure both the sensory and pulmonary irritancy of the whole air samples over an exposure period of 30 min. If possible, a standardized procedure will be used to concentrate the VOCs in each sample by a factor of 2-4 and the test will be repeated. The laboratory will submit full reports of the tests that include the profiles of the breathing rates of all of the individual animals for each test and an interpretation of these results.

If positive test results are obtained for any of the samples of indoor air, the ability of the test to predict human responses in buildings will be evaluated by comparing the results of the mouse bioassay with the prevalence of symptoms in the study locations as reported on the questionnaires administered in Phase 3. Sensory irritation by the mouse test will be compared with eye, nose or throat symptoms, and pulmonary irritancy by the mouse test will be compared with respiratory symptoms. If a sufficient number of samples have been analyzed and positive test results have been obtained, associations will be subjected to statistical analysis.

8. Hypothesis No. 8: Increased noise is correlated with increased symptom prevalence.

a. Background

This hypothesis has not been studied greatly. In the Danish Town Hall Study, noise measurements were made but no results have been published. Sundell (1991), from Sweden, has found a correlation between occupant's sensation of noise and many symptoms. He did not make any measurements of noise. Hodgson et al. (1991) measured noise levels in a survey of five building areas and 147 occupants. He reported no correlation between noise levels and symptoms. In the CHBS Phase 1 questionnaire, occupants were asked, "At your present workstation, how often were you bothered by noise?" It has yet to be determined whether responses to this question are correlated to any symptoms in Phase 1.

Many studies have evaluated the physiological effects due to noise from automobiles, aircraft and industrial machines. Specific effects that have been found in high noise environments include: loss of hearing, headache, high blood pressure, fatigue, and nausea. More generally, noise can be an annoyance or a cause of stress, both of which may cause symptoms.

Noise at higher levels than we anticipate finding in the office environments (e.g., from aircraft and automobiles) has been correlated with symptoms. There is a need to determine if there is a threshold noise level for noise to correlate with symptoms. The measurement of noise level should be relatively easy and inexpensive.

The interpretation of noise is not a straight-forward task. Besides the obvious dB scale for measuring the loudness, there are other qualities of sound which should be taken into account. Noise experts suggest that high frequency noise is associated with occupants feeling tense and anxious, whereas low frequency noise is associated with headaches. The extend to which sound is annoying may depend on whether the sound is constant or intermittent and the type of source, e.g., the human voice, typewriter keys or fan noise from the ventilation system. Unfortunately, there are no standard methods for assessing these characteristics of noise.

There are instruments which will measure the sound pressure level adjusted for the response of the ear. This A-weighting sound pressure level has the advantage of providing a number that correlates well with human judgment of relative loudness, but it does not correlate well with human judgment of the subjective quality of the sound. Other scales to measure sound have been designed but no instrument can judge the quality of sound nearly as well as the human ear.

b. Phase-2 Research Plans

Objective

The objective of the Phase 2 investigation will be to investigate the spatial and temporal variations in noise levels within study areas so that appropriate noise-level measurements can be undertaken in Phase 3.

Measurement Methods

Noise amplitude will be measured on the dB(A) and dB(C) scales and the difference between the two values calculated to determine whether the noise is predominantly high or low frequency. Also, we will measure the frequency distribution by octave bands and 1/3 octave bands. If symptoms are correlated preferentially with frequency, then the frequency distribution will aid in further analysis. The sampling will be an integrated sample with a integrating period of 5 minutes.

There are several manufacturers, such as Brüel & Kjær (B&K), that make sound level instruments that will measure all of the required parameters. Measurements will be made with a B&K model 2230 sound level meter (or equivalent) using a random incidence microphone or an electronic equivalent. During measurements, the sound level meter will be mounted at the height of an occupant's ear on a tripod. The instrument will be oriented at a 45° angle relative to the planes of the walls and floor. This orientation will reduce the amount of reflected noise that is measured. The instrument will be rented for the period of the Phase 2 study. The rental company calibrates the instrument to manufacturer's specified standards and intervals.

Measurement Locations and Times

Noise levels will be measured in 18 study spaces. At three times during a single day, two sequential five-minute-long measurements will be completed at 8 sites in each study space. The eight measurement sites will be space evenly throughout the study space.

Data Analysis

For each five minute period of data, we will calculate the sound level in the dB(A) and dB(C) scales. To evaluate spatial variability of the sound levels in test spaces, the standard deviation of the sound levels at the eight locations within each study space will be computed and compared to the spatial mean sound levels in the same study space. The variance within test spaces will be compared to the variance in the spatial mean values of sound levels for the 25 different study spaces. The temporal variability in sound levels at a site will be determined from a statistical analyses of the repeated measurements and will be compared to the spatial variation in sound levels within study spaces.

Finally, the frequency distribution of the sound at different locations and times will be compared by visual evaluation of plots of sound level versus octave band and sound level versus one-third octave band.

c. Phase-3 Research Plans

The time periods and number of locations for sound level measurements in each study area will be selected based on the analyses of the Phase 2 data. Sound levels will be measured as described above (see *Measurement Methods*) within all study area during the Phase 3 measurement periods. The correlations between sound levels and symptom prevalences will be evaluated with a regression model. The data will not be compared to symptom data from Phase 1.

9. Hypothesis 9: Flicker from lighting is associated with the prevalence of headaches in office workers.

a. Background

In office buildings, most of the indoor lighting is supplied by fluorescent lamps. The light emitted by the arc discharge in a fluorescent lamp is a function of the instantaneous power input and thus reflects cyclic changes in power input. The cyclic variation in energy output, which is twice the input frequency, is transferred to the emitted light output, with some dampening because of the persistence of the phosphors, and results in a variation in light output which is called "flicker." With a 60-hertz input frequency, the resulting 120-hertz variation is too fast to be noticed by the eye, i.e., fusion occurs.

However, there is experimental evidence that components of the visual pathway respond synchronously to periodically oscillating light stimuli (flicker) at frequencies above perceptual fusion. Berman et al. (1991), for example, have reported synchronous responses of the human retina to a fluorescent luminaire with controllable driving frequency at rates as high as 145 Hz. There is also evidence that lighting flicker at 100 Hz can cause headaches. In a double-blind, crossover experiment, Wilkins et al. (1988) compared two lighting situations: (1) fluorescent lamps with a solid state high frequency ballast giving illumination with 100 Hz, with a peak modulation of less than seven percent and, (2) fluorescent lamps with standard ballasts which fluctuated with a peak modulation of 40 to 50 percent and a principal frequency component of 100 Hz. The incidence of headaches and eyestrain was reduced by half under high frequency lighting. In general, women appear to be more sensitive to lighting flicker than men and young people more sensitive than older people (F. Rubinstein, Personal Communication). Since headache symptoms have often been associated with sick building syndrome and the lighting flicker varies among buildings due to variations in lamp and ballast types, some investigation of office lighting characteristics is appropriate.

Video display terminals (VDT) also have a "flicker" to which the human retina responds (Berman, et al. 1991). The frequency of the flicker, however, is relatively constant across terminals. In Phase 1 of the California Healthy Buildings Study, there was no correlation between symptom prevalence and the number of hours per day spent at a VDT. Consequently, focusing on the flicker from overhead lighting is more important for future phases of the study.

b. Phase-2 Research Plans

In Phase 2, measurements of lighting flicker will be made in the 12 office buildings (29 study spaces) which were investigated in Phase 1 of the study. Since changes in office lighting do not occur frequently, and any changes which have occurred since Summer, 1990 can be determined, it should be possible to examine the relationships between occupant symptom complaints and lighting flicker.

Prior to measuring lighting flicker, the following qualitative information will be gathered for each measurement location: the measurement site/code and the location in the survey area (to be indicated on a copy of the floor plan); and the number of hours that the lamps are turned on each day, including the time of day when they are turned on and off (Since Phase 2 will be conducted during the same season as Phase 1, there should not be any seasonal effect). The building maintenance and management staff will also be questioned regarding any changes in the ballasts or lamps for the fluorescent fixtures in the area since Summer, 1990. The investigator will make sure that the person who provides this information was actually employed in that building and location during Summer, 1990.

