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DISCLAIMER

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THE CALIFORNIA HEALTHY BUILDING PILOT STUDY

I. STUDY DESIGN AND PROTOCOL

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ABSTRACT

The California Healthy Building Pilot Study was initiated by the Indoor Environment Program of the Lawrence Berkeley Laboratory with support from the Department of Energy and by investigators at the California Department of Health Services and the School of Public Health of the University of California at Berkeley. This pilot study, conducted in 12 office buildings in two climate zones in the San Francisco Bay area, was designed to test several hypotheses concerning the relationships between type of building ventilation, air quality, thermal comfort and occupant symptoms.

The primary objectives of the study were 1.) to determine the prevalence of various occupant symptoms and perceptions of thermal comfort in office buildings; 2.) to determine if there is a difference in occupants' symptom prevalence between buildings with natural ventilation and those with mechanical ventilation, both with and without air conditioning; 3.) to examine the relationships between symptoms and measured characteristics of the indoor environment; and 4.) to develop and field test new techniques for characterizing building ventilation and indoor air quality.

Questionnaires were used to obtain data on occupant comfort, health, demographic and psycho-social variables. A new method was employed to characterize the effectiveness of building ventilation for pollutant removal. Concentrations of volatile organic compounds (including aldehydes and ketones), carbon monoxide, carbon dioxide and bioaerosols were measured in indoor and outdoor air, along with indoor temperature and relative humidity.

This pilot study was designed with a unique combination of features. These included explicit testing of prestated hypotheses, selection of public office buildings based on ventilation type, without regard to worker complaints, use of a questionnaire based on work-related symptoms keyed to the time and location of environmental measurements, and the development and testing of new methods for characterizing ventilation effectiveness by means of a Pollutant Control Index and volatile organic compounds by means of an irritancy index. In addition, the questionnaire included measures for "environmental worry" to allow adjustment for biased symptom reporting among those worried about adverse health effects of their indoor environment, and a previously validated scale of job stress/satisfaction to allow control for biased symptom reporting among those dissatisfied with their jobs.

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I. INTRODUCTION

A. Background

Over the past two decades there has been an apparent increase in the incidence of health complaints among occupants of office buildings, particularly new or newly-renovated buildings. The rise in building-associated complaints and illnesses seems to parallel efforts to conserve energy in buildings by reducing ventilation rates. There has also been an increased use of synthetic materials and products in buildings as well as introduction of new types of office equipment and office configurations during this period.

The health complaints typically include irritation of eyes, nose, throat and upper airways, skin reactions, unspecified hypersensitivity reactions, mental fatigue, headache, and nausea or dizziness. Symptoms diminish upon leaving the building. The terms "sick building syndrome" and "building-related illness" have both been used to describe this phenomenon. Recently, some investigators have begun to distinguish two types of building-related problems. The term Building-Related Illness (BRI) is being used increasingly to refer to an outbreak of sub-chronic disease or symptoms in a sub-set of occupants caused by one or a few environmental parameters which are near or above an established health effect threshold, e.g., eye irritation caused from exposure to formaldehyde, hypersensitivity pneumonitis from exposures to bioaerosols. BRI problems, by definition, can generally be solved. The term Sick-Building Syndrome (SBS) is being used increasingly to refer to frequent worker symptom complaints in buildings in which no single parameter exceeds a generally accepted health threshold. Despite many building investigations, the cause(s) of SBS has not been determined. It is also not clear how commonly SBS occurs, nor what the symptom prevalence rates are in "non-problem" buildings, although several investigators have estimated background symptom rates to be about 20% to 30% (Finnegan, et al., 1984; Woods, et al., 1987).

There are several hypotheses that have been advanced to explain SBS. One hypothesis is that the symptoms are caused by exposures to volatile organic compounds (VOC) emitted from various building materials and products used in office buildings. Since the individual VOC are typically present at concentrations which are several orders of magnitude lower than those known to cause symptoms, it has been hypothesized that symptoms are related to the total concentration of all VOC present. Concentrations of total VOC (TVOC) in office buildings can range from less than 1 mg/m^3 to about 30 mg/m^3. Thus, levels of TVOC can approach levels at which individual VOC sometimes cause symptoms. There have been several environmental chamber studies with simple mixtures of 22 VOC which provide some limited evidence for this hypothesis (Molhave et al., 1986; Otto et al., In Press). However, the potencies of individual VOC, with respect to the symptoms of interest, range over as much as five orders of magnitude. Potencies of VOC have not been taken into account in studies done to date.

Another hypothesis is that the cause of SBS is some pollutant or class of pollutants which has not been measured because of the lack of appropriate sampling and analysis methods, e.g., VOC such as isocyanates, amines, bioaerosols, allergens, etc.

A more general hypothesis is that SBS has a multifactorial cause which cannot be demonstrated by measurement and evaluation of independent environmental variables. According to this hypothesis, SBS is a consequence of the influence of multiple variables including pollutant source-emissions (chemical and/or biological) from building materials and furnishings, building-system parameters (e.g., ventilation systems, humidification systems, etc.), building use, environmental factors (temperature, humidity, light, noise, etc.), individual characteristics (sensitivity, gender, age, health status, job type, etc.), and psychosocial factors (e.g., stress, job satisfaction). According to this hypothesis, each of these factors can cause stress and the combined or total stress is directly related to complaints. The functional relationships between the health endpoints and the causative variables have not been specified but they may not be simply additive.

Another hypothesis is that differences in ventilation systems are a major determinant of symptoms among office workers, with symptom rates higher in buildings with HVAC (heating, ventilation and air conditioning) systems than in naturally-ventilated buildings. It is not clear what the actual causative agent(s) or factor(s) would be in air-conditioned buildings. However, if the relationship between ventilation type and symptom prevalence could be confirmed, more detailed studies could focus on identifying these agent(s) or factor(s).

A major impediment to identifying and demonstrating the cause or causes of SBS has been the lack of baseline data for non-complaint or "healthy" buildings. Virtually all of the studies to date in the U.S. have focused on "sick buildings" and have had no or limited control buildings for comparison. Furthermore, the studies have not generally been designed to test specific hypotheses but have been more exploratory in nature. That is, questionnaires were administered to the occupants to determine symptom prevalence and common and easily measured environmental variables were determined. In addition, administration of questionnaires and measurements of environmental parameters were not always well coupled in time and location, and questionnaires did not allow for control of the effects of "environmental worry" and job stress/dissatisfaction on symptom reporting.

B. Meta-Analysis of Previous Studies

Many of the building studies published to date have investigated the associations between the type of building ventilation and the prevalence of worker complaints. The results of these studies, however, appear to be contradictory. As a first step in considering the problem of SBS, Mendell and Smith (1990) undertook a re-analysis of the combined existing data from six European studies. In this meta-analysis, additional information was obtained from the original authors and the data were regrouped into standardized ventilation categories across all of the studies. Prevalence odds ratios (POR) and 95% confidence limits were then calculated for symptoms in each ventilation category relative to a reference category of naturally ventilated buildings. The POR, used to compare prevalence of an outcome between two populations, is calculated as $[p/(1-p)/q(1-q)]$, where p and q are the prevalences in the two populations and each prevalence is measured as a proportion between 0 and 1. For example, if prevalence of work-related headaches is 20% among workers in air- conditioned buildings and 10% among workers in naturally-ventilated buildings, then the POR for work-related

TABLE 1. - PREVALENCE ODDS RATIOS (AND 95% C.I.'S) FOR REPORTED WORK-RELATED SYMPTOMS AMONG OFFICE WORKERS IN DIFFERENT BUILDING VENTILATION CATEGORIES RELATIVE TO NATURALLY VENTILATED BUILDINGS:

		BUILDING VENTILATION CATEGORIES				
STUDY	SYMPTOMS	I Natural POR (95% CI)	II Simple Mechanical POR (95% CI)	III Air-Conditioned No Humidification POR (95% CI)	IV Air-Conditioned Steam Humidification POR (95% CI)	V Air-Conditioned Water-Based Humidification POR (95% CI)
	CENTRAL NERVOUS SYSTEM					
1	headache	1.0	-----	3.1 (1.7-5.7)	2.3 (1.3-4.0)	2.5 (1.6-3.8)
	lethargy	1.0	-----	5.1 (2.9-9.2)	2.6 (1.5-4.7)	4.2 (2.7-6.5)
2	headache	1.0	-----	2.5 (1.9-3.3)	-----	2.1 (1.7-2.7)
	lethargy	1.0	-----	4.2 (3.2-5.5)	-----	3.2 (2.6-4.0)
3	headache	1.0	0.8 (0.6-1.0)	1.3 (1.0-1.6)	1.4 (1.1-1.9)	1.4 (1.1-1.7)
	lethargy	1.0	0.7 (0.6-0.9)	1.4 (1.1-1.7)	1.5 (1.2-2.0)	1.9 (1.5-2.3)
4	headache	1.0	2.2 (1.3-3.7)	-----	-----	2.7 (1.9-3.8)
5	headache	1.0	-----	-----	-----	4.2 (1.9-9.3)
	lethargy	1.0	-----	-----	-----	4.0 (1.6-9.9)
6	headache, fatigue, or malaise	1.0	1.1 (0.9-1.3)	-----	-----	2.3 (1.7-3.1)
	UPPER RESPIRATORY/MUCUS MEMBRANE					
1	nose symptoms	1.0	-----	2.6 (1.1-5.9)	3.0 (1.4-6.2)	3.8 (2.2-6.5)
	dry throat/blocked nose	1.0	-----	2.5 (1.2-5.1)	2.2 (1.1-4.5)	4.8 (3.1-7.6)
	eye symptoms	1.0	-----	1.5 (0.5-3.9)	2.5 (1.1-5.4)	3.1 (1.8-5.3)
2	nose symptoms	1.0	-----	2.9 (2.1-3.9)	-----	1.2 (0.9-1.6)
	throat symptoms	1.0	-----	2.5 (1.9-3.4)	-----	2.4 (1.9-3.1)
	eye symptoms	1.0	-----	1.9 (1.4-2.7)	-----	2.4 (1.8-3.3)
3	runny nose	1.0	0.8 (0.6-1.1)	1.3 (1.0-1.8)	1.4 (1.0-2.0)	1.5 (1.2-1.9)
	blocked nose	1.0	0.7 (0.6-0.9)	1.4 (1.1-1.7)	1.4 (1.0-1.8)	1.8 (1.5-2.3)
	dry throat	1.0	0.9 (0.7-1.1)	1.7 (1.4-2.1)	1.6 (1.2-2.1)	2.0 (1.6-2.5)
	dry eyes	1.0	1.1 (0.8-1.5)	2.0 (1.5-2.7)	1.8 (1.3-2.4)	2.2 (1.7-2.9)
	itching eyes	1.0	0.9 (0.7-1.2)	1.6 (1.2-2.1)	1.3 (1.0-1.8)	1.7 (1.3-2.1)
4	sore throat, coughs, or colds	1.0	1.0 (0.6-1.8)	-----	-----	3.0 (2.1-4.2)
	irritated/sore eyes	1.0	1.2 (0.7-2.2)	-----	-----	4.5 (3.2-6.5)
6	eye, nose, or throat symptoms	1.0	1.0 (0.8-1.2)	-----	-----	2.0 (1.4-2.7)
	LOWER RESPIRATORY					
1	tight chest	1.0	-----	0.6 (0.1-4.8)	0.5 (0.1-3.8)	2.7 (1.2-6.4)
	short of breath	1.0	-----	0	0	1.2 (0.4-4.0)
	wheeze	1.0	-----	0	0	1.7 (0.8-3.7)
3	tight chest	1.0	0.8 (0.5-1.3)	1.7 (1.1-2.6)	1.5 (0.9-2.5)	2.1 (1.4-3.2)
	difficulty breathing	1.0	1.0 (0.6-1.6)	1.7 (1.1-2.6)	1.4 (0.8-2.3)	2.1 (1.4-3.2)
	flu-like symptoms	1.0	0.9 (0.7-1.3)	2.1 (1.6-2.8)	2.1 (1.5-3.0)	2.1 (1.6-2.8)
	SKIN					
1	dry skin	1.0	-----	1.0 (0.3-3.1)	1.8 (0.7-4.4)	1.8 (0.9-3.5)
	rash	1.0	-----	1.5 (0.3-8.0)	1.8 (0.4-7.9)	1.3 (0.4-4.3)
	itching skin	1.0	-----	1.0 (0.2-4.9)	1.6 (0.4-5.6)	1.9 (0.7-4.7)
2	dry skin	1.0	-----	1.7 (1.1-2.7)	-----	2.1 (1.5-3.1)
6	dry skin or rash	1.0	1.3 (0.9-1.7)	-----	-----	2.5 (1.6-4.1)

