AL-TR-1992-0016

AD-A251 638

# GUIDE FOR INDOOR AIR QUALITY SURVEYS

ARMSTRONG LABORATORY

P. Diane Bright, Captain, USAF, BSC
Michael J. Mader, Captain, USAF, BSC
David R. Carpenter, Major, USAF, BSC
Ivette Z. Hermon-Cruz, First Lieutenant, USAF, BSC

OCCUPATIONAL AND ENVIRONMENTAL
HEALTH DIRECTORATE
Brooks Air Force Base, TX 78235-5000



May 1992

Final Technical Report for Period October 1990 – January 1992

Approved for public release; distribution is unlimited.



AIR FORCE SYSTEMS COMMAND
BROOKS AIR FORCE BASE, TEXAS 78235-5000

NOTICES

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely Government-related procurement, the United States Government incurs no responsibility or any obligation whatsoever. The fact that the Government may have formulated or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication, or otherwise in any manner construed, as licensing the holder or any other person or corporation; or as conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

The mention of trade names or commercial products in this publication is for illustration purposes and does not constitute endorsement or recommendation for use by the United States Air Force.

The Office of Public Affairs has reviewed this report, and it is releasable to the National Technical Information Service, where it will be available to the general public, including foreign nationals.

This report has been reviewed and is approved for publication.

Government agencies and their contractors registered with Defense Technical Information Center (DTIC) should direct requests for copies to: DTIC, Cameron Station, Alexandria VA 22304-6145.

Non-Government agencies may purchase copies of this report from: National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield VA 22161.

P. DIANE BRIGHT, Capt, USAF, BSC
Consultant, Environmental Health Branch

MARK H. STOKES, Colonel, USAF, BSC
Deputy Chief, Occupational Medicine Division

# REPORT DOCUMENTATION PAGE

*Form Approved*
*OMB No. 0704-0188*



**1. AGENCY USE ONLY** *(Leave blank)*

**2. REPORT DATE**
May 1992

**3. REPORT TYPE AND DATES COVERED**
Final October 1990 - January 1992

**4. TITLE AND SUBTITLE**
Guide for Indoor Air Quality Surveys

**5. FUNDING NUMBERS**

**6. AUTHOR(S)**
P. Diane Bright
Michael J. Mader
David R. Carpenter
Ivette Z. Hermon-Cruz

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
Armstrong Laboratory
Occupational and Environmental Health Directorate
Brooks Air Force Base, TX 78235-5000

**8. PERFORMING ORGANIZATION REPORT NUMBER**
AL-TR-1992-0016

**9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)**

**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**

**11. SUPPLEMENTARY NOTES**
Supercedes USAFOEHL Report 87-037, A Procedural Guide on Sick Building Syndrome.

**12a. DISTRIBUTION/AVAILABILITY STATEMENT**
Approved for public release; distribution is unlimited.

**12b. DISTRIBUTION CODE**

**13. ABSTRACT** *(Maximum 200 words)*

This report presents an informative, inclusive and concise process by which indoor air quality problems can be assessed in the field. It demonstrates the importance of team concepts for investigating problems and performing surveys. A history of indoor air quality is reviewed, including survey results by the indoor air quality survey team from Armstrong Laboratory. Recommendations are made that will improve the quality and efficiency of field investigations.

**14. SUBJECT TERMS**
Indoor Air Quality, Tight Building Syndrome, Air Quality Surveys

**15. NUMBER OF PAGES**
60

**16. PRICE CODE**

| 17. SECURITY CLASSIFICATION OF REPORT | 18. SECURITY CLASSIFICATION OF THIS PAGE | 19. SECURITY CLASSIFICATION OF ABSTRACT | 20. LIMITATION OF ABSTRACT |
|---|---|---|---|
| Unclassified | Unclassified | Unclassified | UL |

NSN 7540-01-280-5500

Standard Form 298 (Rev 2-89)
Prescribed by ANSI Std Z39-18
298-102

## TABLE OF CONTENTS

# GUIDE FOR INDOOR AIR QUALITY SURVEYS

## INTRODUCTION

### Purpose

This technical report provides guidance for performing indoor air quality (IAQ) surveys at base level. It provides Military Public Health Officers (MPHOs) and Bioenvironmental Engineers (BEEs) with checklists and other aids for effectively running an IAQ program with occupational health issues in mind. This report replaces USAFOEHL Report 87-037, A Procedural Guide on Sick Building Syndrome (Liebhaber, 1987), and supplements AFOEHL Report 90-169, Recommended Carbon Dioxide and Relative Humidity Levels for Maintaining Acceptable Indoor Air Quality (Carpenter and Poitrast, 1990).

### Background of Problem

Poor indoor air quality is a term used to describe nonindustrial indoor spaces where occupants complain of health problems which disappear when they leave the building. In the United States Air Force (USAF), the primary areas of concern are office buildings, although base housing may have its share of IAQ problems. An IAQ problem begins when decisions are made about design, operation, or maintenance of a facility without considering the impact on workers' health or comfort. The result is reduced productivity and low morale because workers suffer daily from symptoms such as sinus congestion, drowsiness, lack of concentration, dry itchy skin, eye irritation, room temperature extremes, and allergies.

When the situation warrants investigation, the BEE or the MPHO is called to find the cause of the complaints and recommend solutions. Corrections may cost substantial sums of money and often are seen as contrary to policies in place regarding energy conservation or operation and maintenance of ventilation systems. Therefore, to be successful in remediating IAQ problems, it is essential for the BEE and MPHO to operate with an effective game plan.

USAFOEHL Report 87-037 was dedicated to the BEE protocol for indoor air quality investigations. Since its publication in 1987, several national interest items have come into play, such as passive tobacco smoke and indoor pollutants. At the present time, there is a great deal of research and political effort to pass a national indoor air quality bill.

### Scope

This report will discuss current knowledge of the causes and effects of poor indoor air quality and provide the protocol necessary for reliable investigations. It will describe the roles and responsibilities of all team players and the steps necessary to perform proper IAQ investigations. This report will stress the importance of teamwork to run an effective IAQ program from the occupational health perspective.