A fast-response photodiode directly connected to an oscilloscope will be used to measure the depth of modulation. The photodiode is placed on a level surface somewhere near the center of the survey area. The oscilloscope is then adjusted to obtain the waveform and the data are stored. If an oscilloscope with digital storage is not available for storing the measurement data, a Polaroid camera will be used to photograph the wave on the oscilloscope screen.

From the measurement data, percent flicker will be determined for all of the office areas in which symptom questionnaires were received. Percent flicker is calculated as 100(A-B)/(A+B), where A and B are the heights of the maximum and the minimum, above the zero light baseline, of the wave for a single cycle (IES Lighting Handbook, 1984) (See Figure 1). Percent flicker for a cool white fluorescent lamp, for example, is 26 percent. For those study spaces in which fluorescent ballasts have not been changed, the association between percent flicker and headache symptoms for phase 1 will be investigated using the regression models.

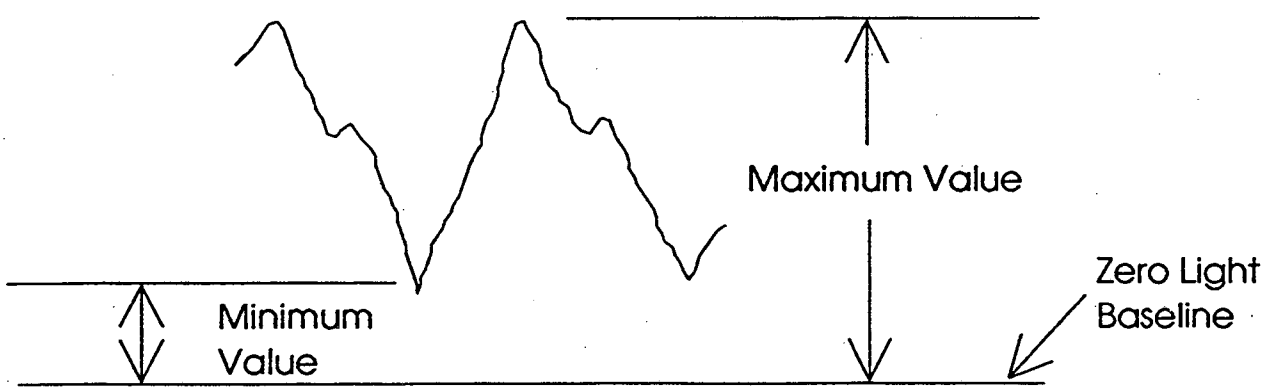

Figure 1. Curve of the light output variation from a fluorescent lamp during each cycle.

c. Phase-3 Research Plans

If the results of the regression models indicate a positive association between lighting flicker measured in phase 2 and headache symptoms reported in Phase 1, we will undertake experiments to confirm this result in phase 3.

10. Hypothesis 10: Skin irritation symptoms reported by office workers using photocopiers are due to skin exposures to : (1) black toner particles emitted by this equipment; and/or (2) irritant chemicals on the photocopies produced by this equipment.

a. Background

In Phase 1 of the California Healthy Buildings Study, increased symptoms of dry and irritated skin were associated with use of photocopiers for more than one hour per day. The associated odds ratio (and 95% confidence interval) was 3.1 (1.4 to 6.9). Skin symptoms are not likely to be associated with ozone, a respiratory irritant sometimes emitted by photocopiers. There are, however, other emissions from photocopiers that might be causal agents.

Schnell et al. (1992) have recently reported measurements of black aerosol from photocopiers. These investigators found that the concentration of black aerosol, measured with an aethelometer, rose from 0.2 to 0.5 ug/m^3 (background) to 0.6 to 2 ug/m^3 in a 15' x 20' work room over a 10 to 15 minute period during operation of a single copier. Emission factors were not determined. They also noted that this black carbon aerosol was electrically charged and deposited rapidly on surfaces. Thus, skin contact through direct deposition from the air and through skin pick-up of aerosol deposited on surfaces are potential pathways of human exposure to this aerosol.

The black aerosol is from the toner particles used in xerographic photocopiers and laser printers. The toner generally consists of 8-15 μm particles of a thermoplastic powder colored by a dispersion of 5-10 percent carbon black particles of less than 1 μm (Kirk et al. 1978). The thermoplastic powder is often composed of a low molecular weight poly(vinyl butyral) blended with a phenol-formaldehyde resin (*Ibid.*). During the heat-treatment of the toner, it would seem possible that monomers, dimers, etc. are released. These might be emitted as vapors and/or sorbed on the particles. These fragments of the polymers are potential irritants because of their chemical functional groups, i.e., aldehyde, vinyl, and phenolic.

Irritant chemicals that might be formed during the heat treatment could also be deposited on the paper. Consequently, exposure by direct contact with irritant chemicals on the photocopies must also be considered as a potential exposure pathway.

b. Phase-2 Research Plans:

No research related to this hypothesis will be performed during Phase 2.

c. Phase-3 Research Plans:

Exploratory Research:

Phase 3 plans, to undertake exploratory research, are contingent upon funding and have a lower priority than the non-exploratory research plans. Exploratory experiments will be undertaken to try to determine if the toner particles emitted by photocopiers and laser printers have sorbed organic irritants that might cause the observed symptoms and, if so, to determine emission factors for a limited number of pieces of office equipment. We will also explore the possibility of irritant chemicals being present on the photocopies.

In order to determine if there are organic irritant compounds sorbed on emitted particles, we will collect samples of aerosol from the air in the vicinity of two dry-toner photocopiers and two laser printers, while the equipment is in continuous operation. The equipment will be selected to yield high levels of particles on the filters. The preliminary screening, to select the copiers and printers for aerosol collection, will be done with an aethelometer (Hansen and Rosen 1990, Hansen and Novakov 1990). The aethelometer provides a rapid, real-time measurement of black carbon and is therefore highly suitable for this application.

By collecting air samples rather than surface-deposited aerosol, we should minimize background interferences from other materials deposited on surfaces or from the surfaces themselves. The samples will be collected on a quartz fiber filter which has been pre-cleaned to remove sorbed organics. Background samples will also be collected for comparison. These will be collected in the same building, before the work day begins and photocopiers are in use. The organics on the particles will be recovered from the samples by thermal desorption of the loaded filters or by solvent extraction. The recovered organics will be analyzed by capillary gas chromatography-mass spectrometry (GC/MS).

In order to determine if there are any irritant chemicals on the photocopies or printed pages from laser printers, samples of pages from several photocopiers and laser printers will be extracted by sonication in an organic solvent. After filtration, the solvent extract will be reduced in volume under vacuum in a rotary evaporator. The extract will be analyzed by GC/MS and the presence of any known irritant chemicals will be evaluated from the chromatograms.

The photocopiers and laser printers may also emit volatile or semi-volatile organic irritants as vapors which are subsequently deposited on surfaces. Volatile organic compounds are generally defined as those with boiling points below 200°C while semi-volatile organic compounds are defined as those with boiling points above about 200°C. The latter are found in both the vapor and particle phases in air. In order to determine if such compounds are emitted by photocopiers and laser printers, we will also collect vapor-phase samples with sorbent samplers in the vicinity of several operating photocopiers. The samples will then be thermally desorbed and analyzed by GC/MS. Background samples will also be collected before the work day begins.

Laboratory Measurements:

If the analyses from the exploratory research indicate that irritant compounds are emitted by photocopiers and laser printers at levels which might result in symptoms, measurements of the source strengths for black aerosol and organic irritants (vapor and particle) will be made. Source strength measurements will be made in the environmental chamber at LBL so that background concentrations of particles and organic compounds can be minimized and the air exchange rate can be controlled. Three copiers and/or laser printers will be selected for measurements in the chamber for the purpose of obtaining some information on the range and variability of the emission factors. Selection will be based on the initial screening measurements and the availability of the equipment for chamber testing.

During the chamber experiments, the equipment will be operated under a standard protocol, e.g., 20 copies per minute for 10 minutes. Temperature, humidity and the air exchange rate of the chamber will be determined. Real-time measurement of black carbon aerosol will be made with an aethelometer. Time-integrated samples of particulate matter will be collected on quartz filters for determination of particle mass, black carbon mass, and sorbed organic compounds. Volatile and semi-volatile organic compounds, which may be simultaneously emitted as vapors, will be collected on sorbent samplers. The filter and sorbent samples will be thermally desorbed into a GC/MS for analysis. Chamber background samples will be collected prior to each chamber experiment. The source strength will be calculated from the air concentrations in the chamber and the air exchange rate. The source strength measurements can than be used to estimate air concentrations in office settings under a variety of conditions (e.g., different room sizes, ventilation rates, and copying rates).