headaches in air-conditioned buildings is [0.2/(1-0.2)/(0.1/(1-q)] = 2.25. This is not the same as the risk ratio, which is simply 0.20/0.10 = 2, although under sopme circumstances the POR approximates the risk ratio. A summary of the results of the meta-analysis is in presented in Table 1, taken from Mendell and Smith (1990).

This re-analysis showed a striking pattern of association between the type of building ventilation and the prevalence of worker complaints. Air-conditioned buildings, relative to naturally- ventilated buildings, were consistently associated with increased prevalence of work-related headache (POR=1.3-3.1), lethargy (POR=1.4- 5.1), and upper respiratory/mucus membrane symptoms (POR=1.3-4.8). Humidification was not a necessary factor for the higher symptom prevalence associated with air-conditioning. Mechanical ventilation without air-conditioning was not associated with higher symptom prevalence. Re-analysis of additional studies from Germany and the Netherlands (Kroeling, et al., 1988; Zweers, et al., 1990) since then have found similar patterns.

All of the 106 buildings in the six studies of the meta-analysis were European buildings, which differ from U.S. buildings in both climate conditions and HVAC system design and operation. Thus, it is not clear to what extent the findings from the European studies apply to the United States. Furthermore, even if the same associations of worker symptoms and building ventilation type could be demonstrated in the U.S., the cause of greater symptom prevalence in air-conditioned buildings would remain to be determined.

C. Significance of Building-Related Problems

The extent of building-associated illness (BRI and SBS) in the U.S. has not yet been determined, although there is information which indicates that it is a significant problem. Based on a telephone log of complaints of individuals for fiscal years 1984 and 1985, the California Division of Occupational Safety and Health (California Occupational Safety and Health Standards Board, 1986) estimated about 350 nonindustrial indoor air quality complaints per year which they classified as due to "inadequate ventilation". They stated that they considered the category of "inadequate ventilation" most closely corresponds to the popular term "tight building syndrome," which is another term used for building-associated illness. They considered this complaint rate to be an underestimate.

Sexton (1985) has reported the results of a survey of private companies which make air contaminant measurements in nonindustrial indoor environments. Over a 12-month period (July, 1983 to July, 1984), the 43 firms responding to the questionnaire reported more than 350 investigations of office buildings, more than 400 investigations of public buildings, and more than 350 investigations of schools.

A survey of office workers in nine demographic areas of the U.S. (Woods, et al., 1987) found that 19 percent of respondents (115 out of 600) often or sometimes had difficulty doing their work because of air quality. Eight to nine percent of all respondents reported symptoms of congested nose, eye irritation and difficulty breathing as being very serious or somewhat serious problems.

Although these surveys cannot be used to provide estimates of the incidence of BRI and SBS in the U.S., they do suggest that the problem is significant. Since there is a public perception that the cause of building problems is, at least in part, reduction in ventilation to conserve energy, problem buildings also have the potential to compromise DOE efforts to increase buildings' energy efficiency in the U.S.

In 1988, the Indoor Environment Program at the Lawrence Berkeley Laboratory, prepared a research initiative for the U.S. Department of Energy (DOE) proposing that a multi-disciplinary "Healthy Building" investigation be undertaken on a national level. The primary purpose of the study would be to identify the major factors that make energy- efficient buildings healthy, comfortable and productive work environments. In addition, the study would be designed to determine quantitative relationships between worker health, comfort and productivity and the multiple environmental and psychosocial factors associated with the design and operation of energy-efficient buildings. This information could then be used to design, construct and operate "healthy" and energy-efficient buildings. To date, this study has not been funded.

II. OBJECTIVES

To provide information and methods that could be used to design a national study, a small, pilot study was undertaken with existing funding using buildings in the San Fransciso Bay Area. The San Francisco Bay Area presents a unique setting in which to undertake such a pilot study because it encompasses at least two distinct climate zones within a small geographic area. The climate in San Francisco itself is moderate all year due to its proximity to the Pacific Ocean. Outside air is often sufficiently cool to eliminate the need for air conditioning, i.e., cooling is achieved by supplying large amounts of outside air using what is termed an "economizer" cycle. The East Bay Area, across from San Francisco, although not quite as cool as San Francisco, has a very similar climate. In contrast to these two areas, the area to the east of the coastal hills becomes quite hot on many days of summer, with afternoon temperatures typically in the range of 27 to 35 C. Office buildings in this area are typically air conditioned throughout the summer and consequently recirculate much of the indoor air. In addition, there are many public-owned buildings in the Bay Area. Thus, it is possible, within this small geographic region, to select a reasonably representative group of buildings with a range of ventilation systems, without consideration or pre-knowledge of frequency of complaints, and to conduct a study within a single season with only government workers in the study population. In addition, there are several institutions in the area with expertise on buildings and air quality: Lawrence Berkeley Laboratory (Indoor Environment Program and the Center for Building Science); California Department of Health Services (Indoor Air Quality Program and the Environmental Epidemiology Section); and the University of California, Berkeley (School of Public Health and the Department of Architecture).

The major objectives of the California Healthy Building Pilot Study were to:

1. Determine the prevalence of health symptoms and thermal comfort among workers

in buildings not pre-selected as complaint buildings;

2. Test the hypothesis that there are differences in the prevalence of occupant symptoms among buildings with natural ventilation, with mechanical ventilation and no air conditioning, and with mechanical ventilation and air conditioning;

3. Investigate relationships between the prevalence of occupant symptoms and environmental variables including ventilation rate, concentrations of aldehydes and other VOC, temperature and humidity;

4. Develop new methods for characterizing:

   a. Building ventilation effectiveness for pollutant removal

   b. Exposures to VOC, including aldehydes, as a function of irritancy; and

5. Develop protocols and strategies for use in a national Healthy Building Study.

III. STUDY DESIGN

A. Overall Approach

The overall approach was to design a multidisciplinary, multi- institutional pilot study to test an explicitly stated set of hypotheses. To test some of the hypotheses, an occupant questionnaire to characterize health, comfort, demographic and psycho-social factors was designed, pre-tested, and then used in this pilot study. The respondents symptom reporting was keyed to the specific times and locations of the environmental measurements.

Office buildings were selected for the study without regard to, or knowledge of, worker complaints about health and comfort. Rather, the buildings were selected to represent a population of buildings with three major types of ventilation: natural, mechanical without air conditioning, and mechanical with air conditioning. Windows in the non-air conditioned building categories could be opened and in the air-conditioned buildings were sealed. In the building selection process, efforts were made to select buildings so as to minimize variations in other building variables such as size, age, and types of occupant jobs, although this was not fully achieved.

New methods for characterizing the effectiveness of ventilation for pollutant removal and the concentrations of VOC with respect to their irritancy were also developed and tested. Relationships between an Irritancy Index (based on VOC measurements) and irritancy symptoms measured with the questionnaire are still to be investigated.

B. Hypotheses

The European studies indicate that there are wide variations in the prevalence of workers' symptoms among office buildings selected without regard for known worker problems, and that there are a substantial number of buildings with high symptom prevalence. The symptoms which are elevated in these buildings are the same symptoms that occur in known "problem" buildings, suggesting that this phenomenon is not restricted to rare "problem" buildings due to some unusual but specific exposure (Mendell and Smith, 1990). Thus, there may be a broad distribution of buildings with varying degrees of worker symptoms rather than a clear distinction between "healthy" and "problem" buildings.

The European studies also demonstrate that symptom prevalence is clearly associated with individual worker differences such as gender, job type, and job stress. However, after adjusting for the effects of these factors, substantial differences between buildings, presumably related to environmental factors, remain (Hedge et al., 1989; Skov et al., 1989).

Sealed air-conditioned buildings have been found to be consistently associated with higher symptom prevalence, although, in some cases, only after re-analysis of the data. Other environmental factors, such as the use of humidifiers, elevated indoor temperatures, elevated levels of organic dust, and the presence of carpets or cloth-covered surfaces, have been associated with higher symptom prevalence in individual studies (Finnegan et al., 1984; Hedge et al., 1989; Skov et al., 1987; Mendell and Smith, 1990). To date, studies have not positively associated many of the suspected environmental factors, e.g., elevated concentrations of total VOC, low humidity, low ventilation rate, with higher symptom prevalence.

The California Healthy Building Pilot Study was designed to assess the prevalence of selected symptoms (upper respiratory/ mucus membrane irritation, headache, and lethargy) among workers in public office buildings in the San Francisco Bay Area, chosen without regard to known worker complaints and representing a variety of ventilation types. The specific hypotheses tested in this study were as follows:

H_1: There will be substantial differences in the prevalences of work-related symptoms (i.e., symptoms which diminish on days away from work) among buildings.