## DISCUSSION

### Getting the Proper Perspective

According to AFR 161-33 (1987), the objective of the Aerospace Medicine Program is to promote and maintain the health and well-being of USAF personnel and ensure a vital and fit military organization. This broad objective includes many projects with higher priorities than IAQ investigations. It is important, however, to find the time to investigate IAQ complaints for several reasons. First, once an IAQ problem begins, workers are affected almost daily by symptoms which reduce productivity and lower morale. Second, ignoring minor IAQ problems can lead to the development of serious illnesses. Third, there is excellent potential for success in solving the problem.

### Fundamentals

We spend 85-90% of our time in some form of shelter, i.e., home, office, car, or school (Stolwijk, 1990). Therefore, it is obvious that the quality of the indoor air can have a significant effect on our health. A comprehensive study of over 4,000 British office workers in buildings without known problems (Burge et al., 1987) makes this clear. Researchers reported that 57% of the workers complained of lethargy. Blocked nose, dry throat, and headache were listed as frequent symptoms by 40%-50% of the workers, and about 25% of the workers suffered from itchy eyes, dry eyes, runny nose, and flu-like symptoms. In a study of United States (U.S.) buildings (Kreiss, 1989), the World Health Organization (WHO) estimated the number of buildings plagued by poor indoor air quality to be as high as 50% and to affect 25% to 40% of all employed persons in the United States. Studies such as these show how IAQ problems can become significant public health issues.

Common descriptive names for this public health issue are Sick Building Syndrome (SBS), Tight Building Syndrome (TBS), Building Associated Illness (BAI), and Building Related Illness (BRI). Some researchers divide cases into two categories (SBS and BRI), depending on the symptoms that are manifested (Besch, 1989). Nearly everyone, however, accepts the term "Indoor Air Quality." We prefer this latter term because it is descriptive of all types of nonindustrial building problems, and it implies a proactive approach to their solutions.

#### Standards

Neither the Occupational Safety and Health Administration (OSHA) nor the USAF have published standards concerning regulation of IAQ. OSHA is in the prerule making process for an IAQ standard as of September 1991 (56 Federal Register, 1991), and HQ USAF/SGPA has prepared a first draft for an AFOSH standard on IAQ. In addition, there has been some effort in Congress for several years to pass an Indoor Air Quality bill. It will probably be a few years before any of these efforts comes to fruition.

A number of federal agencies, such as the Department of Energy (DOE) and the Consumer Product Safety Commission, are actively involved in IAQ research or policy guidance, but no one agency has a clear regulatory role (Besch, 1989). The federal agencies most active in IAQ are the National Institute of Occupational Safety and Health (NIOSH) and the Environmental Protection Agency (EPA), both of which publish guidance, case studies, and summaries of their findings (DHHS-NIOSH, 1989; EPA, 1991).

The only United States consensus standard on IAQ is from the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). ASHRAE Standard 62-1989, Ventilation for Acceptable Indoor Air Quality, makes some important contributions to IAQ investigations, but is most useful as a tool for the Heating, Ventilating, and Air-Conditioning (HVAC) experts. The standard describes two procedures for providing acceptable air quality and includes design criteria for HVAC systems.

Perhaps the most important contribution from ASHRAE 62-1989 is its definition of acceptable indoor air quality as "air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction."

ASHRAE also has published Standard 55-1981, Thermal Environmental Conditions for Human Occupancy, which describes thermal conditions acceptable to 80% or more of typical office workers.

Several international organizations have published standards or guidelines for IAQ. These organizations include WHO, the Nordic Committee on Building Regulations (NKB), the Swedish Council for Building Research (Johnson et al., 1991; Berglund and Lindvall, 1991), and the Ontario Ministry of Labour (MOL) (Rajhans, 1989). These standards primarily set concentration limits for air contaminants, with values similar to the U.S. EPA National Ambient Air Quality Standards (NAAQS). The most recent and comprehensive international standard is NKB Publication 61E, Indoor Climate - Air Quality (NKB, 1991), which discusses ventilation systems in detail.

Currently there are two issues regarding standards that are hotly debated among IAQ researchers. The first issue concerns the purpose behind regulating indoor air. Many researchers, such as Fanger (1991), believe indoor air should be regulated to satisfy both health and comfort requirements. Others such as Sundell (1991) emphatically state that improvement of health should be the primary/only concern of IAQ regulation. Sundell cites health deterioration of epidemic proportions to illustrate his concern, such as the doubling of asthma and allergic rhinitis cases in Scandinavia over the course of only 10 years. In our opinion, both health and comfort requirements should be considered in resolving IAQ complaints. Health concerns should receive emphasis because every worker has a right to a healthy work environment, yet comfort concerns (such as drowsiness or cold temperatures) should also be stressed for productivity and morale reasons.

The second controversial issue concerns setting chemical exposure limits for office work. ASHRAE (1989) recommends using one-tenth of the Threshold Limit Values (TLVs) of the American Conference of Governmental Industrial Hygienists (ACGIH, 1991) as standards for nonindustrial workers. On the other hand, both the MOL and the NKB state that occupational standards or fractions of them are not relevant in nonindustrial settings. The ACGIH agrees with the latter assessment and so do we.

## Medical Implications

Symptoms of poor IAQ can vary depending on the problem in a building. However, the typical outbreak of IAQ includes "core" symptoms of lethargy (sleepiness, fatigue); mucous membrane irritation (dry throat, stuffy or running nose); headache; eye irritation (dry, itchy, watery, inability to wear contact lenses); and dry, itchy skin or rash (Lyles et al., 1991). Other symptoms encountered may be frequent coughing or sneezing, dizziness, nausea, persistent colds or sinus congestion, chest tightness or difficulty breathing, difficulty concentrating, flu-like symptoms, and an unusual taste or odor (Jones, 1990; Burge and Hoyer, 1990). In addition, some specific diseases have been linked to building occupancy, such as hypersensitivity pneumonitis, humidifier fever, allergic asthma, and allergic rhinitis (Burge and Hoyer, 1990).