If the exploratory research indicates that there are reasonably high levels of irritant chemicals on photocopies, we will undertake a limited set of laboratory experiments to try to estimate how much of these irritant chemicals might be transferred to skin during paper handling.

Exposure Pathways and Measurements in Office Buildings

Both the sampling strategies and the exposure measurements to be undertaken in office buildings are contingent upon the results of laboratory measurements and an assessment of probable exposure pathways. Some of the possibilities are discussed below.

The laboratory-based experiments in Phase 3 are designed to determine if irritants are emitted by photocopiers and laser printers or deposited on photocopies or paper from laser printers. In order to relate symptoms in office workers to exposures, the pathway of exposure must be considered. In Phase 1 of the study, the highest odds ratio observed in relation to use of photocopiers more than an hour per day (relative to use less than one hour per day) was for skin irritation (Mendell 1991). The exposure pathway for skin irritation is most likely to be contact with surface-deposited particles or vapors from the photocopiers and/or laser printers. Thus, a worker who spends more than an hour a day at a photocopier, is likely to pick up deposited dusts on his/her hands or arms. These materials may subsequently be transferred to the face through hand-to-face contact. Alternatively, or in addition, chemicals on the photocopies or laser-printed pages may be transferred to skin by handling. For the skin exposure pathway, some direct measure of what is deposited on workers hands would be ideal. Such a method, however, has not been developed. If the laboratory experiments suggest that this is an important pathway, some have to be done to develop an appropriate method for measuring the exposure.

The odds ratios for eye, nose and throat irritation and for chest tightness or difficulty breathing were also elevated among workers who spent more than an hour per day at a photocopier. For these symptoms, an inhalation exposure pathway is more likely. Exposure to airborne organic irritants could be measured in several ways. If the laboratory studies indicate that the irritant chemicals are associated with the black carbon, personal or area samples of aerosol could can be collected on a filter over an 8-hour work day period. The relative blackness of the filter would serve as an indicator of exposure to toner aerosol. Filter blackness would be measured using the laser transmission method (Gundel et al. 1984). In this method, the attenuation of visible light is measured as it passes through a particulate matter sample on a filter. The method is simple and inexpensive, and required equipment is available at LBL. The method is somewhat indirect since there will be some background black carbon aerosol from the outdoor air. However, if emission factors are high enough so that the background aerosol is a relatively small contribution to what is collected on the filter, the method should be adequate for characterizing exposures. If not, specific chemical analysis of filter samples might be required.

It is also possible that the photocopiers emit significant amounts of volatile or semi-volatile organic irritants in the vapor phase. If this proves to be the case, then sorbent samplers and GC/MS analyses would probably have to be used to characterize exposures. The number of samples that could be taken would be limited by the difficulty and expense of this type of analysis.

11. Hypothesis 11: Carbonless copy paper releases organic chemicals that cause sensory irritation and respiratory symptoms. The exposure route may be inhalation or via physical contact.

a. Background

Over a million tons of carbonless copy paper are used annually. Numerous complaints have been reported by office workers about adverse health effects resulting from use of this paper. These complaints have resulted in a number of studies which include case reports for individual workers, large cross-sectional surveys, and

skin tests and other challenges to isolate specific components of the paper. The most commonly observed symptoms in these studies included skin irritation, and irritation of the eyes, nose or throat. Respiratory problems, headache and fatigue were less frequently observed. In their review of these studies, Buring and Hennekens (1988) conclude that the relationship between complaints and use of carbonless copy paper is unsubstantiated because of confounding variables and the lack of adequate controls in all of these studies. While this criticism may be correct in the strictest sense, the large number and general consistency of the complaints and study findings strongly suggest that a link does exist between health effects and the use of carbonless copy paper.

One of the cross-sectional surveys reviewed by Buring and Hennekens was a study of about 4,000 office workers in 14 Danish town halls (Skov et al. 1987). Among these workers, frequent handling of carbonless copy paper was significantly associated with the occurrence of work-related mucousal irritation and general symptoms including headache and fatigue. There was no association with skin irritation, and respiratory symptoms were apparently not assessed. The analysis of the data using a logistic regression model corrected for the influence of other variables and confirmed the significance of these associations (Skov et al. 1989).

Phase 1 of this California investigation was consistent with the results of the Danish town hall study and provided additional information since more symptom categories were included. In Phase I, it was found that use of carbonless copy paper for more than one hour per day was associated with increases in almost all symptoms assessed (Mendell 1991). The highest odds ratios were for chest tightness or difficulty breathing, and fatigue or sleepiness, with statistically significant increases for these and for irritation of the eye, nose or throat. There was no association with skin irritation.

One laboratory study attempted to chemically identify the factor(s) in carbonless copy paper that may be responsible for the health complaints (Norback et al. 1988). The study focused on identifying the solvents which are used as a carrier for the ink. Other components include the ink itself, polymers used to encapsulate the solvent, desensitizing ink which is used on some papers, and paper coatings. Various aromatic compounds are used as solvents, sometimes in combination with kerosene. The solvent with the largest market share is a mixture of partially hydrogenated terphenyls. Other solvents include phenyl-xylyl-ethane and mono-isopropyl biphenyl. Although the solvents are the most likely component of carbonless copy paper to be vaporized, they have relatively low vapor pressures and it is not known how much is transferred to skin when the paper is handled and used. Another study examined the irritant effects of carbonless copy paper using a mouse bioassay which measures a decrease in respiratory rate due to exposure to airborne contaminants (Wolkoff et al. 1988). This study concluded that the causal agent is in the gas phase and that formaldehyde may be involved in the sensory irritation response.

b. Objectives

There will be no investigation of this hypothesis in Phase 2. During Phase 3, the objective of the investigation will be to re-examine the relationship between the use of carbonless copy paper and symptom reporting using procedures that are designed to help identify the causal agent(s). This will involve obtaining a quantitative estimate of carbonless copy paper use from the questionnaire and collecting and chemically characterizing samples of typical forms from the study buildings. The route of exposure, either inhalation or via physical contact, will not be specifically investigated.

c. Phase-3 Research Plans

The relationship between use of carbonless copy paper and symptom reporting will again be assessed by the questionnaire which asks respondents to report the time they spend during a typical day working with carbonless copy paper. If the same or similar results are obtained as in Phase 1, the significance of the relationship will be greatly strengthened.

Additional information may help identify the casual agent(s). For example, the type of paper may affect symptom reporting as different solvents are used by the various manufacturers. Formaldehyde content is

another potentially significant factor that may vary with the manufacturing source. The solvent can be identified by chemical analysis of solvent extracts of the paper using gas chromatography (Norback et al. 1988). Formaldehyde content can be quantified by chemical analysis of water extracts of the paper. Therefore, it is proposed that samples of frequently used forms be collected from each building immediately following the administration of the questionnaire. This will be accomplished through contacts with office managers. Samples of at least five typical forms will be obtained from each building. The percent of the total number of forms used in an office that are represented by each of the forms will be estimated. The collected forms will be coded and analyzed for solvent type and formaldehyde content. The results for each building will be reported as the percent of the forms which are in each solvent-type category and as the weighted-average formaldehyde content of the forms. The frequency of carbonless copy paper use by individual workers in each building can then be corrected to reflect the handling frequency for forms of different types and formaldehyde content. If the type or formaldehyde content of the forms are important factors, the statistical significance of the relationship between the use of carbonless copy paper and symptoms should be strengthened by this categorization.

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I.D. Number ____
Location Code ____

EPA INDOOR ENVIRONMENTAL QUALITY SURVEY

This survey is being conducted to determine the environmental quality of your office building. This questionnaire asks about how you think your office environment and your work affect you. Please answer the questions as accurately and completely as you can, regardless of how satisfied or dissatisfied you are with conditions in the office.

ALL OF YOUR ANSWERS WILL BE TREATED IN THE STRICTEST CONFIDENCE.

I. WORKPLACE INFORMATION

1. How long have you worked in this building, to the nearest year?

__ __ years

If less than one year, how many months have you worked in this building?