H_2: Sealed air-conditioned buildings will have higher symptom prevalences than non-air-conditioned buildings with openable windows. Among non-air-conditioned buildings with openable windows, mechanically ventilated buildings will have symptom prevalences similar to, or somewhat higher than, naturally- ventilated buildings. These differences will not be fully explained by other measured variables.

H_3: Certain individual factors will be associated with higher symptom reporting (i.e., female gender, clerical job-type, high job stress/dissatisfaction, and concern over health effects of indoor air); however, differences in symptom prevalences across building types will persist even after adjustment for these individual factors.

H_4: Symptom prevalence will increase in association with increased temperature, or alternatively with decreased thermal comfort as measured by indices combining temperature and humidity; however, symptom prevalence, in general, and "dry" mucuous membranes, in particular, will not be associated with humidity within the range expected.

H_5: Symptom prevalence will not be related to concentrations of total VOC;

H_6: Symptom prevalence will not be associated with total concentrations of airborne viable bacteria or fungi;

H_7: Increased symptom prevalence will be associated with the presence of "high-surface area" materials, such as carpets and fabric-covered partitions.

A number of other relationships in the data will be assessed. Such relationships include those between different symptoms (i.e., clustering of symptoms); between symptoms and various worker characteristics; between symptoms and climate zone; and between symptoms and the Pollutant Control Index, the Irritancy Index, and fungal levels.

Because this is a pilot study, there are a number of hypotheses and relationships which cannot be evaluated but which may bear further investigation in future studies.

C. Characterizing Building Ventilation

Background

Traditionally, the ventilation in a building is characterized by the rate of outside air supply normalized by either the building volume, floor area, or number of occupants. Complex instrumentation systems that employ tracer gases can be used in buildings to measure these ventilation rates (Fisk, et al., 1988, 1989; Persily and Grot, 1985; Lagus and Persily, 1985); however, such measurements and equipment are too time consuming and expensive for use in surveys in large numbers of buildings.

A new approach was taken to characterize ventilation in buildings for the present study. Instead of measuring traditional ventilation rates, we determined the effectiveness of the ventilation in controlling the time-average (e.g., during the 45-hour work week) indoor concentration of both an occupant-generated pollutant (carbon dioxide) and a simulated pollutant from a source that is uniformly distributed per unit floor area and that emits at a constant rate. The measurements to determine effectiveness of pollutant control, described below, are much simpler than measurements of traditional ventilation rates. In addition, the new measurements require no manipulation of the building ventilation system, properly account for time variations in ventilation rate (e.g., due to regulation of outside air supply rates, nighttime shut-down of ventilation systems, and weather-induced infiltration); and, in the case of carbon dioxide (CO_2), account for variations in occupancy over time and space.

Delta-CO_2 Concentration

Persily and Dols (1989) have pointed out the difficulty in determining ventilation rates based on mass-balance equations, with measurements of indoor and outdoor CO_2 concentrations, and estimates of occupancy as inputs. However, CO_2 is one of several occupant- generated pollutants and the difference between the time-averaged outdoor CO_2 concentration and the time-averaged indoor concentration at a specific location is a simple but useful indicator of effectiveness in controlling occupant-generated pollutants at that location. Time-averaging can take place over any time period of interest. For the present study, a 45-hour work week, 8:30 to 17:30 on Monday through Friday, was selected.

The measurement procedure is simple. Bag samplers (described elsewhere) pumped samples of building air into storage bags at a constant rate over the time period of interest. The sample bags were transported to the laboratory and a calibrated infrared CO_2 analyzer drew a sample from each bag and measured the CO_2 concentration. Corresponding outdoor concentrations were subtracted from all indoor concentrations.

Pollutant Control Index

Many pollutants are emitted by building materials and furnishings which are distributed throughout a building (e.g., carpets and carpet adhesives, caulking compounds, and fabric-covered dividers). The total emission rates of some of these pollutants will scale approximately with floor area and and emissions are continuous over time at roughly a constant rate for periods of weeks or months. Passive emitters of perfluorocarbon tracers (PFTs) developed by Dietz, et al. (1986) were used to simulate the emission of pollutants from this general type of source. These PFT emitters or sources were distributed uniformly per unit floor area throughout a building in all areas of occupancy (basement mechanical rooms and storage rooms were omitted). Emission rates of PFTs were determined by weighing each source as closely as possible to the times of installation and removal. During the time period of interest, bag samplers, pumped samples of air containing PFT into sample bags at a constant rate. After completion of sampling, a measured volume of the sample within the bag was injected through a glass tube containing a carbonaceous sorbent. Virtually all PFT is adsorbed on this sorbent. The glass tube was then capped and mailed to a laboratory for analysis to determine the quantity of PFT on the sorbent. A new parameter called the Pollutant Control Index (PCI) was calculated using these data. One can compare values of PCI measured in different buildings and at different locations within the same building. In addition, measured values of PCI can be compared to a reference value. The PCIs were scaled to a reference value of 100 for a hypothetical building with perfectly mixed indoor air, 7 occupants per 100 m^2 floor area, and ventilated continuously (24 hours per day) at 10 L/s-occupant. The ventilation rate and occupancy for this reference case are the minimum ventilation rate and default occupant density specified for office buildings in ASHRAE Standard 62-1989, "Ventilation for Acceptable Indoor Air Quality" (ASHRAE 1989A).

D. Sensory Irritation of Gaseous Pollutants

Irritation of the mucous membranes of the eyes and the upper respiratory tract is a common complaint among office workers in modern buildings and is a characteristic symptom of the "sick-building syndrome." Such irritation can arise from the interaction between gaseous chemical pollutants and the receptors of the trigeminal nerve system in the mucosa of the eye and the nose (Neilsen and Alarie, 1982; Neilsen and Bakbo, 1984). Low level stimulation of the trigeminal nerves may also provide a basis for the sensation of "poor" air quality.

An animal bioassay has been developed to evaluate the sensory irritating properties of airborne chemicals and has been used to predict sensory irritation in humans (Alarie, 1966; Alarie, 1981). The basis of the bioassay is that when irritating airborne chemicals impinge on the nasal mucosa, the trigeminal nerve endings are stimulated, and inhibition of respiration occurs. The net decrease in respiratory rate is linearly related to the log of the exposure concentration of each chemical. From this relationship, the concentration necessary to evoke a 50 percent decrease in respiration rate can be calculated. This value, termed RD_{50}, is the basis for comparing the irritancy of various chemicals.

The RD_{50} values have now been determined for a large number of volatile chemicals (Danish National Institute of Occupational Health, 1989). The measured potency of these chemicals varies over five orders of magnitude (Alarie, 1981). The most irritating of the chemicals tested is toluene diisocyanate with an RD_{50} of 0.4 ppm. For comparison, acetone has an RD_{50} of 77,500 ppm. Formaldehyde, another very irritating compound, has an RD_{50} of 3.1 ppm.

The RD_{50} values for the mouse bioassay are highly correlated with threshold limit values (TLVs) for industrial exposures for many compounds whose exposure limits are based on irritation (Alarie, 1981). Multiplication of the RD_{50} values by 0.03 gives values that are close to the TLVs. Thus, the mouse bioassay provides data that can be used to predict the irritancy of chemicals to humans and, therefore, to rank chemicals by their potential irritancy.

A model for the mechanism of action of chemicals at the receptors of the trigeminal nerve system has been proposed (Neilsen and Alarie, 1982; Neilsen and Bakbo, 1984). According to the model, the nerve endings are stimulated either by chemical reaction with the receptor or by physical adsorption. Adsorption is much less efficient in activating the receptor compared to chemical reaction. For substances with low chemical reactivity, the sensory irritating capacities are related to the saturated vapor pressures. Chemical reactivity is correlated with reactivity toward nucleophilic groups in proteins.

Formaldehyde and acrolein are two strong sensory irritants. Groups of mice were exposed to atmospheres containing various combinations of formaldehyde and acrolein and their respiratory rates were monitored (Kane and Alarie, 1978). The data supported the hypothesis that formaldehyde and acrolein acted at the same receptor sites and that they exhibited competitive agonism when present together at relatively high concentrations. At lower concentrations, when all of the receptors are not filled, the response to a mixture of compounds may be expected to be more nearly additive.

In the present study, a scheme was developed to adjust the measured concentrations of aldehydes and other VOC so that the potential irritancies of the mixtures of VOC in the twelve buildings could be compared. Based on the available data base of mouse RD_{50} values, each quantified compound was assigned a multiplier that reflected its expected relative irritancy in humans. A range of irritancy spanning four orders of magnitude was assumed since the most reactive compounds, such as toluene diisocyanate, were not measured. Compounds with low sensory irritation were assigned a multiplier of one. This category included C_2 and C_3 alkyl benzenes, many ketones, and higher molecular weight aldhehydes. Compounds with very little or no effect were assigned a multiplier of 0.1. This category included alkane hydrocarbons, low molecular weight alcohols and acetone. Moderately irritating compounds were assigned a multiplier of ten. This category included C_4 and higher alkyl benzenes, low molecular weight unsaturated hydrocarbons, and some oxygenated compounds. Formaldehyde and acrolein, the most irritating compounds measured, were assigned a multiplier of 100. An Irritancy Index which provides a relative measure of irritancy of VOC mixtures was then calculated by summing the weighted concentrations of the compounds in each building.

E. Biological Aerosols

The term bioaerosols is used to designate a broad range of aerosols originating from biological materials. Examples include fungi, bacteria, viruses, pollen and other allergens, endotoxins, and mycotoxins. Bioaerosols, including infectious agents, can be transmitted by air and ventilation systems in buildings. Contaminated ventilation system equipment can be a source of pathogens, such as Legionella pneumophila, the bacterium responsible for Legionnaire's disease. In other cases, low fresh air ventilation and recirculation of air have contributed to outbreaks of tuberculosis, chicken pox and measles (LaForce, 1986).

Bioaerosols have been hypothesized to play a role in SBS, although they have not been conclusively associated with SBS. Some researchers have suggested that symptoms that were found to be correlated with building humidification and cooling were due to microbial contamination of the equipment (Burge, et al., 1987; Finnegan, et al., 1984). Endotoxins, mycotoxins and other biological products are being studied as possible causes of SBS because their effects could account for typical complaints that resolve when occupants leave a building. Hypersensitivity reactions are another response that the occupants of buildings with biological contamination can experience. Most of the responsible building-related antigens are assumed to be of fungal or bacterial origin.

Complete bioaerosol characterization is complicated and expensive, and therefore, was not attempted in the California Healthy Building Pilot Study. Rather, the concentrations of viable airborne bacteria and fungi were measured indoors at several locations and outdoors for each study building in order to provide an indication of the levels that were present on a typical work day.