Jones (1990) theorizes that there are at least two subsyndromes of IAQ. The first subsyndrome predominant in new buildings and probably caused by chemical sources, is characterized by dry, irritated eyes, nose and throat; fatigue; headache; and sometimes nausea or dizziness. The second subsyndrome (probably caused by bioaerosols) is predominant in older buildings. This subsyndrome consists of such symptoms as itchy, watery eyes; itchy, congested, runny nose; and sometimes wheezing, chest tightness or flu-like symptoms. This theory is bolstered by Anderson (1991) who reports that chemicals such as volatile organic compounds (VOCs) affect the neurological centers of the brain giving rise to fatigue, irritation of the eyes and airway, and increased heart and breathing rates.

Lyles et al. (1991) define an IAQ or SBS problem with two requirements: there must be excessive reporting of one or more of the above symptoms by building occupants, and the symptoms must be work related. Burge and Hoyer consider "excessive" to mean 20% or more of the building population. Jones describes "work related" as a pattern of increasing severity and/or number of symptoms during the workday followed by rapid improvement and relief of symptoms within a short period after leaving work.

## Our Experience

The Occupational Medicine Division at the Armstrong Laboratory conducted IAQ surveys of 46 government office buildings during the period of January 1985 to January 1992. All buildings surveyed were by request, because there was an unsolved IAQ problem. These buildings are located in every region of the United States. Worker populations ranged from 10 to over 2,000 persons. The year of construction of the buildings is roughly split evenly among the five decades from the 1940s to the 1980s. One-half of the buildings were used for the same purpose as originally designed with only minor modifications. The other half were substantially modified or converted from a warehouse, mainframe computer center, or light industrial complex. A no-smoking policy existed in more than 80% of the buildings at the time of our surveys.

The table summarizes our findings of the major causes of IAQ problems in the buildings we surveyed. Our collection of observations and air sampling data show the three most frequent sources of unacceptable IAQ are: inadequate design and maintenance of air handlers, shortage of fresh air, and low relative humidity. The rates of occurrence shown in the table indicate that we usually find more than one major problem source in a building.

TABLE. AL/OEM IAQ Experience With 46 Office Buildings

| Cause | Selected Subcauses | Selected Subrates(%) | Overall Rate(%) |
|---|---|---|---|
| A. Inadequate Design or Maintenance of HVAC | | | 70 (32/46) |
| | A1. Mold | 47 (15/32) | 33 (15/46) |
| | A2. Temp Control | 44 (14/32) | 30 (14/46) |
| B. Insufficient Fresh Air | | | 54 (25/46) |
| C. Low Relative Humidity | | | 39 (18/46) |
| D. Poor Housekeeping/ Chemical Source in Work Space | | | 30 (14/46) |
| E. Contamination Source in Air Handler | | | 26 (12/46) |
| | E1. Insulation | 58 ( 7/12) | 15 ( 7/46) |
| F. Poor Circulation in Work Space | | | 17 ( 8/46) |
| G. Mold Sources in Work Space | | | 15 ( 7/46) |
| H. Smoking | | | 13 ( 6/46) |
| I. Stress/Poor Management | | | 11 ( 5/46) |

In a pamphlet by NIOSH (1989), building air quality problems were categorized by origin of the source of the problem. NIOSH listed only one major problem source per building. The categories of problems NIOSH recognized are inadequate ventilation (52%), chemical (17%), outside contamination (11%), microbial contamination (5%), building fabric contamination (3%), and unknown sources (12%). Our experience is largely in agreement with that of NIOSH, except that we have been able to identify at least one major problem source in 100% of the buildings compared to an 88% rate by NIOSH, and we have encountered microbial contamination in nearly 50% of the buildings compared to a 5% rate by NIOSH.

## Factors Influencing Indoor Air Quality

There are many theories about the causes of IAQ-related symptoms. The causes most implicated in the literature include comfort parameters such as carbon dioxide ($CO_2$) concentration, relative humidity, temperature, and occupant density; contaminants such as biological aerosols, dust and fibers, VOCs, tobacco smoke, combustion products, ozone, pesticides, asbestos, and radon; and problems with the operation or maintenance of the ventilation system (Burge and Hoyer, 1990). Each of these causes will be discussed in more detail later. To supplement this discussion, Appendix A contains a chart of IAQ causative agents cross-referenced by their acute effects, as reported by IAQ investigators.

Carbon Dioxide and Fresh Air

In our experience, $CO_2$ concentration is a useful indicator of inadequate make-up (fresh) air. We also believe that concentrations above 600 parts per million (ppm) are the cause of some specific IAQ irritations and have found some excellent correlations. The intensity of the symptoms and the number of people experiencing them is correlated with the level of $CO_2$. In our experience, between 15% and 33% of the population will have symptoms when the level is between 600 and 800 ppm. Roughly one-third to one-half become symptomatic between 800 and 1,000 ppm, and virtually everyone will have some or all the symptoms when the level is above 1,500 ppm.

ASHRAE 62-1989, on the other hand, states that "comfort (odor) criteria are likely to be satisfied if the ventilation rate is set so that 1,000 ppm $CO_2$ is not exceeded." Other organizations which also recommend 1,000 ppm $CO_2$ are the Swedish Council for Building Research (Johnson et al., 1991), the Ontario MOL, the WHO, and the Japanese government (Rajhans, 1989). Some researchers recommend lower limits. Quinlan et al. (1989) recommends a limit of 800 ppm, and Rajhans (1983) and Strindehag et al. (1990) recommend a limit of 600 ppm.

ASHRAE 62-1989 points out that a concentration of 1,000 ppm $CO_2$ is not considered a health risk. Many IAQ researchers unfortunately interpret "no health risk" to mean the same as "no physiological effect," and waste their resources looking for a mystery contaminant that is causing discomfort in workers. On the contrary, Pritchard (1976) reports that the human body is very sensitive to the incoming concentration of $CO_2$. Slight changes from the ambient concentration of 300-400 ppm will cause a compensatory increase in the breathing rate. Burge and Hoyer (1990) report that headache, drowsiness, difficulty concentrating, and dizziness are associated with elevated concentrations of $CO_2$. Rajhans (1983) adds eye irritation, a sensation of stuffy or stale air, and fatigue to this list. Wallingford (1986) reports that one should expect occasional complaints at $CO_2$ concentrations of 600 to 800 ppm, more complaints at 800 to 1,000 ppm, and general complaining above 1,000 ppm.