__ __ months

2. On average, how many hours a week do you work in this building?

__ __ hours per week

3. During LAST WEEK, how many days did you work in this building?

__ days

4. Which best describes the space in which your current workstation is located?

__ Private office
__ Room shared with 1 to 3 others
__ Open space with partitions
__ Open space without partitions
__ Other (specify) _____

4a. How many people work in the room in which your workstation is located (including yourself)?

__ 1 __ 2-3 __ 4-7 __ 8 or more

5. Is there carpeting on most or all of the floor at your workstation?

__ Yes
__ No

6. In general, how clean is your workspace area?

__ Very clean
__ Reasonably clean
__ Somewhat dusty or dirty
__ Very dusty or dirty

7. Please rate the lighting at your workstation.

__ Much too dim
__ A little too dim
__ Just right
__ A little too bright
__ Much too bright

8. About how many hours a day do you work with a computer or word processor, to the nearest hour?

__ __ hours per day

9. Which one of the following statements best describes the windows in your work area?

__ There are no windows in my personal workspace and none in the general area visible from my workspace (when I am either standing or seated).

__ There are no windows in my personal workspace, but I can see one or more windows in the general area.

__ There are one or more windows in my personal workspace.

10. If there is a window visible from your workspace, how far (in feet) is the closest window from your desk chair?

___ ___ ___ feet ___ Check here if no window

11. During the PAST THREE MONTHS, have the following changes taken place within 15 feet of your current workstation?

	YES	NO
New carpeting		
Walls painted		
New furniture		
New partitions		
New wall covering		
Water damage		

12. How much do you use the following at work, on the average? (Check the appropriate box for each item.)

	never	1 to 15 minutes a day	16 to 30 minutes a day	31 to 60 minutes a day	More than 1 hour a day
Photocopier					
Laser printer					
Facsimile (FAX) machine					
Self-copying (carbonless) copy paper					
Cleanser, glue, correction fluid, or other strong-smelling chemical					

II. INFORMATION ABOUT HEALTH AND WELL-BEING

1. Have you ever been told by a doctor that you have or had any of the following?

	YES	NO
Migraine		
Asthma		
Eczema		
Hay fever		
Allergy to dust		
Allergy to molds		

2. Do you consider yourself especially sensitive to the presence of other chemicals in your workspace (e.g., fumes from office machines, carpets)?

__ Yes
__ No

3. What is your tobacco smoking status?

__ never smoked
__ former smoker
__ current smoker

4. How old were you on your last birthday?

___ years

5. Are you:

__ male
__ female

6a. During the **LAST FOUR WEEKS YOU WERE AT WORK**, how often have you experienced each of the following symptoms while working in this building? • If you answer "Not in Last 4 Weeks" for a symptom, please move down the page to the next symptom.					6b. During the **LAST FOUR WEEKS YOU WERE AT WORK**, what happened to this symptom at times when you were away from work? (eg, holidays, weekends)			6c. During **LAST WEEK**, on how many days did you experience this symptom?
SYMPTOMS	Not in Last 4 Weeks	1-3 days in last 4 weeks	1-3 days *per wk* in last 4 wks	Every or Almost Every Workday	Got Worse	Stayed Same	Got Better	Number Days Last Week
dry, itching, or irritated eyes								
headache								
unusual tiredness, fatigue, or drowsiness								
chest tightness								
stuffy or runny nose, or sinus congestion								
cough								
sneezing								
dry throat								
shortness of breath								
pain or numbness in hands or wrists								
dry skin								

III. DESCRIPTION OF WORKPLACE CONDITIONS

1a. During the **LAST FOUR WEEKS YOU WERE AT WORK**, how often have you experienced each of the following environmental conditions while working in this building? • If you answer "Not in Last 4 Weeks" for a condition, please move down the page to the next condition.					1b. During **LAST WEEK**, on how many days did you experience this environmental condition?
CONDITIONS	**Not in Last 4 Weeks**	**1-3 days in last 4 weeks**	**1-3 days per wk in last 4 wks**	**Every or Almost Every Workday**	**Number of Days Last Week**
too much air movement					
too little air movement					
temperature too hot					
temperature too cold					
air too humid					
air too dry					
tobacco smoke odors					
chemical odors (e.g., paint, cleaning fluids, etc.)					
other unpleasant odors (e.g.. body odor, food odor, perfume)					

2. How satisfied are you with the following aspects of your workstation?

a. Conversational privacy	b. Freedom from distracting noise
__ Very satisfied __ Somewhat satisfied __ Not too satisfied __ Not at all satisfied	__ Very satisfied __ Somewhat satisfied __ Not too satisfied __ Not at all satisfied

IV. CHARACTERISTICS OF YOUR JOB

1. What is your job category?	2. All in all, how satisfied are you with your job?	3. What is the highest grade you completed in school?
__ Managerial __ Professional __ Technical __ Secretarial or Clerical __ Other (specify) _____	__ Very satisfied __ Somewhat satisfied __ Not too satisfied __ Not at all satisfied	__ 8th grade or less __ Some high school __ High school graduate __ Some college __ College degree __ Graduate degree

4. **The next series of questions asks HOW OFTEN certain things happen at your job. (Check the appropriate box for each question.)**

	Rarely or never	Sometimes	Fairly Often	Very Often
How often does your job require you to work very fast?				
How often does your job require you to work very hard?				
How often does your job leave you with little time to get things done?				
How often is there a great deal to be done?				
How often are you clear on what your job responsibilities are?				
How often can you predict what others will expect of you on the job?				
How much of the time are your work objectives well defined?				
How often are you clear about what others expect of you on the job?				

APPENDIX 2. Protocol For HVAC Inspections and Collection of Samples of Duct Liner and Suspected Microbiological Contamination Within HVAC Systems.

A. Background and Objectives

This appendix describes the protocol for the inspection of HVAC systems and the collection of samples of duct liner and suspected microbiological contaminants within HVAC systems. One goal of this effort is to collect information on potential sources of fibers and VOCs within the HVAC systems. The information collected and the analyses of duct liner samples (described in Section IV-1.1) will increase our knowledge of pollutant sources in HVAC systems. Some of the information collected via this protocol will be compared to the prevalence of occupant health symptoms reported during the Phase 1 study. In addition, through implementation of this protocol, we will gain experience in inspection of HVAC systems using a standard protocol. The purpose of the assessment of microbiological contamination within HVAC systems during Phase 2 is to gain experience with the associated inspection, sampling, and sample analysis protocols. We will not assume that the results of the Phase-2 microbiological assessment are representative of the prior Phase-1 study period. However, the experience gained in Phase 2 will lead to improved protocols that can be used in the future (e.g., in a Phase 3 study) coincident with the collection of data on occupant health symptoms.

Duct liners and fiberglass ducts are suspected sources of VOCs and fibers that could enter the occupied space. Consequently, evaluation of the surface area of duct liners and collection of duct liner samples for laboratory analyses of VOC emissions is one component of this effort. Although a determination of the surface area of fiberglass ducts is also desirable, the area determination could be time intensive; hence we seek only to determine if this type of duct is present in the HVAC systems. Another potential VOC source that will be characterized is chemicals (e.g., cleansers or insecticides) that are stored in fan rooms or other sections of HVAC systems.

Microorganisms and other biological material (e.g., dead insects) within HVAC systems are considered potential sources of microbiological contamination within the occupied spaces. This protocol includes an inspection for biological material in the HVAC system components that are readily accessible and often associated with biological contamination (e.g., drain pans). Collection and analysis of samples are included to confirm visual evidence of microbiological contamination.

B. Selection of HVAC Units for Inspection

Based on information collected prior to the Phase-1 study, the twelve buildings have 37 air handlers plus exhaust fans for bathrooms. Nine small air handlers in Building 5 are unlikely to significantly impact the environmental conditions in the study spaces because these air handlers serve the core sections of specific floors that are well-isolated from the test spaces. We will inspect all other air handlers.