IV. BUILDING SELECTION AND CHARACTERIZATION

A. Building Selection

Building selection was based upon a list of San Francisco Bay Area public buildings which was assembled by contacting all cities and counties in the area as well as the State of California. This list was narrowed to include only buildings which were state, county, or city owned, located in San Francisco, Contra Costa, or western Alameda Counties, contained more than 10,000 square feet of currently occupied office space, and had one of the three types of ventilation systems of interest in this study. Jails, hospitals, and police, highway patrol, and fire stations were eliminated from the list as non-representative of most office buildings. Similarly, buildings with unusual pollutant sources, such as laboratories, large repair shops, etc., were excluded. Buildings in which renovations or major employee relocations were scheduled for the same period as the study were also excluded. Air-conditioned buildings with windows that were either openable or which were openable when built and later sealed were eliminated to provide a more uniform group of air-conditioned buildings.

Buildings on the reduced list were then categorized into two main climate zones: moderate summer (San Francisco and East Bay) and hot summer (east of the coastal hills). All buildings in the hot-summer zone were, without exception, air-conditioned, although the other zone had buildings of all three types.

In seeking permission to include the buildings on the reduced list in the study, we found that the October, 1989 earthquake had severely damaged three of the large, older, naturally ventilated buildings in the moderate climate zone, taking them off the list. Permission to study a number of other buildings was denied. In addition, a number of buildings, upon physical inspection, turned out to be different than described, and thus became either ineligible or had to be moved into another ventilation category.

Ultimately, the number of buildings available within each category was equal to, or just slightly larger than, the original planned sample size for the study, giving us little further choice among buildings. Where possible, buildings containing substantial "open-plan" office space with a large proportion of clerical or similar type of work were selected. The selected buildings (see Table 2) included 6 air-conditioned and 6 non-air-conditioned buildings. Of the 6 non-air-conditioned buildings, 3 were naturally ventilated and 3 mechanically ventilated. All 6 of the non air-conditioned buildings and 4 of the air-conditioned buildings were in the moderate summer zone; the other 2 air-conditioned buildings were in the hot summer zone. (Lack of available buildings precluded a more optimal 3:3 split in air-conditioned buildings by climate zone).

Although the buildings were not selected in a probabilistic way, there is no reason to expect that they are not representative of public office buildings in this area, with the desired types of ventilation systems.

Smoking was not allowed in any of the buildings except within small designated areas. "Complaint" status was not considered in choosing study buildings, with buildings neither sought nor excluded on this basis. One of the air-conditioned buildings was

Table 2. Summary of Buildings Selected for the California Healthy Buildings Study

BUILDING NUMBER	0[a]	1	2[b]	3	4	5	6	7	8	9	10	11	12
Year of Construction	1989	1964[c]	1978	1982	1987	1956	1955	1964	1964	1954	1895	1915	1915
Interior Area (10^3 sq.ft.)[d]	22	39	171	210	39	90	68	93	90	25	25	516/14[e]	516/10[e]
Number of Floors	2	10	9	4	3	12	2	5	4	4	3	4	4
Climate Zone[f]	MS	MS	MS	MS	HS	HS	MS	MS	MS	MS	MS	MS	MS
Ventilation Type[g]	AC	NAT	AC	AC	AC	AC[h]	MECH	AC	AC	MECH	NAT	MECH	NAT
Number of Spaces Included	2	2	2	3	4[i]	3	1	2	2	4[i]	5[i]	1	1

FOOTNOTES:

a. Building used for pretesting of questionnaire
b. Known "complaint" building
c. Totally renovated in 1964, though building constructed in 1912
d. May be net or gross interior area
e. Total building area / area of study region
f. MS = Mild Summer; HS = Hot Summer
g. NAT = Natural Ventilation; MECH = Mechanical Ventilation with no AC; AC = Air Conditioned
h. Local induction coils for cooling
i. Environmental measurements made in only 3 study areas

found to be a classic "problem " building, with occupant complaints and investigations by various agencies starting immediately after its initial occupancy 12 years before. LBL staff had performed one of these investigations and published their findings (Turiel et al., 1983).

Among the air-conditioned buildings included in the study, all but one had cooling coils located in central mechanical rooms, either on the roof or in the basement. These are the most common configurations in this area. One of the six air-conditioned buildings contained cooling coils in perimeter wall induction units. (Some research suggests higher symptoms associated with this latter type of system, presumably due to risk of biologic contamination of condensate on these relatively inaccessible coils.)

Study areas within the buildings were selected using information gathered through inspection and through discussion with management so that environments and workers would be as uniform as possible across buildings. Wherever possible, open office areas, with 50 or more clerical workers, were selected as the major sampling sites. When this was not possible, smaller areas were combined to provide 50 workers for questionnaire administration and environmental characterization. In some buildings, it was possible to study multiple areas, each with 50 or more workers. One to five areas were included for each building. In the one building with five areas, environmental measurements were not made in the two smallest areas.

B. Building Characterization

Information was collected on each study building, from agency records, by physical inspection and from interviews with building management and engineering staff. The following information was obtained: responsible public agency; use(s) of building; number of full-time office workers; date of construction and date of last major remodel; floor plans and square footage of occupied space; number of stories; presence of attached parking garage; window type (built openable, built sealed, built openable and sealed later); smoking policy; ventilation system characteristics.

The following types of information were collected on the ventilation system of each building:

- Type of ventilation: natural or mechanical;

- Location of mechanical rooms, if any;

- Location of building air intakes and exhausts;

- Presence of air conditioning;

- Number of air-handling units and building space in each air- handling zone;

- Method of temperature control: constant-volume with variable supply temperature or variable-air-volume with constant-supply temperature;

- Presence and type of humidification;

- Recirculation of air;

- Use of economizer cycle;

- Location of air supply and return in occupied spaces (if any);

- Cooling coils centralized or localized, and if localized, whether in ceiling plenum or perimeter walls.

V. QUESTIONNAIRES

The study questionnaire is a modified version of a self- administered questionnaire used in a recent study of several U.S. Government buildings in Washington, D.C. (including the Madison Building of the Library of Congress). The Washington, D.C. study was carried out jointly by staff of the Environmental Protection Agency (EPA), the National Institute for Occupational Safety and Health (NIOSH), the Pierce Foundation at Yale University, and Westat, a private contractor.

The federal building questionnaire was shortened for the California Healthy Building Pilot Study from 45 minutes to 15 minutes. Those questions most closely related to specific study hypotheses were retained. The long work stress/dissatisfaction section in the original questionnaire was replaced with a shorter, well-tested scale developed by Alan Hedge of Cornell University and is part of a standard indoor-air questionnaire he is producing for the American Society for Testing and Materials. Questions were added about environmental concerns (that is, worker concerns about health hazards of their indoor environment), based on questions developed by the Environmental Epidemiology Section of the California Department of Health Services. (This group's studies of communities near hazardous waste sites has shown that symptom reporting can be substantially increased in worried populations with no apparent exposures.) Worker concern may increase symptom reporting and it is important to attempt to control for this potential confounding factor.

The modified questionnaire was pretested in several small groups, and then after preliminary revision, one final time in a group of 47 office workers in an air-conditioned building. As most of the questions had been used extensively and refined previously, only minor problems with question comprehension were found and these were corrected. A copy of the final questionnaire is included as Appendix 1.

Questionnaires were distributed to all workers in each selected space. All workers in these spaces were considered eligible except for those who had worked in the building less than three months, those who worked in the building less than 20 hours per week, and those who were out of the office for a period of two weeks or longer overlapping the study period.

Sample size calculations based on data from the first British study (Finnegan et al., 1984) suggested that a sample size of approximately 600 workers in 12 buildings would provide sufficient power to test major hypotheses about ventilation type and primary symptoms of interest. The total number of potentially completed questionnaires from 12 office buildings was estimated to be 950, based on the number of eligible workers and a response rate of about 85%.

VI. ENVIRONMENTAL SAMPLING, ANALYSIS AND MEASUREMENTS

A. Goals and Basic Strategy

The primary goal of the environmental measurements was to characterize key features of the indoor environment that were suspected to be related to the prevalence of occupant symptoms, based on the relevant literature and our hypotheses. Secondary goals were to expand the small existing data base of simultaneous pollutant and ventilation rate measurements in office buildings and to evaluate a new method of characterizing building ventilation. Based on these goals and practical constraints, the following environmental parameters were measured: (1) indoor and outdoor concentrations of VOC, including aldehydes (primarily because they are irritants); (2) indoor and outdoor concentrations of carbon dioxide (these measurements are the basis for one method of characterizing ventilation); (3) indoor and outdoor concentrations of carbon monoxide (primarily as an indicator of exposure to vehicle exhaust); (4) indoor and outdoor concentrations of viable airborne bacteria and fungi; (5) indoor temperature and humidity (because they impact thermal comfort and possibly other symptoms); and (6) an new parameter, called the Pollutant Control Index, for characterizing the effectiveness of ventilation for pollutant removal.

The 12 buildings were divided into groups of 3, in geographically close proximity for convenience. Measurements were made simultaneously made in each group of 3 buildings. Measurements in each group of buildings required approximately 3 weeks for completion - one week for setting up instrumentation, the second week for environmental measurements and the third week for the questionnaires and for removing the instrumention. Thus, the schedule for completion of the field portion of the study extended over a period of a little more than 12 weeks for these 12 buildings. Measurements in the first building (0) were made about 4 weeks prior to those made in the other 12 buildings.

The environmental measurement periods coincided with the time period for which the occupants reported symptom frequencies. The environmental measurements were made during all or part of the work week (8:30 to 17:30 on Monday through Friday) that preceded the distribution of the questionnaire, and the questionnaire then collected data on symptoms for both this previous work week and the previous twelve months.

The number and locations of the environmental measurements were additional considerations. Obviously, the measured indoor environmental conditions should be representative of the conditions surrounding the occupants that completed questionnaires. To reduce the number of measurements required, one or more study areas were selected in each building for questionnaire administration and environmental characterization. To the extent possible, study areas had a relatively open plan (few enclosed private offices) and were served by only a single air handling system. These features reduced the spatial variability of environmental conditions within each area. However, the measurements of indoor pollutant concentrations and thermal conditions are limited and may not be completely adequate for determining individual exposures. Based on the limited data and budgetary constraints, pollutant concentrations were measured at three indoor locations and one outdoor location in each building. Temperature was measured at four indoor locations and humidity at two indoor locations.

Criteria were established for selecting the specific measurement locations within each study area. These criteria included proximity of measurement locations to occupants, significant pollutant sources, and heat sources (e.g., pollutants were not measured within 2 m of a copy machine). All measurements were made at a height of 1.0 m - 1.4 m above the floor which corresponds to the typical breathing level for seated adults. The measurement procedures are described in the following subsections.