To demonstrate the correlation between $CO_2$ concentration and specific complaints, we modeled human response to $CO_2$ by assuming there is a "no-effect" concentration of $CO_2$ where all persons are satisfied. We also assumed the concentration of $CO_2$ cannot rise high enough to dissatisfy everyone. Therefore, we used an equation of the exponential form to correlate our data.

We correlated $CO_2$ concentrations with percentage satisfaction, based on complaints of fatigue, drowsiness, lack of concentration, and sensations of breathing difficulty (items 9 to 12 from the questionnaire in Appendix B). "Dissatisfaction" is defined by a response of 2 (often) or 3 (always) on at least one of those four items. Figure 1 shows a log-linear regression line of data from medical interviews and questionnaires performed in 18 buildings. (Stratification of $CO_2$ concentration in some buildings allowed us to have more than one data point per building.) The equation of the regression line in the figure is:

$$S_c = 100 \cdot \exp[-0.0015 \cdot (C_s - 435)] \qquad (1)$$

where: $S_c$ = satisfaction rate (%),

and $C_s$ = steady state $CO_2$ concentration in the work space (ppm).

The correlation coefficient, $r^2$, is 0.79. Confidence limits of 95% are drawn in the figure.

An 80% satisfaction rate or better requires $CO_2$ concentrations below 580 ppm according to the model, which we round to 600 ppm. When $C_s$ is 1,000 ppm, a 42% satisfaction rate is predicted.

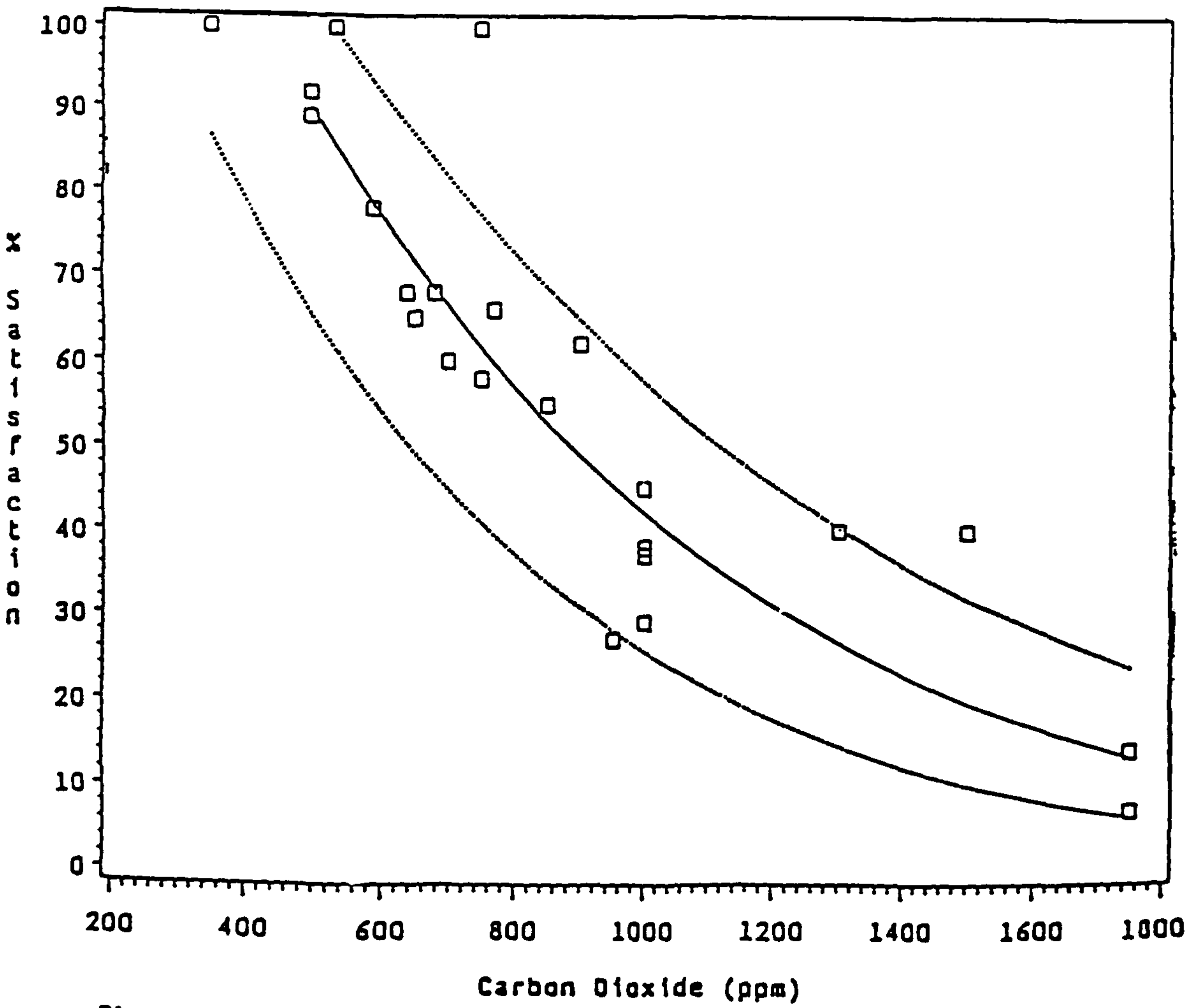


**Figure 1. Rate of satisfaction of building environment based on physiological effects of carbon dioxide.**

Workers are the only significant source of $CO_2$ in an office environment, so it is fairly simple to relate $CO_2$ concentration to fresh air flow using tracer gas theory. Using the steady state $CO_2$ concentration, the relation is

$$Q = \frac{11{,}500\ n}{C_s - C_a} \qquad (2)$$

where: Q = fresh air flow rate (cubic feet per minute, cfm),

n = the number of persons served by the air handler,

$C_s$ = steady state $CO_2$ concentration in the work space (ppm),

$C_a$ = the concentration of $CO_2$ in the ambient (outdoor) air (ppm),

and 11,500 is a constant based on the average human $CO_2$ generation rate of 0.0115 cfm per office-worker. This constant comes from ASHRAE 62-1989, which assumes a breathing rate of 9 liters of air per minute and a concentration of $CO_2$ in the expired breath of 37,000 ppm.