C. Selection of HVAC Components for Inspection

The following components will be inspected: outside air intakes, dampers, mixing boxes, fan rooms or compartments, air filters, cooling coils, drain pans, central heating coils (i.e., those near the fans), and plenums or ductwork located within 10 feet of fans and coils. These components are usually located in mechanical rooms or in a packaged (prefabricated) air handler, are usually accessible, and are more likely than other components to have porous liners, moisture (and hence microbiological contamination), and stored chemicals. Components that are distributed throughout the building and that will not be inspected, include most of the ductwork used for air distribution and return, supply diffusers, return grilles, VAV boxes, heating coils near the terminal equipment, and balancing dampers.

D. Inspection Procedure

The inspections will be implemented using the "California Healthy Building Study-Phase 2 HVAC Inspection Sheet" that follows. The inspectors will be experienced with inspection of HVAC systems. Permission to undertake inspections will be requested from the appropriate building personnel, normally HVAC maintenance staff, and only authorized activities will be undertaken. Access to components of large air handling units will be via access doors. Components of smaller packaged air handlers will be accessed by removing cover plates or panels. When these options are not possible, a boroscope will be used for remote inspection, taking great care not to damage components when drilling holes for the boroscope in ducts or panels. Inspections will be documented using a camcorder so that responses can be checked after the inspections are completed. When the presence of microbiological contamination (i.e., mold or bacterial slime) is suspected, samples will be collected and analyzed using the procedures that follow to confirm that the suspect material is indeed microbiological contamination.

E. Procedure for Collecting Samples of Duct Liner

In each HVAC system with an interior duct liner, a four inch by four inch sample of duct liner will be collected using cutting and scraping tools if permission is granted by the HVAC operation and maintenance staff. If the liner is attached to the duct with an adhesive, the adhesive should be included in the sample to the degree possible. Each sample will be wrapped tightly in aluminum foil that has been precleaned with methanol to remove residual oils. The sample will then be placed in a solvent-cleaned one-pint paint can and the can sealed. The can will be labeled with a sample ID# which is also included on the California Healthy Building Study-Phase 2 HVAC Inspection Sheet (Appendix 3). If, based on visual inspection, the HVAC system contains more than one type of duct liner, a sample of each type will be collected. The inspectors shall offer to fill the void left by sample removal with a piece of new duct liner attached to the duct with an adhesive. If sampling is restricted by the HVAC operation and maintenance staff, priority should be placed on collection of a sample from the HVAC system(s) that directly serve the test spaces. The method of analyzing the samples is described in Section IV-1.1.

F. Procedure for Identification of Materials Potentially Contaminated with Mold, Algae or Bacteria

To gain experience with different protocols, the nature of surface contamination within HVAC systems will be determined in several ways: (1) visual inspection in the field; (2) ability of aqueous sodium chloride to bleach out color; (3) examination of adhesive tape specimens in the laboratory; (4) subculture using contact plates; (5) collection of bulk solid material samples for examination in the laboratory; (6) swab samples of biofilms; and (7) collection of liquid samples for examination in the laboratory. Assuming that we will encounter few (e.g., fewer than 10) cases of biological contamination, we will use all methods appropriate for the surface and type of contamination to permit an intercomparison of results. Each method is described in greater detail in the following paragraphs.

In the field, materials that apparently are contaminated will be examined with a magnifying glass to observe fungal spores or hyphae, algal growth, or amorphous soil and dirt particles (ASTM-D3274-82).

Suspected fungal or algal growth will be tested with a drop of 5% aqueous sodium chloride (ASTM-D4610-86). Fungal or algal discoloration typically will bleach within 1 min. Discoloration that does not is bleach very likely to be dirt.

Surface samples will be collected with clear adhesive tape. After touching the sticky tape surface to the apparent growth, the tape will be attached to a clean glass slide. The slide will be labeled with the sample identification number and placed in a slide carrier for transport to the laboratory. In the laboratory, the specimen will be examined by microscope for fungal spores or hyphae, and for other evidence of biological contamination.

Contact plates are made by gently pressing special plates of nutrient agar medium to the suspected surface. In the laboratory, the plates will be incubated for 10 days and the amount of each type of growth noted. Typically, when only one organism predominates this is taken as evidence of active growth; whereas when a mixture of organisms is present, they may represent incidental contamination.

When possible, sections of apparently-contaminated solid materials (such as duct liner or layers of mold) will be excised or bulk samples will be collected with a spatula using the following procedure.

1. Select a sample identification number based on the code described in the California Healthy Building Study-Phase 2 HVAC Inspection Sheet (Appendix 3). Enter the number on the inspection sheet and on a adhesive backed label. Fix the label to a new plastic bag.

2. Clean a scalpel, scissors, or other appropriate implement for bulk sample collection with an alcohol wipe.

3. Using scissors, remove a portion of the material with an area of 5 cm^2 or greater or use a spatula to collect at least 1 cm^3 of the suspected contaminant from the sampling site and place it in the plastic bag. Record the approximate surface area removed of material removed on the label. Seal the bag with a twist tie. Return the sample to the laboratory (Room 353, 2151 Berkeley Way, Berkeley, CA, Attention J. Macher) as quickly as possible.

In the laboratory, the excised or bulk sample specimens will be examined by dissecting microscope for evidence of fungal spores or hyphae, or other microbiological growth. To recover culturable bacteria and fungi from bulk dust or excised material, we shall suspend a weighed portion in sterile peptone water, mix the suspensions thoroughly, and then inoculate aliquots onto culture media. The proposed culture media and incubation temperatures for dust and air samples will support, preferentially, meso-and thermophilic bacteria and saprophytic fungi (Burge et al. 1989, Nash and Krenz 1991) We also shall stain portions of the sample suspensions to determine the total cell counts by microscope (American Public Health Association 1984, American Public Health Association 1989).

We shall sample suspect biofilms from wetted HVAC surfaces directly by wiping measured areas (e.g., 1 to 10 cm^2) with sterile swabs. The swabs will be placed in test tubes with transport medium and kept in a cool, dark place until delivered to the laboratory. In the laboratory, the swabs will be washed in the transport medium and serial dilutions of the resulting suspension plated onto nutrient agar. The remaining sample will be refrigerated until the first plates are examined and used for further analysis, if necessary. Growth (generally bacteria or yeasts) on the initial plates will be examined to determine the number of types that are present and their relative amounts.

Water that has collected or accumulated in HVAC systems (e.g., in drain pans) will be collected with sterile pipettes or beakers and transported to the laboratory in sterile containers and kept in a cool, dark place until delivered to the laboratory. These samples will be examined as described above for swab samples by culturing onto nutrient agar.

Three of these sampling procedures (adhesive tape, collection of bulk solid, and swab samples) will be implemented at approximately five comparable locations with no visual evidence of microbiological contamination. Comparison of results from apparently contaminated and uncontaminated sites will help us to further validate the protocols.

G. Training

All personnel that participate in the HVAC inspections will attend a training session prior to any work in the study buildings. W. Fisk and A. Hodgson of LBL and J. Macher of the California IAQ Program within the

California Department of Health Services will lead the training session. The following topics will be addressed: (1) objectives; (2) the inspection protocol; (3) the inspection check sheet; (4) collection and handling of duct liner samples; (5) visual identification of microbiological contamination; and (6) collection and handling of microbiological samples.

H. References for Appendix 2

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Burge, H.A., Feeley, J.C., Sr., Kreiss, K., Milton, D., Morey, P.R., Otten, J.A., Peterson, K., Tulis, J.J., and Tyndall, R. 1989 *Guidelines for the Assessment of Bioaerosols in the Indoor Environment* (Cincinnati, OH: American Conference of Governmental Industrial Hygienists, 1989).

Nash, P. and Krenz, M.M. (1991) "Culture Media," in *Manual of Clinical Microbiology*, 5th ed., A. Balows, Ed. (Washington, DC: American Society for Microbiology, 1991), pp. 1226-1288.

APPENDIX 3. California Healthy Building Study-Phase 2 HVAC Inspection Sheet.