B. Bag Air Sampler

For collection of multipoint environmental samples, thirteen "bag samplers" were constructed (one unit is a spare). Each sampler was a large suitcase (0.70 m X 0.56 m X 0.23 m) that contained three peristaltic pumps, a programmable time switch, an elapsed time indicator, wiring, and tubing. Two of the peristaltic pumps were identical (Barnant Model 900-0488), rotated at 10 revolutions per minute (RPM) and were nearly silent, minimizing disturbance of building occupants. Each pump could accept three different sizes of tubing resulting in flow rates of 0.5, 1.5, and 5.5 mL/min. The third pump was nearly identical (Barnant Model 900-0487) but rotated at 3 RPM yielding flow rates of approximately 0.15, 0.45, and 1.6 mL/min. (Three RPM pumps were used due to a limited supply of 10 RPM pumps.) To double flow rates or produce another sample stream, two identical- size tubes could be installed simultaneously in a pump if the tubing was made from a soft flexible material (such as silicone); however, this practice is no longer recommended by the manufacturer. The programmable time switch (Fischer Scientific Model 06-662-12) controlled the delivery of 110 volt, 60 Hertz power to the three pumps (one circuit is switched) and, if desired, permitted different sampler start and stop times for each day of the week. The time switch had a battery backup that maintained memory during power outages. The elapsed time indicator (Yokogawa Model YE 240214AAAB) recorded the amount of time that power was supplied to the pumps (with a 0.1 minute resolution and a 10,000 minute maximum), could be reset (e.g., elapsed time is set to zero at the start of each one-week sample period), and also produced little noise. The elapsed-time information was an indicator of proper or improper sampler operation; for example, the elapsed time indicator of a sampler that was temporarily unplugged would indicate a decreased elapsed time.

Four sample tubes, typically 1 - 3 m long, extended from the desired indoor sample locations, into the suitcase, and connected with tubes that were installed in the peristaltic pumps. The sample tubes, made from Norprene or Viton, had an internal diameter of 1.6 mm. One sample tube drew a sample through an aldehyde sampler (described elsewhere) located at the inlet end of the sample tube. The sample was drawn at approximately 5.5 mL/min during the entire 45- hour work week. Another sample tube drew a sample through a VOC sampler (also described elsewhere) at approximately

5.5 mL/min. The VOC sampler was installed at the inlet end of the sample tube only during one nine-hour day of the five-day sampling period. During the same day, another sample tube, installed in the same peristaltic pump, drew a sample that was directed into a five-liter gas sample bag (typically made of Tedlar by SKC, Inc.). The sample in this bag was used to determine the Pollutant Control Index (described subsequently) for the day of VOC sampling which, in turn, can be used to estimate the one-week VOC concentrations from the VOC measurements on a single day, assuming that the VOC source strengths are the same throughout the week. Finally, the fourth sample tube drew a sample at 1.6 mL/min (using the 3 RPM pump). This sample stream was directed into a 20-L sample bag (made of Tedlar by BGI, Inc.) during the entire 45-hour work week. The sample in this large bag was analyzed to determine time-averaged concentrations of carbon dioxide and carbon monoxide and to determine the Pollutant Control Index for the work week.

The flow rates of each sample stream were measured twice during each 45-hour sample period and at least once during each nine-hour sampling period (single-day samples only) using a bubble flow meter. Sampler operational data were recorded on a form that was stored within the suitcase.

C. CO_2 and CO Measurements

Samples in the 20-L (45-hour) sample bags were analyzed to determine the time-averaged concentrations of carbon dioxide (CO_2) and carbon monoxide (CO). An infrared CO_2 analyzer (Horiba Model APBA 210), calibrated with 6 calibration gases spanning the range of 0 ppm to 2650 ppm, drew samples from the bags and produced an output voltage that was translated into a CO_2 concentration with a precision of a few ppm. The analysis of CO was similar except the infrared CO analyzer (Thermal Electron Model 48) had an output that was linear with CO concentration. Thus, only CO-free air and a 39.8 ppm scan gas were used for instrument calibration. Carbon monoxide measurement precision was approximately 0.5 ppm.

D. Characterizing Building Ventilation Using the Pollutant Control Index

The detailed procedure for characterizing building ventilation efficiency for the removal of pollutants and determining the Pollutant Control Index is described in Appendix 2. The method is based upon simulation of a source of indoor air pollutants through the use of constantly-emitting PFT sources which are distributed uniformly per unit floor area throughout the building. The resultant work-week average concentrations of the PFT in the air at various locations throughout the building are determined and then scaled (normalized) to determine a PCI value.

The PFT sources were installed in the building at least three days prior to air sampling. The bag samplers were used to collect samples of air containing the PFT (over one 45-hour work week) and an aliquot of the air in each bag was removed for PFT analysis to determine the PFT concentration in air at the location of that sampler. The sources of PFT were removed at the end of the sampling period and the weight loss of each was determined by weighing. The Pollutant Control Index was calculated:

$$PCI\ (bag) = K\ C_{PFT}(bag) \qquad (1)$$

where K is a scale factor which is different for each building, and $C_{PFT}(bag)$ is the concentration of the PFT in a given bag. The scale factor, K, normalizes (corrects) for building-to-building variations in PFT emission rate per unit floor area and also yields a parameter that has a value of 100 for the "ideal" case of a building with perfectly mixed indoor air ventilated continuously (24 hours a day) at the minimum rate per occupant for office buildings (and default occupant density) specified in ASHRAE Standard 62-1989 (10 L/s- occupant with 7 occupants per 100 m^2 or 0.7 L/s-m^2). The value of the scale factor is determined from:

$$K = [100\ A\ (0.7)]/[E_{avg}N], \qquad (2)$$

where A is the floor area in m^2, E_{avg} is the average PFT emission rate (L/s) for the sources based on the change in weight measured for each source and averaged over all N sources. Typically, 70 to 170 sources are deployed throughout a building. Values of PCI measured at different locations in the same building can be compared to indicate the spatial variability of ventilation (actually of the effectiveness of ventilation in pollutant removal). Average values of PCIs for buildings or parts of a building can also be intercompared or compared to the reference value of 100.

The PCI is a new concept and parameter; thus, we do not have prior experience with measurements of PCI. If the measurement technique is valid, measured values of PCI must not change significantly if the locations of PFT sources are changed to yield another spatially-uniform configuration. The sensitivity of PCI to source locations is being evaluated by deploying two or three types of PFT sources simultaneously, but in different locations, in the same buildings. Variations in PFT emission rates with location in the building or with time are another potential source of error. Data analysis will include a comparison of emission rates from PFT sources at different locations within a building. A comparison of emission rates when sources are located in buildings to the emission rates of the same sources when they are stored in the laboratory is also planned. Additional checks of measurement precision and accuracy will undoubtedly be required in the future.

E. Sampling and Analysis of Volatile Organic Compounds (VOC)

General Approach

It was originally intended to collect integrated work-week samples of VOC in the same Tedlar sampling bags used to collect work- week samples of the PFT tracers, CO_2 and CO. Such bags are routinely used for the collection of one-day samples of selected VOC in studies of ambient air pollution. However, there are no published data on storage stabilities in these bags for a broad range of VOC over longer time periods. Therefore, the suitability of Tedlar bags for work-week sampling of VOC was investigated in the laboratory prior to the initiation of the study. First, sampling bags from different manufacturers were evaluated for contamination. Bags with the least contamination were then evaluated for recovery of selected VOC. It was found that all Tedlar bags were contaminated with N,N- dimethylacetamide and phenol. However, bags from one manufacturer (BGI, Inc.) were otherwise relatively clean. Using these bags, recoveries were determined for ten compounds of interest to the study which either had relatively low vapor pressures, or contained relatively reactive functional groups. After storage for five days, the recoveries of many of these compounds were unsuitably low, and the idea of using Tedlar bags for the collection of VOC was abandoned.

Lacking a relatively inexpensive means of collecting integrated work-week samples of VOC, it was decided to collect one-day samples directly on sorbent tubes. The expense and time required for the analysis of VOC samples limited this collection to a single set of one-day samples per building. To obtain what were considered to be the best estimates of typical work-day concentrations, samples were not collected on Mondays when ventilation systems are starting up after being off over the weekend, or on Fridays when some employees leave early. In each building, a one-day bag sample for PFT tracers was collected concurrently with the VOC samples. The intent of this sample was to determine if the PCI on the day of collection was typical of the entire work-week. If a large change in ventilation rate occurred due, for example, to a large change in ambient temperature, the one-day and work-week PCI measurements could then be used to estimate the average VOC concentrations for the work week assuming the VOC source strengths remained the same.

Sampling

Samples for VOC were collected on multisorbent samples (Part No. ST032, Envirochem, Inc., Kemblesville, PA) which are packed in series with glass beads at the inlet followed by Tenax-TA, Ambersorb XE-340, and activated charcoal in order of increasing affinity for low-boiling compounds (Hodgson and Girman, 1989). Prior to use, the samplers were conditioned by heating to 300 C for 10 min with a helium purge. Each sampler was capped and placed in a sealed glass vial for transport and storage.

Multisorbent samplers were typically placed at three indoor locations and one outdoor location in each building. In addition, one sampler which was treated identically with the others was used as a field blank. The standard procedure was to sample from 8:30 to 17:30. Samplers were most often installed just prior to 8:30, and the sample on and off times were controlled by the programmable time switch in the bag samplers.

Samplers were held in aluminum brackets that were taped to vertical or horizontal surfaces at a height of 1-1.4 m above the floor. Samplers were not placed within 2 m of office machines such as photocopiers and blue print machines. Each sampler was connected to a 2-m length of Viton tubing with a stainless-steel union and plastic luer fittings. This tubing was installed in a 10-rpm peristaltic pump in the bag sampler which drew air through the multisorbent sampler at about 5.5 mL/min. Sample volumes were approximately three liters. Another tubing installed in the same peristaltic pump drew air into a 5-L gas sampling bag for determination of the PCI over the one-day period.

The air flow rate through each sampler was measured near the beginning and end of the one-day sampling period. These measurements were made with the sampler in place. A bubble flow meter was attached to the outlet of the Viton tubing downstream of the pump, and the elapsed time for 5 cm^3 of flow was recorded with a stop watch. The measurements were averaged to obtain the flow rate for the sampling period.

Analysis

Immediately prior to analysis, known masses of four deuterated standard compounds were added to each sample. These standards served as retention time markers to aid in the identification of compounds. The analytical procedure has been previously described (Hodgson and Girman, 1989). In brief, a sample was thermally desorbed from a multisorbent sampler with a UNACON Model 810A (Envirochem, Inc.) sample concentrating and inletting system and introduced into a capillary gas chromatograph (GC) connected via a direct interface to a Series 5790B Mass Selective Detector (MSD, Hewlett Packard Co.). The MSD was operated to continuously scan masses m/z 33-250. For quantitative analysis of the compounds of interest, characteristic ions were extracted from the total-ion chromatograms. Calibrations were performed using external standards. Standard gas mixtures were prepared by injecting aliquots of liquid mixtures of the analytes of interest into 2-L flasks with septum caps.