We have verified this equation in several buildings. We use this equation to calculate the fresh air flow required per person to keep the $CO_2$ concentration at 600 ppm or below. The average outdoor concentration of $CO_2$ we find on surveys is 325 ppm. Thus, Q/n = 11,500/(600-325) = 42 cfm/person.

Using a similar equation, ASHRAE recommends that a minimum of 20 cfm/person of fresh air be provided in office settings to achieve 1,000 ppm $CO_2$ or lower. Before 1989, ASHRAE's recommendation was a minimum fresh air flow rate of 5 cfm/person. This smaller figure is still common in state or local building codes, although many are changing to 20 cfm/person (Offermann and Gilbertson, 1991). In either case, a building designed to just meet the minimum fresh air flow recommendations of ASHRAE is an excellent candidate for $CO_2$-related complaints.

Only one other organization makes fresh air flow recommendations substantially different from ASHRAE. The Swedish Allergy Commission recommends a fresh air flow of 30 cfm/person for buildings with average emissions and 60 cfm/person in buildings with high emissions (Johnson et al., 1991).

A simple method of guaranteeing enough fresh air to a work space is to measure and control the carbon dioxide level in the return (exhaust) air chamber of the HVAC air handler. At least two companies have begun marketing carbon dioxide control systems.

In summary, our experience indicates that 1,000 ppm $CO_2$ is too high to satisfy 80% of the population, as ASHRAE asserts. Our observations show that $CO_2$ has physiological effects at levels above 600 ppm, which lead to discomfort and dissatisfaction with the environment. We recommend that the $CO_2$ concentration not exceed 600 ppm and that a minimum of 40 cfm/person of fresh air be provided to satisfy this requirement. If the $CO_2$ concentration exceeds 600 ppm, one can expect to find complaints of drowsiness, fatigue, difficulty concentrating, and difficulty breathing.

## Relative Humidity

In our experience, relative humidities below 40% cause specific physiological effects which lead to discomfort and dissatisfaction with the environment. Symptoms include dry and sore nose and throat, bleeding nose, sinus and tracheal irritation, dry scratchy eyes, inability to wear contact lenses, and dry itchy flaking skin. The number of persons affected increases as the relative humidity decreases below 40%. Quinlan et al. (1989) and Lyles et al. (1991) report similar symptoms.

The inability to wear contact lenses in a dry building results from the loss of fluid from the surface of the eye to the too dry atmosphere. The loss of lubrication which results causes irritation and irritative conjunctivitis. This irritation enhances the possibility of infection. Even without contact lenses the eyes burn, feel dry, irritated, and itchy.

Low relative humidity also contributes to an increase in respiratory illness by weakening the defense provided by the mucous membrane. There are many examples in the literature which support the increased opportunity for infection inside buildings with low relative humidity (Kreiss, 1989; Brundage et al., 1988; Mosher, 1987; Morey and Woods, 1987). A significant side effect of respiratory illness that often signals a low humidity problem is headache from sinus congestion.

To model human response to low relative humidity, we used the same technique as used for $CO_2$ earlier. We assume there is a "no-effect" relative humidity where all persons are satisfied, but there is no relative humidity so low that all persons are dissatisfied. Again, we use an equation of the exponential form.

We correlated relative humidity measurements with percentage satisfaction, based on complaints of nasal problems, sinusitis, eye irritation and itching, dry and itchy skin, and headaches (items 2, 5, 7 and 8 on the questionnaire in Appendix B). "Dissatisfaction" is defined by a response of 2 (often) or 3 (always) on at least one of those four items. Figure 2 shows a log-linear regression line of data from medical interviews and questionnaires performed in 20 buildings. (Stratification of relative humidity in some buildings allowed us to have more than one data point per building.) The equation of the regression line in the figure is:

$$S_r = 100 \cdot \exp[-0.0245(72 - R_s)] \quad (3)$$

where: $S_r$ = satisfaction rate (%),

and $R_s$ = work space relative humidity (% RH).

The correlation coefficient, $r^2$, is 0.49. The 90% confidence limits are drawn in the figure. The correlation is weak, but we believe this is because HVAC systems do not control humidity. In other words, while the questionnaire responses are based on the prevailing humidity in a building, the relative humidity we measured on a particular day may not have been indicative of the prevailing humidity.