Date: _____

Building Name: _____ Building No. _____

Building Address: _____

Name of person responsible for HVAC system: _____ Phone #: _____

Name of inspector(s): _____

Identification # for air handler (e.g., AHU# or AC#): _____

Note on Sample ID #s: Use the following codes for sample ID #s:

Microbiological Samples: Building # (two digits), AHU or AC ID# (letters plus two digits), M (for microbiological), two digit # Example 01, AHU03, M, 04

Duct Liner Samples for VOC Analysis: Building # (two digit), AHU or AC ID# (letters plus two digits), DL (for duct liner), two digit # Example 12,AHU01, DL, 01

Outside Air Intake

Location: rooftop ground level Other (specify) _____

Screen in place: Y N

Nearby Pollutant Sources:

Motor Vehicles:	Y (describe, distance)	_____	N
Combustion Vents:	Y (describe, distance)	_____	N
Exhaust Ducts:	Y (describe, distance)	_____	N
Other:	Y (describe, distance)	_____	N

Nearby Cooling Tower: Y Distance(ft) _____ N

Bird Droppings: Y N

Dead Insects: Y N

Microbiological Contamination None
Estimated Area (ft^2) _____
Description _____
Location _____
Sample ID# _____

Another Type of Microbiological Contamination None
Estimated Area (ft^2) _____
Description _____
Location _____
Sample ID# _____

Comments: _____

Outside Air Damper

Appears Operational: Y N Can not determine Intentionally Fixed

Microbiological Contamination None
Estimated Area (ft^2) _____
Description _____
Location _____
Sample ID# _____

Another Type of
Microbiological Contamination None
Estimated Area (ft^2) _____
Description _____
Location _____
Sample ID# _____

Comments: _____

Return Air Damper

General Appearance: Clean Average Dirty

Appears Operational: Y N Can not determine Intentionally Fixed

Microbiological Contamination None
Estimated Area (ft^2) _____
Description _____
Location _____
Sample ID# _____

Another Type of
Microbiological Contamination None
Estimated Area (ft^2) _____
Description _____
Location _____
Sample ID# _____

Comments: _____

Other Damper (describe _____)

General Appearance: Clean Average Dirty

Appears Operational: Y N Can not determine Intentionally Fixed

Microbiological Contamination None
Estimated Area (ft^2) _____
Description _____
Location _____
Sample ID# _____

Another Type of
Microbiological Contamination None
Estimated Area (ft^2) _____
Description _____
Location _____
Sample ID# _____

Comments: _____

Air Filters

Type: Flat Panel Pleated Panel Bag HEPA Electronic Air Cleaner Other _____

Manufacturer _____ Model _____

Total Area (ft^2) Missing Filters: Y N

Leakage Around Filters: Low Medium High

Cleanliness: Clean Average Dirty

Estimated Number of Dead Insects Per ft^2 of Face Area: _____

Microbiological Contamination None Estimated Area (ft^2) _____
Description _____
Location _____
Sample ID# _____

Another Type of
Microbiological Contamination None Estimated Area (ft^2) _____
Description _____
Location _____
Sample ID# _____

Comments: _____

Mixing Box (where outside and recirculated air mix)

Cleanliness: Clean Average Dirty

Moisture: Dry Area of Wet Surface (ft^2) _____

Microbiological Contamination None Estimated Area (ft^2) _____
Description _____
Location _____
Sample ID# _____

Another Type of
Microbiological Contamination None Estimated Area (ft^2) _____
Description _____
Location _____
Sample ID# _____

Stored Chemicals or Cleansers: Y N

If yes identify, indicate quantity, indicate if well sealed, ask building manager if present in Phase 1

_____

_____

_____

Comments: _____

Supply Fan Rooms or Compartments

Fan ID #(s): _____

Cleanliness: Clean Average Dirty

Moisture: Dry Area of Wet Surface (ft^2) _____

Microbiological Contamination None Estimated Area (ft^2) _____
Description _____
Location _____
Sample ID# _____

Another Type of
Microbiological Contamination None Estimated Area (ft^2) _____
Description _____
Location _____
Sample ID# _____

Stored Chemicals or Cleansers: Y N

If yes identify, indicate quantity, indicate if well sealed, ask building manager if present in Phase 1

_____

_____

_____

Comments: _____

Return Fan Room or Compartment

Fan ID #(s): _____

Cleanliness: Clean Average Dirty

Moisture: Dry Area of Wet Surface (ft^2) _____

Microbiological Contamination None Estimated Area (ft^2) _____
Description _____
Location _____
Sample ID# _____

Another Type of
Microbiological Contamination None Estimated Area (ft^2) _____
Description _____
Location _____
Sample ID# _____

Stored Chemicals or Cleansers: Y N

If yes identify, indicate quantity, indicate if well sealed, ask building manager if present in Phase 1

_____

_____

Comments: _____

Cooling Coils

Cleanliness: Clean Average Dirty

Estimated Number of Dead Insects Per ft^2 of Face Area: _____

Microbiological Contamination None Estimated Area (ft^2) _____
Description _____
Location _____
Sample ID# _____

Another Type of
Microbiological Contamination None Estimated Area (ft^2) _____
Description _____
Location _____
Sample ID# _____

Comments: _____

Drain Pans

Standing Water: Y N Water Sample ID# _____

Cleanliness: Clean Average Dirty

Microbiological Contamination None Estimated Area (ft^2) _____
Description _____
Location _____
Sample ID# _____

Another Type of
Microbiological Contamination None Estimated Area (ft^2) _____
Description _____
Location _____
Sample ID# _____

Comments: _____

Heating Coils

Cleanliness: Clean Average Dirty

Estimated Number of Dead Insects Per ft^2 of Face Area: _____

Microbiological Contamination None Estimated Area (ft^2) _____
Description _____
Location _____
Sample ID# _____

Another Type of
Microbiological Contamination None Estimated Area (ft^2) _____
Description _____
Location _____
Sample ID# _____

Comments: _____

Internal Porous Duct Liner for Insulation and Sound Adsorption

A. Look for internal insulation/duct liner in the vicinity of fans, coils, filters, mixing, box, and plenums within 10 ft of fans or coils. Answer the following questions. If the HVAC system has more than one type of duct liner, use this section of the inspection sheet for one type of liner and attach additional inspection sheets with information for the other types of duct liner.

Type (describe) _____
Locations (describe) _____

Total Area (Ft^2) _____

Cleanliness: Clean Average Dirty

Wet Liner?: None Estimated area of wet surface(ft^2) _____
Damaged with Loose Fibers: None Estimated Area (ft^2) _____

Microbiological Contamination None Estimated Area (ft^2) _____
Description _____
Location _____
Sample ID# _____

Another Type of
Microbiological Contamination None Estimated Area (ft^2) _____
Description _____
Location _____
Sample ID# _____

Duct Liner Sample For VOC Analyses
Microbiological Contamination None Location: _____
Size: _____
Sample ID#: _____
Comments: _____

Comments: _____

B. Ask HVAC operator if air supply or return ducts, VAV boxes, or mixing boxes of dual duct systems, or other components of the air distribution system not inspected in Part A have a porous internal liner. Indicate which components if any have a liner:

_____
_____

Comments: _____

Fiberglass Duct:

Ask the HVAC operator if the system contains fiberglass ducts. Do not include sheet metal or other ducts with external fiberglass insulation that does not contact the airstream. Describe the section(s) of ductwork fabricated from fiberglass: _____
_____
_____

Comments: _____

APPENDIX 4. Collection and Analysis of Gaseous Chemical Contaminants.

A. Volatile Organic Compounds (VOCs)

In this study, numerous samples for the analysis of VOCs will be collected in outdoor and indoor air and from ventilation systems and environmental chambers. All of these samples will be collected on commercially available multisorbent samplers (Part No. ST032, Envirochem, Inc.) which are packed with glass beads at the inlet followed by Tenax-TA, Carboxen carbon molecular sieve, and activated charcoal, in series (Hodgson and Girman 1989). These multisorbent samplers are reusable. Prior to each use, they will be cleaned and conditioned by heating them to 300° C for 15 minutes under a flow of helium.

Each sample for VOCs will be collected in duplicate so that backup samples are available for replicate analyses or for use in the case of loss of the primary sample during analysis. Sample volumes will typically be 2-3 L of air. The air flow rates will range from 5-100 cm^3 min^{-1}. The flow rates will be regulated with electronic mass-flow controllers located between the samplers and the downstream pumps. All samples will be stored in a freezer and will be analyzed within one week of sample collection.