During the thermal desorption procedure, eight percent of each sample was split off and analyzed directly without chromatographic separation by a flame-ionization detector (FID) to give a measure of C_3 and higher molecular-weight hydrocarbons in the sample. This measure was termed total volatile organic carbon (TVOC), and results were given as parts per billion carbon. The FID was calibrated with a mixture of normal alkane hydrocarbons, prepared as described above. An alternate method for quantifying TVOC was also used. All of the peaks in the total-ion chromatograms were integrated and then were summed over several retention-time intervals. The summed areas were quantified using the total-ion chromatograms of normal alkane standards that fell within each retention-time interval.

F. Sampling and Analysis of Volatile Aldehydes

General Approach

Aldehydes are a class of VOC. Formaldehyde is typically the most important compound in studies of VOC in buildings because it is a strong irritant and has a number of potential indoor sources. The most prevalent, relatively strong, indoor source of formaldehyde is medium-density fiberboard. Other low molecular weight aldehydes of interest are acetaldehyde which is present in some consumer products and acrolein which is a component of environmental tobacco smoke. These aldehydes can not be analyzed by the multisorbent method for VOC described above. However, other commonly occurring aldehydes such as hexanal and benzaldehyde are adequately analyzed by this method. In this study, a separate method was used specifically for the sampling and analysis of low molecular weight aldehydes. This method allowed for the collection of integrated work-week samples.

Sampling

Samples for formaldehyde, acetaldehyde and acrolein were collected using C_{18} Sep-Pak cartridges (Millipore Corp.) impregnated with purified 2,4-dinitrophenylhydrazine (DNPH) and phosphoric acid (Kuwata et al., 1983; Fung and Wright, 1990). Prepared cartridges were obtained from Atmosphere Assessment Associates (4121 Matisse Ave., Woodland Hills, CA). When air is drawn through the cartridges, the aldehydes in the air react with the DNPH to form the hyrazone derivatives which are relatively stable.

Aldehyde samplers were typically placed at three indoor locations and one outdoor location for each building. In addition, one sampler was deployed as a field blank at an indoor location. The multisorbent samplers were placed at corresponding locations. The standard procedure was to sample for aldehydes from 8:30 to 17:30 on Monday through Friday in conjunction with the collection of the work-week bag sample. The sample on and off times were controlled by the progammable time switch in the bag samplers.

Just prior to installation, each sampler was assembled with an inlet and outlet tube. The inlet tube was a 3-mm O.D. by 20-cm long Teflon tube attached to the inlet end of the sampler with a plastic luer fitting. The purpose of this tube was to limit the diffusive sampling of aldehydes during the periods when air was not actively being drawn through the sampler. A similar tube 30-cm long was attached to the outlet of the sampler to limit any potential back diffusion of aldehydes from the Norprene sample tubing. The samplers were handled using plastic gloves during assembly, installation, removal and analysis to minimize contamination.

For each building, a blank sampler and a backup sampler were prepared. The blank sampler was assembled as described above with a short section of plugged Norprene tubing connected to the outlet tube. This sampler was deployed at one of the indoor locations adjacent to the active aldehyde sampler. The purpose of the blank sampler was to measure the analytical blank inclusive of any diffusive sampling that might have occurred during the sampling "off" periods. The backup sampler was attached in series to the outlet of one of the indoor samplers using a short section of Teflon tubing. The purpose of the backup sampler was to check for possible breakthrough of the analytes on the primary sampler.

Each active aldehyde sampler was connected to a 2-m length of Norprene tubing with plastic luer fittings. This tubing was installed in a 10-rpm peristaltic pump in the bag sampler which drew air through the aldehyde sampler at about 5.5 mL/min. Sample volumes were approximately 15 L. The air flow rate through each sampler was measured near the beginning and the end of the work-week sampling period. Often, additional measurements were made. A bubble flow meter was attached to the outlet of the Norprene tubing downstream of the pump, and the elapsed time for 5 cm^3 of flow was recorded with a stop watch. A time-weighted average flow rate was calculated from these measurements.

Analysis

The samples were analyzed using a high-performance liquid chromatograph (HPLC) with a diode array detector. Each sampler was eluted with 2 ml of acetonitrile. The eluent was collected in a 2-ml volumetric vial, and a 10-ul aliquot was manually injected into the sampling loop of the HPLC. The compounds were separated isocratically on a microbore, reverse-phase C_{18} column with a 65:35 v/v mixture of water and acetonitrile as the mobile phase. The peak area responses at 360 nm were determined for the hydrazone derivatives of formaldehyde, acetaldehyde, acrolein and acetone. External calibration standards were prepared from purified hydrazone derivatives. Aldehyde concentrations in parts per billion were calculated from the sample volumes and the quantified masses after blank correction.

G. Biological Aerosol Sampling and Characterization

Air was sampled with a Surface Air System (SAS) air sampler (Pool Bioanalysis, Italiana, Milan, Italy). The sampler has 220 impaction holes, an air flow rate of 90 L/min and uses Rodac plates (Falcon, Becton Dickinson Labware, Lincoln Park, N.J.) each filled with 13 mL of agar. Bacteria were isolated on trypticase soy agar (BBL Microbiology Systems, Cockeysville, MD), incubated at 35 C. Fungi were collected on malt extract agar (Bacto Laboratories, Detroit, MI), incubated at 25 C for 72 hours (ACGIH, 1989). Duplicate 0.3 m^3 air samples were collected on both media at 3 or 4 indoor locations in the breathing zone of a seated person and at one outdoor location for each building. The indoor locations were near those where other air sampling was occurring. The air concentrations were reported in colony-forming units per cubic meter of air (cfu/m^3). It should be noted that, in order to achieve optimal recovery of viable microorganisms, the sampling period for bioaerosols was on the order of minutes. In addition, for a number of the buildings, bioaerosol sampling was not done in conjunction with other environmental measurements.

H. Temperature and Humidity Measurements

Each of the eight sets of equipment used to measure the temperature and humidity consists of an analog-to-digital converter with input signal multiplexer, a laptop computer, two semiconductor temperature sensors and a bulk polymer humidity sensor. Each set of equipment is housed in a hard cover briefcase with a hole provided for a power cord and sensor cables.

The analog-to-digital converter with signal multiplexer is a 12- bit battery powered Serial Analog Module (SAM) manufactured by Fowlkes Engineering. The SAM's are capable of reading four temperature sensors and four $\pm$ 200 mV analog signals. A connection is provided for communication with a computer.

A NEC laptop computer, Model PC-8201A, with sufficient memory to store more than 35 Kbytes of data, was connected to the SAM via an RS323 port. A BASIC program stored in the NEC controlled the data acquisition and data transmission to and from the SAM. The battery that powers the SAM also preserves data in memory while AC power is disconnected.

The Analog Devices AD590 temperature sensors were calibrated in a well-mixed water bath at four temperatures using a platinum resistant thermometer as reference.

Based upon this calibration and a linear regression analysis, the accuracy of the recorded temperatures is estimated to be better than ± 0.25 C.

The General Eastern Model RH-3-I-S relative humidity sensors outputs a 0-200 mV signal with a load resistor. Based upon the data from a calibration using three saturated salt solutions, the accuracy is better than ± 6% relative humidity.

During the measurement period of approximately one week, data were recorded 24 hours per day at 15 minute intervals. The SAM queries all of its channels every 15 seconds, but the data recorded are for the average of the last 15 minutes. The temperature data was recorded to the nearest 0.1 C and the humidity data to better than ± 1% relative humidity. The date and time were also recorded for each data point.

Two general approaches are being used to evaluate the temperature and humidity data. First, the number of hours that temperatures and humidities are outside of the bounds of the comfort zone, defined by the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE 1989B), are computed, as well as the number of hours above and below other limits. The second approach is more complicated and yields an estimate of the expected extent of dissatisfaction with the thermal environment based on information in the International (Comfort) Standard (ISO 7730). The measured temperatures and humidities, plus an assumed air velocity typical of office spaces (0.137 m/s), and an assumed clothing value of 0.6 clo, are inputs to a computer program that yields a predicted mean vote (PMV). It is assumed for this calculation that the mean radiant temperature is equal to the measured air temperature. The PMV is an index that ranges from +3 (indicating hot) to -3 (indicating cold). The PMV is then used to compute the Predicted Percentage Dissatisfied (PPD), i. e., the predicted percentage of people in a large group that would be dissatisfied with the thermal environment. The PPD is computed from each 15-minute set of temperature and humidity data. Finally, to derive an index of thermal discomfort that is representative of the entire work week, the the sum of PPD values multiplied by the time elapsed at each value is determined with units of PPD-hours.

VII. ANALYSIS OF QUESTIONNAIRE DATA

A. Methods

Questionnaire data will be double key-entered on a personal computer (PC) and corrected for entry errors using Epi Info (Version 5, U.S. Center for Disease Control) data entry software. Environmental data, after preliminary analysis for entry errors and correction, will be transferred to Epi Info, which will then convert all data to SAS (Statistical Analysis System) data sets. The data will then be uploaded to an IBM mainframe computer for SAS analysis. Data analysis will include both univariate (descriptive) and multivariate components. Hypothesis testing will focus on the seven explicit hypotheses to be tested as part of this study but other relationships will also be investigated for hypothesis generation.

B. Univariate (Descriptive) Analyses

Descriptive analyses of the questionnaire data will include specific work-related symptom prevalences, demographic variables (age, gender, education), job variables (job-type, specific job activities), comfort variables, and psychological variables (worry, satisfaction and control).

Descriptive analyses of environmental measurement variables will include PCI, Irritancy Index, TVOC, CO_2, CO, temperature, humidity, and concentrations of viable fungi and bacteria. Descriptive analyses of environmental characterization data will include ventilation type, building age, climate zone, presence of carpets, and presence of fabric partitions.

C. Multivariate Analyses

Relationships among and between three groups of variables - questionnaire, environmental measurement, and environmental characterization (e.g., ventilation type) - will be assessed with crude and stratified analyses, and finally with multivariate modeling. Cluster analysis will be used to test for symptom clusters as potential building-related syndromes. Multiple logistic regression will be used to assess the following associations (controlling simultaneously for other measured factors): between specific work- related symptoms (or symptom clusters) and other individual job and environmental factors; between environmental factors and reported respiratory illness, respiratory illness-related absence, and respiratory illness-related doctor visits; and between different environmental variables, such as ventilation type and specific environmental measurements.