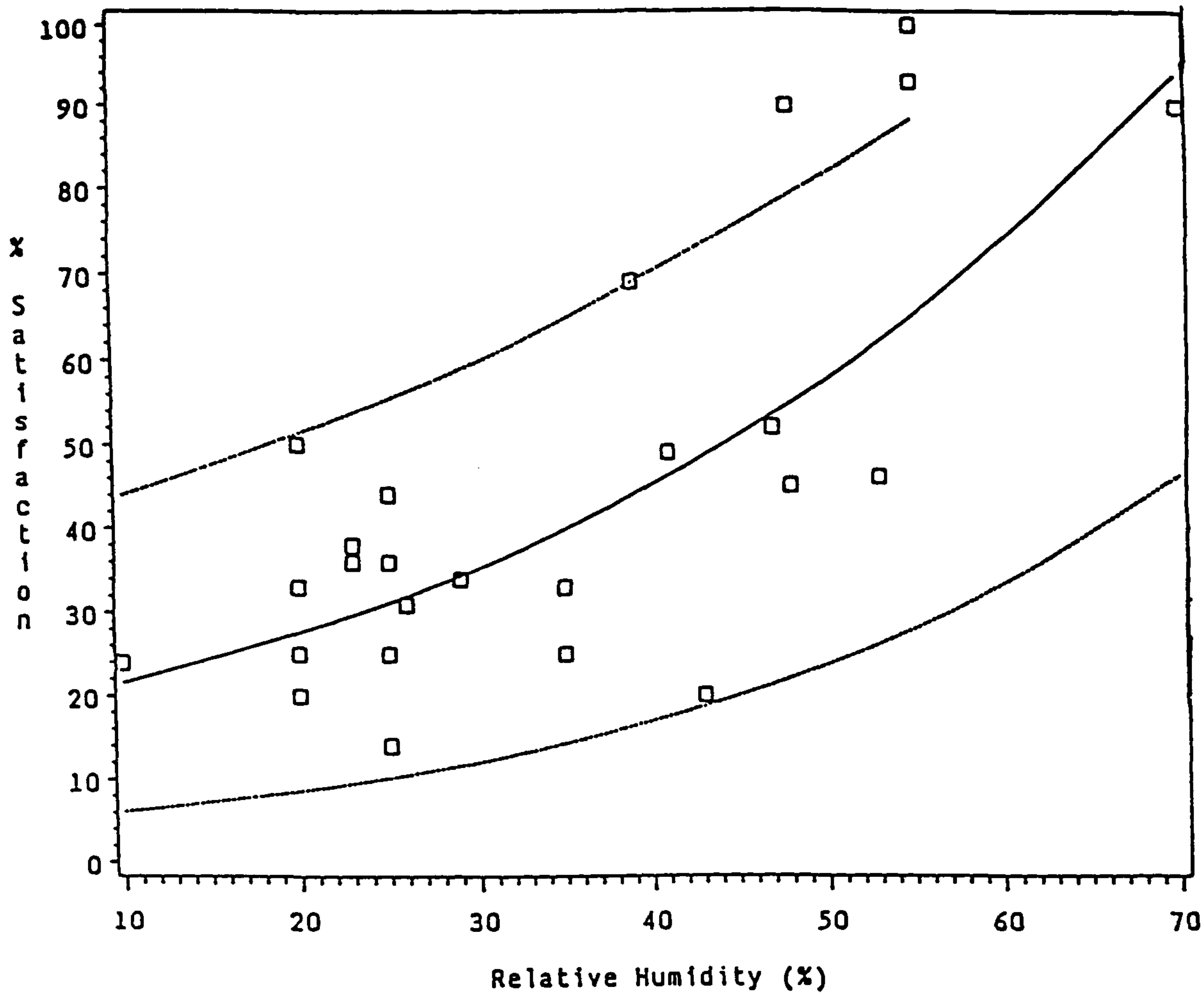


**Figure 2. Rate of satisfaction of building environment based on physiological effects of relative humidity.**

An 80% satisfaction rate or better is predicted by the equation when the relative humidity is above 63%. While the data shown is not convincing enough to flatly recommend a relative humidity of 63%, it is obvious from Figure 2 that relative humidities below 40% cause strong dissatisfaction with the environment.

At the other end of the spectrum, we have found relative humidities above 65% cause other problems. Carpets, curtains, furniture, etc. can absorb enough moisture at 65% relative humidity to promote microbial growth. Therefore, we recommend controlling the relative humidity in an office in the 40% to 60% range.

ASHRAE 55-1981 recommends for thermal comfort that the dew point be kept between 35°F and 62°F, which is the equivalent of 30% to 60% relative humidity at their recommended operative temperatures. ASHRAE 62-1989 also states that relative humidities from 30% to 60% are acceptable for office environments. It warns against high humidity (above 70%) since fungal contamination begins to appear at this moisture level. Johnson et al. (1991) report that VOCs are emitted at greater rates in humidity above 70%.

We believe it is important to have humidity control devices in HVAC systems since the range of acceptable humidities (40% to 60%) is narrow and in most parts of the country, "natural" humidification does not keep a building within this range all year. However, there is a USAF policy prohibiting the inclusion of humidity control devices when control would be for human comfort only. Reasons for this are: (1) the sensing devices require very extensive maintenance and (2) dust interference can make a building humidity worse.

We have not found literature sources that advocate humidity control in general for office buildings. The NKB (1991) recommends humidification efforts only if the humidity drops below 20%, although they acknowledge that buildings with humidity controls have fewer dry air complaints.

To increase humidity, both ASHRAE 62-1989 and Morey and Shattuck (1989) recommend using steam in an air handler, but caution that chemically treated steam should be avoided and care should be taken not to wet any interior insulation downstream of the steam pipe. Offermann and Gilbertson (1991) recommend enclosing the steam pipe with a grid that captures all condensation and drains it out of the air handling unit. At least one company has developed a cool mist (ultrasonic) humidification unit which doesn't wet surfaces downstream and is therefore an acceptable alternative to steam.

In summary, we recommend relative humidities of 50% $\pm$ 10% and the installation of humidity control systems to meet this requirement when necessary. If the humidity is consistently below 40%, one can expect complaints of dry itchy skin, irritated eyes, nose and throat, sinus congestion, and headaches. If the humidity is consistently above 70%, one can expect mold growth and allergic reactions.

Temperature

In our experience, office workers are tolerant of dry bulb temperatures between 20°C (68°F) and 24.4°C (76°F). HVAC systems are designed to control temperatures within this range, and most do a good job on the average. However, we often find parts of a building with wide temperature variations over short periods of time, such as cold blasts of air coming out of supply air diffusers. Temperature variations in an indoor work environment can cause significant worker dissatisfaction. We have performed surveys where more than 50% of the workers complain of being too cold, and more than 50% of the same workers complain of being too hot.

We also find significant temperature dissatisfaction among workers in buildings where thermostats are nonexistent or "tamper-proofed," even if the air temperature is reasonably satisfactory. Denying temperature control to workers can have great effects on morale. Some companies have realized this and have begun marketing individual control systems which give each worker dials on his desk to moderate heat and cooling. While we don't necessarily recommend such systems, we stress that giving workers some control over their environment can help boost morale.