The analytical procedures for VOCs collected on multisorbent samplers have been described previously (Hodgson and Girman 1989). In brief, a sample is thermally desorbed from a sampler, concentrated and introduced into a capillary gas chromatograph (GC) with a UNACON 810A (Envirochem, Inc.) sample concentrating and inletting system. This instrument passes the sample through dual sequential traps to concentrate the sample. Sample components are resolved with a GC equipped with liquid nitrogen sub-ambient cooling and a fused-silica capillary column. The GC is connected via a direct capillary interface to a Mass Selective Detector (MSD, Series 5970B, Hewlett-Packard Co.). The MSD will be operated to scan a mass range of *m/z* 33-250. Compounds will be tentatively identified by comparing the unknown spectra with spectra contained in the EPA/NIH Mass Spectral Data Base. Whenever possible, these identifications will be confirmed by analyzing authentic standards of the compounds under identical conditions. For the quantitative analysis of these samples, abundant and characteristic mass ions for the compounds of interest will be extracted from the total-ion-current chromatograms and integrated. Internal standard calibrations will be prepared using authentic standards. The limits of quantitation for many compounds are less than 1 ppb.

During the thermal desorption procedure, approximately eight percent of each VOC sample is automatically split off and analyzed directly without chromatographic separation by a flame-ionization detector (FID) that is built into the UNACON sample concentrating and inletting system. This produces a measure of the total carbon in the sample over a boiling-point range encompassed by approximately C_3 - C_{14} hydrocarbons (some C_1 and C_2 compounds are also included, depending on their functional groups). The results of this analysis are expressed as mass of carbon. The FID is calibrated with a mixture of C_6 - C_{12} normal alkane hydrocarbons that is constituted so that each compound contributed an equal mass of carbon.

B. Formaldehyde

Samples for formaldehyde and other low-molecular weight aldehydes will be collected using two different types of sampling devices. Time-integrated samples of formaldehyde in outdoor and indoor air will be collected over periods of one work day using diffusive samplers. Short-term samples of formaldehyde and other aldehydes will be collected in outdoor and indoor air and from ventilation systems and environmental chambers using active sampling methods. Both the diffusive and active sampling devices contain an acid solution of 2,4-dinitrophenylhydrazine (DNPH) which reacts with the aldehydes and other carbonyl compounds that come in contact with the samplers to form relatively stable hydrazone derivatives of the compounds (Kuwata et al. 1983).

Diffusive samplers that utilize the DNPH chemistry are commercially available (570 Series Formaldehyde Badge, GMD Systems, Inc., Hendersonville, PA). These devices measure formaldehyde with a sensitivity of

about 5 ppb for an eight-hour exposure period, which is adequate for this study. The precision of the sampling rate is about seven percent, relative standard deviation. The devices are inherently simple to use because they do not require a sampling pump.

The diffusive samplers will be mounted either on a metal surface, such as a file cabinet, or a wall. They will not be mounted on, or in the near vicinity of, wood paneling or particle-board furnishings. The mounting height will be 1.2-1.4 m above the floor. At least ten percent of the indoor samples will be collected in duplicate and there will be ten percent field blanks. Duplicate and blank samplers will be mounted between 10-30 cm from the primary samplers. The outdoor samplers will be sheltered from the wind and direct exposure to sunlight by an aluminum enclosure. The samplers will be uncapped at the beginning of the work day and capped at the end of the same work day. The locations of the samplers and the times of uncapping and capping will be recorded.

Short-term active samples for formaldehyde and other low-molecular weight aldehydes will be collected on Sep-Pak silica cartridges impregnated with DNPH. These cartridges are commercially available (Part No. 37500, Millipore Corp.) The air flow rates for samples collected in the buildings will be about 1000 cm^3 min^{-1}. The sample volumes will be 30-60 L. The limit of quantitation for formaldehyde at these volumes is approximately 2 ppb. At least ten percent of the indoor samples will be collected in duplicate and there will be ten percent field blanks.

Both the diffusive and active samplers are analyzed for formaldehyde and other low-molecular weight aldehydes using the same method (Fung and Grosjean 1981). The samplers are first eluted with glass-distilled acetonitrile and made up to volume in a 2-ml volumetric vial. The analysis is performed with a high-performance liquid chromatograph (HPLC) equipped with a diode-array UV detector (Series 1090, Hewlett-Packard Co.). Ten microliter aliquots of the eluate are manually injected into the instrument. The compounds are separated on a 2.1-mm I.D. x 15-cm long, reverse-phase C_{18} column (Vydac Model 201TP5215, The Separations Group) using an isocratic solvent program with a 63:35 v/v mixture of water and acetonitrile as the mobile phase. The peak-area responses of the formaldehyde and other aldehyde hydrazone derivatives are measured at a wavelength of 360 nm. Multi-point, external calibrations are prepared by analyzing serial dilutions of purified aldehyde hydrazone derivatives made up in acetonitrile.

C. References for Appendix 4

Fung, K. and Grosjean, D. (1981) "Determination of Nanogram Amounts of Carbonyls as 2,4-Dinitrophenylhydrazones by High-performance Liquid Chromatography." *Anal. Chem.* 53, pp. 168-171.

Hodgson, A.T. and Girman, J.R. (1989) "Application of a Multisorbent Sampling Technique for Investigations of Volatile Organic Compounds in Buildings." In: *Design and Protocol for Monitoring Indoor Air Quality, ASTM STP 1002*, N.L. Nagda and J.P. Harper, Eds., American Society for Testing and Materials, Philadelphia, PA, pp. 244-256.

Kuwata, K., Uebori, M. and Yamasaki, Y. (1983) "Determination of Aliphatic and Aromatic Aldehydes in Polluted Airs as their 2,4-Dinitrophenylhydrazones by High Performance Liquid Chromatography." *J. Chromatographic Science* 17, pp. 264-268.

APPENDIX 5. Methods of analyzing microbiological samples.

A. Bacteria

All samples for the isolation of culturable meso- and thermophilic bacteria will be inoculated in quadruplicate onto tryptic soy agar, a medium recommended for the recovery of ambient bacteria (Burge and Solomon 1987, Burge et al. 1987, Burge et al. 1989). Air samples from impactor samples will be collected directly onto nutrient agar. Dry material samples will be suspended in peptone water before plating. Aliquots of liquid samples (i.e., water samples from coil drain pans) will be plated directly and after dilution. One set of duplicate plates will be incubated at 30°C to encourage the growth of mesophilic bacteria (i.e., those that prefer moderate temperatures), and one set of duplicate plates will be incubated at 50-55°C to encourage the growth of thermophilic bacteria (i.e., those that prefer elevated temperatures).

After colonies appear, the number of colony-forming units (cfu) on each plate will be counted and the individual colonies will by classified based on their Gram-stain reaction (i.e., as gram-positive or gram-negative) and on their cell shape (e.g., cocci or rods). Selected isolates (e.g., those that appear in several types of specimens from one location or which dominate in samples) may be selected for more complete identification. The colony counts will be converted to concentration in the original sample material by dividing by the volume of sample inoculated onto the plates (e.g., cfu/m^3 of air, cfu/g of bulk material, cfu/mL of water samples or cfu/cm^2 of sampled surface area).

B. Fungi

Samples for the isolation of culturable fungi will be inoculated in duplicate onto malt extract agar, a medium recommended for the recovery of saprophytic fungi, i.e., those that grow on decaying organic matter (Burge and Solomon 1987, Burge et al. 1987, Burge et al. 1989, Burge 1990) and will also be inoculated on malt extract agar with 100 grams of sodium chloride added per liter of agar. The addition of sodium chloride as suggested by Flannigan (1992) yields a culture medium more suitable for growth of zerophillic fungi , i.e., fungi that survive best in less moist environments. Flannigan (1992) has discussed the potential importance of zerophillic fungi in indoor environments. The plates will be incubated at 20-25 °C. After colonies appear, the number of cfu on each plate will be counted and the individual colonies will by identified to the genus level. Selected isolates (e.g., those that appear in several types of specimens from one location or which dominate in a sample) may be selected for identification to the species level. The colony counts will be converted to concentration in the original sample material, as described above.

C. Total Cell Count

The total cell count of material samples (i.e., to estimate all bacteria cells and fungal spores, whether culturable or not) will be determined using a staining procedure (acridine orange). Stained cells showing morphology and size consistent with these microorganisms will be counted by microscope and the concentration in the original material will be calculated, as described above.