VIII. UNIQUE FEATURES OF THE STUDY

The California Healthy Building Pilot Study was designed with a unique combination of features. These include: explicit testing of a number of prestated hypotheses; selection of office buildings based on ventilation type, without regard to worker complaints; use of a questionnaire on work-related symptoms keyed to the specific period of environmental measurements; and use of questionnaire measures of job stress/dissatisfaction and environmental worry to allow adjustment of symptom reporting for these important psychological factors.

A new method for characterizing the effectiveness of the building ventilation for pollutant removal, using the Pollutant Control Index, was developed and tested. An Irritancy Index was developed to adjust concentrations of VOC, including some volatile aldehydes, to account for the irritancy effects of different mixtures of VOC. The relationship between the Irritancy Index and irritancy symptoms reported in the questionnaire will be investigated.

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THE HEALTHY BUILDING STUDY
CONSENT FORM

(Return this form to us with the questionnaire!)

This study will tell your employer and building manager about worker experience in your office environment (though neither they nor anyone else at work will know your individual answers on the questionnaire).

All questionnaires will be kept locked up, and then destroyed after data analysis is complete. Results of the study will be provided in a report to you and other employees, to employee representatives, and to your employer; results will contain group data only, without any personal identifiers.

I WOULD LIKE TO PARTICIPATE IN THE HEALTHY BUILDING STUDY:

I have read the previous instructions for the "Healthy Building Study", and consent to participate.

____________________ name (please print)

____________________ participant's signature

________ date

We will distribute to you a report of the study results when they are available.

NEXT, PLEASE TURN TO THE BACK OF THIS PAGE.

I DO NOT WANT TO PARTICIPATE IN THE HEALTHY BUILDING STUDY:

____________________ name (please print)

________ date

reason (optional): ____

____

If you choose not to participate, please fold the blank questionnaire,
seal it in the envelope provided,
and return it to the box marked "Building Study", located near your mailbox .

PLEASE READ BEFORE COMPLETING QUESTIONNAIRE

Many questions in this questionnaire mention either "LAST WEEK" or "LAST YEAR".

LAST YEAR refers to the 12-month period ending today. If you have worked in this building for less than one year, answer the "LAST YEAR" questions for that part of the year that you have worked in this building.

LAST WEEK refers to all days you worked from Monday through Friday of **last** week (not this week). Please report your ACTUAL EXPERIENCES LAST WEEK, even if last week was unusual for you. If you were not at work all of last week, answer for the most recent full week you were in the office.

Please fill out this questionnaire without discussing it or consulting about it with others: we want your own immediate opinions and responses.

We would like you to answer all the questions as completely as possible, but you do not have to answer any questions that you do not want to, and you may stop at any time.

#_______________

PART I. DESCRIPTION OF YOUR WORKSTATION

This section asks you about your workstation. By WORKSTATION we mean your desk, office, cubicle, or place that is your primary work area. If you work in more than one location, your workstation is the specific location where you spend more time than at any other single location.

1. There are many different types of workstations. Please check the categories that best describe the space in which your current workstation is located.

   a. Type of space (*Check one*)

      1. ☐ Enclosed office with door
      2. ☐ Not an enclosed office, but with partitions or bookshelves giving you visual privacy on <u>four</u> sides
      3. ☐ Not an enclosed office, but with partitions or bookshelves giving you visual privacy on <u>one</u>, <u>two</u>, or <u>three</u> sides
      4. ☐ Open office area, with <u>no</u> visual privacy
      5. ☐ Other (specify) ____________ ____________________

   b. Type of space sharing (*Check one*)

      1. ☐ One occupant only
      2. ☐ Shared with one other person
      3. ☐ Shared with two or more other persons
      4. ☐ Other (describe) ____________ ____________________

2. On what floor of the building do you work? (Enter the floor number; if the basement, write B.)

   ☐☐ floor

3. How long have you been working in the building? (If less than one year, enter number of months)

   ☐☐ years (☐☐ months)

4. a. How long have you worked <u>at your current workstation</u>? (If less than one year,.enter number of months)

   ☐☐ years (☐☐ months)

   b. During an average <u>workday</u>, how many hours do you spend <u>at your workstation</u>?

   ☐☐ hours per <u>day</u>

5. a. During a <u>typical week</u>, how many hours do you work in the building?

   ☐☐ hours per <u>WEEK</u>

   b. LAST WEEK, how many hours did you work in the building ?

   ☐☐ hours LAST WEEK

6. **LAST WEEK during a typical day, approximately how much time did you spend working with each of the following items?** *(If less than 1 hour per day, enter minutes.)*

	hours per day	(minutes per day)
a. Computer or word processor with screen/keyboard	☐☐	☐☐
b. Photocopy machine .	☐☐	☐☐
c. Carbonless copies (NCR paper)	☐☐	☐☐

NOTE:
For the following questions, think of the area within a circle of about 15 feet from your workstation in all directions.

7. Are any of the following items now located within 15 feet of your current workstation? (*Check "no" or "yes" for each item.*)

	No 1	Yes 2
a. Photocopy machine	☐	☐
b. Laser printer..................	☐	☐
c. Plants	☐	☐
d. Window	☐	☐

(If No on "d" go to Q. 9)

8. Is there ever a window open within 15 feet of your desk?

1. ☐ No
2. ☐ Yes

9. **During the LAST YEAR (or since you've been at your current workstation, if that is less than a year) have any of the following changes taken place within 15 feet of your current workstation?** (*Check "no" or "yes" for each item.*)

	No 1	Yes 2
a. New carpeting	☐	☐
b. New plants	☐	☐
c. Walls painted	☐	☐
d Walls rearranged or moved	☐	☐

PART II.
INFORMATION ABOUT YOUR HEALTH AND WELL-BEING

1. *Please answer the three questions to the right (A, B, C) about each symptom listed below*	**A.** How often during the LAST YEAR* did you experience this symptom while working in the building? (If "**never**", skip questions B and C and go down to the next symptom.)					**B.** How many days LAST WEEK** did you experience this symptom while working in the building?	**C.** Does the symptom usually change when <u>not</u> at work?		
	never	**rarely**	**some-times**	**often**	**always**	**(Fill in # of days LAST WEEK)**	**gets worse**	**stays same**	**gets better**
	1	2	3	4	5		1	2	3
a. **runny nose**									
b. **stuffy nose/sinus congestion**									
c. **dry or irritated throat**									
d. **earache**									
e. **dry or itchy skin**									
f. **dry, irritated, or itching eyes**									
g. **problems with contact lenses**									

continue on next page

*LAST YEAR *refers to the <u>12 month period ending today</u> (or for the time you've worked in the building if less than one year).*
**LAST WEEK *refers to any or all days worked from <u>Monday through Friday of last week.</u>*

PART II, CONTINUED

1. *Please answer the three questions to the right* (**A, B, C**) *about each symptom listed below*

	A. How often during the LAST YEAR* did you experience this symptom while working in the building? (If "**never**", skip questions B and C and go down to the next symptom.)					**B.** How many days LAST WEEK** did you experience this symptom while working in the building?	**C.** Does the symptom usually change when not at work?		
	never	**rarely**	**some-times**	**often**	**always**	**(Fill in # of days LAST WEEK)**	**gets worse**	**stays same**	**gets better**
	1	2	3	4	5		1	2	3
h. **unusual fatigue or tiredness**	☐	☐	☐	☐	☐	☐	☐	☐	☐
i. **sleepiness**	☐	☐	☐	☐	☐	☐	☐	☐	☐
j. **headache**	☐	☐	☐	☐	☐	☐	☐	☐	☐
k. **chills or fever**	☐	☐	☐	☐	☐	☐	☐	☐	☐
l. **chest tightness**	☐	☐	☐	☐	☐	☐	☐	☐	☐
m. **difficulty breathing**	☐	☐	☐	☐	☐	☐	☐	☐	☐
n. **toothache**	☐	☐	☐	☐	☐	☐	☐	☐	☐
o. **pain or numbness in shoulder/neck**	☐	☐	☐	☐	☐	☐	☐	☐	☐

please go to next question ←

*LAST YEAR *refers to the* <u>*12 month period ending today*</u> *(or for the time you've worked in the building if less than one year).*
**LAST WEEK *refers to any or all days worked from* <u>*Monday through Friday of last week.*</u>

2\. a. Today, do you have either a cold, an infection in your lungs or chest, or flu?

1. ☐ No
2. ☐ Yes

b. How many separate times in the LAST YEAR have you had either a cold, an infection in your lungs or chest, or flu? *(Write 0 if none.)*

☐☐ times in the LAST YEAR

c. How many times in the LAST YEAR have you seen a physician because you had either a cold, an infection in your lungs or chest, or flu?

☐☐ times in the LAST YEAR

d. On how many days in the LAST YEAR has either a cold, an infection in your lungs or chest, or flu caused you to stay home from work?

☐☐ days in the LAST YEAR

3\. During the LAST YEAR, have you had an illness in which you had repeated episodes of <u>three or more</u> of the following symptoms at the same time: wheezing, cough, shortness of breath, fever, chills, aching joints/muscles?

1. ☐ No
2. ☐ Yes

4\. During the LAST YEAR, have you had any episodes of wheezing (whistling in the chest) <u>without</u> fever or chills or sore throat?

1. ☐ No
2. ☐ Yes

5\. a. Has a physician ever told you that you have, or had, asthma?

1. ☐ No ---------> (**<u>go to Question 6</u>**)
2. ☐ Yes

b. If yes, when was it first diagnosed?

19 ☐☐

c. Have you had an asthma attack during the LAST YEAR?

1. ☐ No
2. ☐ Yes

6\. Do you believe you are or may be allergic to any of the following? (Check "no" or "yes" for each item.)

	No 1	Yes 2
a. pollen or plants	☐	☐
b. animals	☐	☐
c. dust	☐	☐
d. molds	☐	☐
e. other (specify)	☐	☐

____

7\. Do you wear contact lenses at work?

1. ☐ Never
2. ☐ Sometimes
3. ☐ Often
4. ☐ Always

PART III.
INFORMATION ABOUT YOUR PRESENT WORK ENVIRONMENT

In this question, you are asked to report specific responses to the physical environment at your present workstation.