ASHRAE 55-1981 offers the most comprehensive picture of thermal comfort. ASHRAE uses "operative temperature" in setting its limits. The operative temperature takes into account radiant temperature sources and is approximately equal to the average of the dry bulb temperature and the radiant temperature when the air speed is less than 0.4 meters per second (m/s) [80 feet per minute (fpm)] and the radiant temperature is less than 50°C (120°F). This operative temperature applies to most office buildings. ASHRAE recommends summer operative temperatures of 22.7°C to 26.1°C (73 to 79°F) and winter operative temperatures of 20°C to 23.6°C (68 to 74.5°F) in offices. The difference in seasons occurs because ASHRAE assumes persons in the winter will be wearing more clothing, such as sweaters and heavier pants. Thus, "summer" and "winter" settings should depend locally on what people ordinarily wear to work, not strictly on the calendar definitions of summer and winter.

Other factors reported in ASHRAE 55-1981 that affect human perception of "too hot" or "too cold" are: high radiant temperatures, fluctuations in temperature of more than 2.2°K (4°F) per hour, air movement greater than 0.25 m/s (50 fpm) in the work space, a temperature difference from foot to head of more than 3°K (5°F), and radiant asymmetry from any direction (above, below, sideways) caused by a very warm or very cold surface, such as a radiator or window. Johnson et al. (1991) report that the effects of high temperatures are headache, fatigue or lethargy, and a sensation of dry air. They report the effects of cold temperatures are clumsiness and complaints of draftiness and being chilly.

In summary, temperatures outside of the comfort range described by ASHRAE and conditions of high air flow, high radiant heat, or large changes in temperature can lead to significant complaints of being too hot or too cold. Giving workers some control over temperature (e.g., via access to thermostats) can help improve morale.

Occupant Density

We have found that giving workers enough space is essential to their comfort and morale. $CO_2$ concentrations, odor, and relative humidity all will increase with occupant density (Morey and Shattuck, 1989). In addition, as the occupant density increases, the heat load from people and their office equipment can increase beyond the cooling capacity of the air conditioning system.

Air Force Manual 86-2, Standard Facility Requirements (1983), states that each occupant in an office setting should receive no less than "115 $ft^2$/person of net floor area and no more than 130 $ft^2$/person." ASHRAE 62-1989 assumes offices will have a minimum of "140 $ft^2$/person." State and local building codes generally state a minimum of "100 $ft^2$/person," but most commercial office buildings actually provide over "200 $ft^2$/person" (Offermann and Gilbertson, 1991). Occupant densities should be determined for rooms that look crowded and not as an average for a whole building.

Bioaerosols

As shown in the table on page 5, we have found sources of mold in a building to be a major cause of IAQ complaints in almost half the buildings we surveyed. Woods (1989) cites two independent studies in which microorganism contamination was a factor of poor IAQ in 45% of buildings investigated. NIOSH has reported microbiological contamination as the major cause of problems in 5% of the buildings it has surveyed for IAQ (DHHS-NIOSH, 1989).

Workers in bioaerosol contaminated buildings complain of musty odors and allergic or asthmatic reactions confined to the building. We have found that bioaerosol contamination inside buildings results from poorly maintained HVAC systems, high relative humidity, water soaked material (ceiling tiles, walls or carpets), and sick people transmitting viruses in a highly recirculated air stream. Another source of contamination, although to a lesser degree, is agricultural. Farmers harvesting crops containing fungal spores can aerosolize the spores which may find their way into the building's ventilation system.

Burge and Hoyer (1990) describe two types of ill effects from bioaerosol contamination. One ill effect is an increase in infectious disease because of high recirculation of air. Diseases linked to buildings in this regard are influenza, the common cold, measles, rubella, chicken pox, and tuberculosis (Burge, 1989). Kreiss (1989) describes other diseases not ordinarily communicable as becoming epidemic in specialized buildings such as hospitals and laboratories. Brundage et al. (1988) reported the transmission rate of respiratory disease in new, air-tight, army barracks to be 50% to 250% greater than in old style barracks which were more open.

The other type of bioaerosol effect (which is more common) is an allergic reaction which can lead to hypersensitivity pneumonitis, allergic rhinitis, and allergic asthma. This effect is primarily caused by microorganisms such as mold spores or bacteria that have accumulated in the ventilation system.

Burge (1989) explains environmental microorganism contamination as a three-step process. First, an organism must be able to enter the ventilation system. Second, there must be an amplification site which will promote growth of the organism to levels that will cause problems. Finally, dissemination (contaminants becoming airborne) must take place. Standing water, some other source of wetness, and/or excessive dirt in a ventilation system all act as successful amplifiers and disseminators of bacteria and fungi (Burge and Hoyer, 1990).

There are no standards regulating microorganisms in the environment (Burge and Hoyer, 1990). Air sampling is difficult, expensive, and usually unnecessary because a contamination site is usually obvious. It usually costs more to sample a suspected contamination site than it does to clean it up. Burge and Hoyer say that air sampling for bioaerosols is useful only when there is clear medical evidence of hypersensitivity reactions and an obvious source of contaminant is not found. Appendix C contains a protocol for bioaerosol sampling, if the decision to sample is made.

In our bioaerosol sampling experience, concentrations in excess of 200 colony forming units per cubic meter (cfu/m$^3$) usually signify unacceptable contamination. However, the most effective comparisons are with control areas, such as the outdoors and an unaffected building. The Ontario MOL sometimes samples stagnant water and dust within an HVAC system. They report levels of concern as 100,000 colony forming units per milliliter (cfu/mL) of bacteria in stagnant water or slime, and one million cfu/gram of dust.

Shelton and Morris (1991) report normal indoor levels of molds to average 60 cfu/m$^3$ of sampled air, and indoor levels of bacteria average 80-100 cfu/m$^3$. Normal outdoor levels of molds are 200 cfu/m$^3$ and normal outdoor levels of bacteria are 60-80 cfu/m$^3$. Shelton and Morris also report that among the bioaerosols of concern are Cryptococcus species (sp.) and Bacillus anthracis because they attack healthy persons, and Pseudomonas sp., Aspergillus fumigatus, and Legionella sp. in hospitals because they affect immunocompromised individuals. Common molds in the environment are Cladosporium sp., Aspergillus sp. (other than fumigatus), and Alternaria sp. Common bacteria in the environment include Bacillus sp. (other than anthracis), and Corynebacterium sp.