D. Cultures from Samples Collected on Membrane Filters

The polycarbonate membrane filters used to collect bioaerosol samples will be washed with sterile water yielding a suspension of the bioaerosols. Ninety percent of the suspension will be re-filtered on a cellulose membrane filter, and the remaining 10% of the suspension will be re-filtered with a second cellulose membrane filter. The cellulose membrane filters will be placed directly on the culture medium. With this procedure, all bioaerosols in the sample are transferred to culture media. Measurement precision is improved compared to the alternate procedure of plating small portions of the suspension directly on culture media. Splitting the suspension into two components (90% and 10%) permits a wider range of viable bioaerosol

concentrations to be measured. If excessive numbers of colonies develop on the culture plate receiving 90% of the sample, the culture plate with 10% of the sample is likely to be suitable for analysis.

E. References for Appendix 5

Burge, H.A. and Solomon, W.R.. (1987) "Sampling and Analysis of Biological Aerosols" *Atmos. Env.* 21(2), pp. 451-456.

Burge, H.A., Chatigny, M., Feeley, J., Kreiss, K., Morey, P., Otten, P., and Peterson, K., (1987) "Guidelines for Assessment and Sampling of Saprophytic Bioaerosols in the Indoor Environment." *Appl Ind Hyg.* 2(5), pp. R10-R16.

Burge, H.A., Feeley, J.C., Sr., Kreiss, K., Milton, D., Morey, P.R., Otten, J.A., Peterson, K., Tulis, J.J. and Tyndall, R., (1989) *Guidelines for the Assessment of Bioaerosols in the Indoor Environment.* American Conference of Governmental Industrial Hygienists, Cincinnati, OH.

Burge, H.A. (1990) "The Fungi," in *Biological Contaminants in Indoor Environments,* P.R.Morey, J.C. Feeley and J.A. Otten, Eds. American Society for Testing and Materials, Philadelphia, PA, pp. 136-162.

Flannigan, B. (1992) "Approaches to assessment of the microbial flora of buildings", Presented at IAQ'92, Environments for People, October 18 - 21, San Francisco, CA (not included in the proceedings)

APPENDIX 6. Collection of Dust Samples from Floors and Chairs

With input and assistance from Paul Jensen at the National Institute for Occupational Safety and Health, we have developed a new, convenient method of collecting dust samples from floors and chairs. Preliminary evaluations of the procedure have been completed. Dust samples are extracted from the floor or chair surface by drawing air with a pump into a metal sample tube with the open end of the tube slightly below the surface of the carpet or chair or slightly above a hard surface floor. The high velocity air entering the open end of the sample tube captures and transports dust particles and associated bioaerosols. The sample is drawn through a polycarbonate membrane filter with 0.4 μm pores using a convenient and quiet battery-powered personal sampling pump. The sample flow rate is 3 L/min and the internal diameter of the tube is 0.46 cm, yielding a velocity of 3 m/s at the inlet of the tube.

For sampling from floors, the sampling apparatus (described only in general terms here), includes a slotted metal plate with three parallel 0.3 m long slots through the plate. The plate is placed on the floor. A metal disk holds the sample tube and slides across the top of the plate with the sample tube extending through a slot (e.g., extending to the surface of the carpet). This apparatus precisely controls the location of the open end of the sample tube relative to the surface of the floor, resulting in a more repeatable sampling process. By moving the slotted plate to different locations, a spatially integrated sample can be collected. To collect samples near an individual worker, we will sample from approximately 7 linear meters of floor surface, all within a 3-m distance of the worker's chair. This procedure, when employed on a carpeted floor, generally yields a dust sample containing a few tenths of a gram of dust, which is more than sufficient for culturing and adequate for counting of dust mite bodies. Space-wide samples of floor dust are obtained from 32 linear meters of floor surface spaced approximately evenly throughout the floor surface of the study space. Using this procedure on hard-surface floors yields a sample that can be cultured for microorganisms but which is generally too small for counting of dust mite bodies.

A very similar procedure and apparatus will be used to collect dust samples from chairs. However, the positioning of the open end of the sample tube relative to the surface of the chair is less precisely controlled due to the curved surfaces of chairs.

APPENDIX 7. California Healthy Building Study-Phase 2 Carpet Assessment Sheet

Building Name: _____

Building Address: _____

Study Space(s): _____ Location: _____

Measure:

Estimated sq ft of carpet now in study space: _____

Estimated average ceiling height in study space: _____

Estimated sq ft of study space: _____

Person(s) interviewed about carpet changes:

_____ (name)	_____ (position)	_____ (phone)
_____ (name)	_____ (position)	_____ (phone)
_____ (name)	_____ (position)	_____ (phone)

Interview about carpet changes in study space:
(define location of specific study space)

Carpet attached with adhesive: yes/no
Date of carpet installation: year 19 _____ month _____
Changes since summer 1990?
Any carpet added? _____

If yes, where and how much? _____

_____

Any carpet removed & not replaced?

If yes, where and how much? _____

_____

Estimated net sq ft changes to carpet since Phase 1: _____

Net sq ft carpet in Phase 1: _____

Volume of study space (estimated in Ph.1): _____

Sq ft carpet per cu ft study space _____

APPENDIX 8. Office Cleaning/Pest Control Practices Assessment Sheet.

Building Name: _____
Building Address: _____
Study Space Number(s): _____
Study Space(s) Description: _____

Person(s) interviewed for this information (if work performed by outside contractor, include contractor personnel as needed):

(name)	(job title/organization)	(phone)
(name)	(job title/organization)	(phone)
(name)	(job title/organization)	(phone)

INTRODUCTION TO THIS ASSESSMENT FOR INTERVIEWEE (read aloud):

> We want to ask you about some of the cleaning procedures for this building. We will be asking you about some procedures that you might think are unusual, and we would be surprised if they were performed commonly, but we are including them to allow a full range of responses.

GENERAL OFFICE CLEANING INFORMATION

Staff has general written cleaning schedule?

yes	o.k.	_____	1
yes	poor	_____	2
none		_____	3

Comments: _____

Job title and organization of persons and supervisor responsible for cleaning:

(name) (cleaning or supervising?)	(job title/organization)
(name) (cleaning or supervising?)	(job title/organization)
(name) (cleaning or supervising?)	(job title/organization)

Change in responsibility since summer, 1990? _____

SURFACES -- SPECIFIC CLEANING INFORMATION

Floors: Carpets

Job title/organization of person responsible for carpet cleaning: _____

Vacuum carpet — yes _____ 1; no _____ 2

Estimated actual vacuum interval: every _____

Comments: _____

Wash/shampoo carpet — yes _____ 1; no _____ 2

Methods/products/dilutions: _____

Estimated actual wash/shampoo interval: every _____

Comments: _____

Floors: Hard Surface

Job title/organization of person responsible for floor cleaning: _____

Comments: _____

Sweep floor — yes _____ 1; no _____ 2

Estimated actual sweeping interval: every _____

Products (e.g., sweeping compound): _____

Comments: _____

Mop/wash floor — yes _____ 1; no _____ 2

Estimated actual mop/wash interval: every — yes _____ 1; no _____ 2

Products: _____

Comments: _____

Wax floor — yes _____ 1; no _____ 2

Estimated actual wax interval: every — yes _____ 1; no _____ 2

Products: _____

Comments: _____

Office furniture material/cloth (chairs, couches, partitions)

Clean /dust/vacuum? — yes _____ 1; no _____ 2

Estimated actual cleaning interval: every _____

Products used: _____

Comments: _____

Office surfaces: desks, file tops, shelves

Wet-wipe / dust / vacuum ? — yes _____ 1; no _____ 2

Estimated actual cleaning interval: every _____

Products used: _____

Comments: _____

Bathrooms

Estimated actual cleaning interval: every _____

Products used: _____

Comments: _____

_____

_____

How adequate is available staff and time and equipment for all scheduled cleaning?

very good	_____	1
good	_____	2
fair	_____	3
poor	_____	4

Pesticide use

Do they ever spray for insects (cockroaches, ants, etc.) in the offices?

	_____	
yes	_____	2
no	_____	3

If yes:

Who does the spraying? _____

_____

_____

Do they spray occasionally? _____

regularly? _____

seasonally? _____

How often? _____

Products: _____

_____

_____

Has anything about pesticide spraying changed since Summer 1990?

_____

_____

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