1. At your present workstation, HOW OFTEN...	A. ....during the LAST YEAR (*Please check one box.*) (If "**never**", skip question B and go down to next line.)					B. ....during the LAST WEEK (*Please check one box.*)				
	never	**rarely**	**some-times**	**often**	**always**	**never**	**once or twice in the week**	**3 to 4 times in the week**	**about once a day**	**more than once a day**
	1	2	3	4	5	1	2	3	4	5
a. **was there too much air movement?**	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
b. **was there too little air movement?**	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
c. **did you want to adjust the air movement?**	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
d. **was the temperature too hot?**	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
e. **was the temperature too cold?**	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
f. **did you want to adjust the temperature?**	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

continue on next page

*LAST YEAR *refers to the 12 month period ending today (or for the time you've worked in the building if less than one year).*
**LAST WEEK *refers to any or all days worked from Monday through Friday of last week.*

PART III, CONTINUED

1. At your present workstation, HOW OFTEN...	A. ....during the LAST YEAR (*Please check one box.*) (If "never", skip question B and go down to next line.)					B. ....during the LAST WEEK (*Please check one box.*)				
	never	**rarely**	**some-times**	**often**	**always**	**never**	**once or twice in the week**	**3 to 4 times in the week**	**about once a day**	**more than once a day**
	1	2	3	4	5	1	2	3	4	5
g. **was it too humid?**	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑
h. **was it too dry?**	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑
i. **did you want to adjust the humidity?**	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑
j. **was the air too stuffy?**	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑
k. **did you notice unpleasant odors?**	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑
l. **were you bothered by noise?**	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑
m. **were you bothered by dust or soot?**	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑

*LAST YEAR *refers to the* _12 month period ending today_ *(or for the time you've worked in the building if less than one year).*
**LAST WEEK *refers to any or all days worked from* _Monday through Friday of last week._

2. What kind of lighting do you generally use at your desk or workstation? (Check no or yes for each item.)

	No 1	Yes 2
a. fluorescent lights	❑	❑
b. ordinary light bulbs	❑	❑
c. natural light	❑	❑
d. other (specify)	❑	❑

____

3. Please rate the lighting at your workstation.

1. ❑ Much too dim
2. ❑ A little too dim
3. ❑ Just right
4. ❑ A little too bright
5. ❑ Much too bright

4. Can you see out an outside window from your workstation?

1. ❑ No
2. ❑ Yes

5. How much natural daylight do you have at your usual desk or workstation? (Check appropriate box.)

1. ❑ No natural daylight
2. ❑ Very little natural daylight
3. ❑ A moderate amount of natural daylight
4. ❑ Much natural daylight

6. Are you worried or concerned about the indoor air where you work? (Check appropriate box.)

1. ❑ not at all worried--> (go to Q. 8)
2. ❑ slightly worried
3. ❑ somewhat worried
4. ❑ very worried

7. If you are worried or concerned about the ventilation or indoor air where you work, why is this? (Check no or yes for each item.)

	No 1	Yes 2
a. because of some personal comfort problems	❑	❑
b. because of some personal health problems	❑	❑
c because of health problems of someone else in the building	❑	❑
d. because of things you have heard or read about certain kinds of buildings	❑	❑
d. other (specify)	❑	❑

____

____

8. Compared to other office buildings, how would you rate the indoor air quality in your building? (Check appropriate box.)

1. ❑ much better than others
2. ❑ somewhat better than others
3. ❑ about the same, or not sure
4. ❑ somewhat worse than others
5. ❑ much worse than others

9. How **satisfied** are you with the following? (Check one box for each item, a through d.)

	Very Satisfied	Mostly Satisfied	Uncertain	Mostly Dissatisfied	Very Dissatisfied
a. **control over the lighting at your workstation**	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
b. **control over the temperature at your workstation**	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
c. **control over the air movement at your workstation**	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
d. **the overall physical environment at your workstation (that is, the air quality, temperature, light, noise, odor, etc.) during the LAST WEEK**	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
e. **the overall physical environment at your workstation (that is, the air quality, temperature, light, noise, odor, etc.) during the LAST YEAR**	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐

PART IV. CHARACTERISTICS OF YOUR JOB

1. Please say **how much you agree or disagree** with each of the following statements about your job:

	Strongly Agree	Mostly Agree	Uncertain	Mostly Disagree	Strongly Disagree
a. **My job is usually interesting**	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
b. **I'm happy in my job**	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
c. **I dislike my job**	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
d. **I am satisfied with my job**	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
e. **I'm enthusiastic about my job**	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
f. **My job is rather monotonous**	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
g. **My job is not very stressful**	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
h. **I usually have to work fast**	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
i. **I often feel stressed at work**	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
j. **My job demands a lot of concentration**	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
k. **I often feel overworked**	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
l. **I have a lot of control over how my work is done**	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
m. **I have enough space in my work area to do my work**	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
n. **Air quality in the office has caused health problems for me**	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
o. **My workspace gives me adequate visual privacy**	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐

PART V. CONCLUDING QUESTIONS

This section concludes this survey. Your answers to these questions, like your answers to the previous questions, will be kept confidential. This information is needed for statistical purposes.

1. Are you :

   1. ☐ Male
   2. ☐ Female

2. What was your age on your last birthday? (Check appropriate box.)

   1. ☐ less than 20
   2. ☐ 20 - 29
   3. ☐ 30 - 39
   4. ☐ 40 - 49
   5. ☐ 50 - 59
   6. ☐ 60 or over

3. a. What is your race/ethnic group? (Check the appropriate box.)

   1. ☐ White
   2. ☐ Black
   3. ☐ Asian/Pacific Islander
   4. ☐ Other (specify) ____________________
   5. ☐ Decline to state

   b. Are you of Spanish/Hispanic origin?

   1. ☐ No
   2. ☐ Yes
   3. ☐ Decline to state

4. Which of the following best describes your job duties and responsibilities? (If more than one applies, check the ONE box for the job duties on which you spend the most time.)

   1. ☐ Managerial (such as administrator, manager, etc.)
   2. ☐ Professional (such as engineer, scientist, lawyer, etc.)
   3. ☐ Technical (such as technician, programmer, etc.)
   4. ☐ Administrative Support (such as clerical, secretarial, word processing, key entry, etc.)
   5. ☐ Other (specify)

      ____

5. What is the highest grade you completed in school?

   1. ☐ 11th grade or less
   2. ☐ High school graduate
   3. ☐ 2 years of college or Associate Degree
   4. ☐ Bachelor's or technical degree
   5. ☐ Some graduate work
   6. ☐ Graduate or professional degree

6. a. **Which of the following best describes your history of smoking tobacco products such as cigarettes, cigars, or pipes?**

   1. ☐ Never smoked--> (**go to Q. 7**)
   2. ☐ Former smoker
   3. ☐ Current smoker

   b. **In a typical 24 hour day, how many CIGARETTES do you usually smoke?**

   1. ☐ None
   2. ☐ 1 to 5
   3. ☐ 6 to 10
   4. ☐ 10 to 20
   5. ☐ 21 or more

7. Give the date when you finished this questionnaire:

   ☐☐ (month) ☐☐ (date) , 1990

10. Is there anything else you would like to tell us about environmental or health matters in your building? If so, please use this space provided for that purpose:

When you are finished, please:

fold this questionnaire in half, with the signed consent form,
seal it in the envelope provided, and
return it to the place or person described on the front Instruction Sheet.

THANK YOU VERY MUCH FOR YOUR TIME AND PATIENCE IN FILLING OUT THIS QUESTIONNAIRE.

APPENDIX 2

CHARACTERIZING BUILDING VENTILATION USING THE POLLUTANT CONTROL INDEX

1. While stored in the laboratory, sources are maintained at a typical indoor temperature (e.g., 24 C) because they emit PFT at a rate that varies significantly with temperature.

2. Using an estimated floor area (A), estimated ventilation rate per unit floor area (Q/A), and the nominal emission rate of PFT per source assuming a source temperature of 25 C [E(25)], the number (N) of PFT sources is selected, generally to yield an estimated indoor PFT concentration ($C_{estimated}$) of 0.5 to 10 parts per trillion (ppt). The following equation is employed

$$C_{estimated} = [\ N\ E(25)\ ] / [\ A\ Q/A\ ].$$

We generally aim for 70 to 170 sources, recognizing that a larger number of sources results in a more uniform tracer emission per unit floor area.

3. Using floor plans for the building, we divide the floor area into many equal-area regions. An equal number of PFT sources will be placed in each region. Approximate locations for each PFT source are indicated on the floor plans.

4. The day before installation, the weight of each PFT source is determined using a electronic balance with a resolution of 0.0001 g or smaller. (The change in weight per week of an individual source is on the order of 0.005 g.) The weight, time and date of weighing, and the source number is recorded. After weighing, each sources is inserted into the hole in a folded cardboard tab that can be taped to an indoor surface.

5. Sources are transported to the building in an insulated container (ice chest) containing bottles of water at typical room temperature (in order to maintain sources at as constant a temperature as possible). They are installed throughout the building by taping the cardboard tab to a surface at a height of 1.1 to 1.3 m. Sources are installed at least three days prior to initiating sampling so that concentrations during the sampling are not diminished due to recent source installation.

6. During the desired time periods (e. g., 08:30 to 17:30 on Monday through Friday), bag samplers pump air samples containing PFT tracer into sample bags at a constant rate. The concentration of PFT in the final bag sample equals the time-average indoor concentration at the sampling location during the period of sampling.

7. PFT sources and sample bags are removed from the building as soon as possible after sampling terminates (usually the following Monday) and each source is weighed. Based on the change in weights and the density of the PFT tracer, the average [E(average)] PFT emission rate is computed.

8. We compute the sample volume (SV) of air containing PFT tracer that will be

withdrawn from the bag samples and injected through the glass tubes containing a sorbent using the expression

$$V_{pft}(\text{minimum}) < (SV)\,(C_{expected}) < 10 \times 10^{-12}\ L$$

where V_{pft}(minimum) is the minimum accurately measurable volume of tracer gas which depends on the type of PFT tracer used. For PFT types designated as PMCP, PMCH, and mPDCH, respectively, V_{pft}(minimum) equals 10×10^{-15}, 60×10^{-15}, and 100×10^{-15} L.

9. Using a syringe with volume graduations, the appropriate volume is withdrawn from each sample bag and injected through the glass tube containing the carbonaceous sorbent. The injection rate must not exceed 0.5 L/min. Each glass tube is capped. [The glass tubes are typically installed in buildings with one end uncapped for passive (diffusion-controlled) sampling of PFTs and are called capillary adsorption tubes (CATS) as described by Dietz et al. 1986.]

10. The CATS are mailed to a laboratory for determination of the volume of PFT that adsorbed onto the sorbent in each tube designated V_{pft}(CATS).

11. The concentration of PFT in each sample bag is computed

$$C_{pft}(\text{bag}) = V_{pft}(\text{CATS}) / SV.$$

12. The scale factor (K) for computing the pollutant control index is determined

$$K = [\,70\,A\,] / [\,N\,E(\text{average})\,]$$

where A is the floor area.

13. Finally, the pollutant control index (PCI) for each sample bag is calculated

$$PCI\,(\text{bag}) = K\ C_{pft}(\text{bag}).$$

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