Legionnaire's disease is often a concern among occupants of a building with bioaerosol contamination. However, Legionnaire's disease is a rare occurrence because of the steps required for infection (Offermann and Gilbertson, 1991). Legionella sp. commonly resides in water, but the water must stagnate at a temperature between 21.1 and 50°C (70°F and 120°F) to have amplification. It is rare for water to stagnate in a ventilation system in this temperature range, but it can happen within domestic water systems and cooling towers. The dissemination step requires the water to aerosolize and move into the breathing zone. Generally this process occurs only with infrequently used showers or cooling towers sited extremely close to the air intakes of an HVAC system. The final step required is that a person must be immuno-compromised to be susceptible to the disease. An example outbreak of Legionnaire's disease occurred recently in Richmond, California. The water in a janitor's closet was kept at about 50°C (120°F), although the recommended minimum domestic water temperature is 60°C (140°F). The water system was found to contain Legionella sp. in excess of 1,000 cfu/mL. The janitors unknowingly aerosolized the Legionella sp. by spraying the water into buckets. Eleven persons (all janitors) were diagnosed with Legionnaire's disease (Offermann and Gilbertson, 1991).

In summary, bioaerosol contamination can be a significant health threat in buildings, causing allergic and asthmatic reactions and eventually hypersensitivity pneumonitis and humidifier fever if left untreated. Sources of bioaerosols are poorly maintained ventilation systems and any porous material that has become soaked. While we have minimal control over most bioaerosols in the outdoor environment, in the indoor environment, we have access to the techniques and resources for their identification, measurement, and prevention or minimization.

### Dust and Fibers

When dust or fiber concentrations are high and humidity low, we have found enhanced skin problems. The skin dries when the humidity is low. This dryness decreases its resistance to irritating effects. We have surveyed an office where fiberglass fibers caused such an irritating rash that workers were certain the office was infested with fleas. Burge and Hoyer (1990) also report that fiberglass can cause epidemics of rash and itching. If video display terminals (VDTs) or other sources of static electricity are present, irritation of the skin (particularly of the face around the eyes) often occurs. The irritation is caused by the VDT attracting dust particles and later propelling them outward to the operator.

The NKB (1991) reports that typical outdoor dust levels are between 5 and 30 micrograms per cubic meter ($\mu g/m^3$). They report that dust levels inside buildings typically run about 100 to 200 $\mu g/m^3$. It is noteworthy that the EPA has established National Ambient Air Quality Standards (NAAQS) for total particulate matter in outdoor air of 150 $\mu g/m^3$ over any 24-hour period and 50 $\mu g/m^3$ as an annual average.

Poor housekeeping sometimes is the cause of high dust levels, but dust and fibers build up in an office building primarily through the ventilation system. More often than not, the air filters we find in air handlers have less than 20% capture efficiency. Thus, dust from the outdoors is allowed to enter and collect in the system. Also, the current trend in air handlers is to line the inside of ductwork with fiberglass insulation rather than wrap it around the outside. After just a few years, the interior insulation deteriorates and releases fibers into the air. HVAC maintenance crews rarely give a second thought to removing or replacing damaged insulation.

Recently, there have been stories in the media that fiberglass is as carcinogenic as asbestos, or worse. From our knowledge of aerosol behavior, asbestos, and fiberglass, fiberglass does not break into the same size and shape of fibers as asbestos and, therefore, is not a cancer-causing hazard. It is, however, a severe irritant to the skin and can cause respiratory irritation if inhaled in high enough concentrations.

In summary, high concentrations of dust and fibers cause skin and respiratory system irritation. The most common reasons for high concentrations are low efficiency particulate filters and deteriorating fiberglass insulation in the air handler.

Volatile Organic Compounds (VOCs)

VOCs have been widely implicated as a primary source of irritation in office buildings, with formaldehyde the compound of most concern (Burge and Hoyer, 1990). Other VOCs commonly found in the workplace are heavy alkanes (7 to 11 carbons in a hydrocarbon chain), aromatics (toluene, xylene, ethylbenzene), and cyclic compounds (cyclohexanol, butylcyclohexane)(Lyles et al., 1991). The NKB reports the range of VOC concentrations measured in offices have been from 0.05 to 1.3 milligram per cubic meter ($mg/m^3$), compared to outdoor levels of 0.01 to 0.04 $mg/m^3$. Higher concentrations of VOCs will exist in new buildings or in buildings with new furniture or paint. Such levels will dissipate within a few weeks unless the air is highly recirculated.

Quinlan et al. (1989) report the symptoms of low-level formaldehyde concentrations to be headache and irritation of the eyes, nose, and throat. Irritation for many people begins at about 0.1 ppm. Molhave et al. (1986) conclude that persons exposed to low concentrations of VOCs are likely to complain of eye and mucous membrane irritation, an unpleasant odor, a sensation of temperature increase, and difficulty concentrating. The concentrations Molhave et al. studied were 5 $mg/m^3$ and 25 $mg/m^3$, or 4 to 100 times the typical concentrations found in offices by the NKB. No one has done a rigorous study of VOC effects at levels below 1 $mg/m^3$. Other reported symptoms of elevated VOC concentrations are headache, nausea, dizziness, fatigue or lethargy, and respiratory irritation (Quinlan et al., 1989; Lyles et al., 1991; Anderson, 1991). The chronic effects of low-level exposures of VOCs are unknown (Burge and Hoyer, 1990).

The symptoms associated with VOC concentrations above 5 $mg/m^3$ are nearly indistinguishable from symptoms associated with elevated $CO_2$ concentrations and low relative humidity. In addition, each of the three agents shares a common cause (i.e., high recirculation and little or no fresh air). Therefore, it can be difficult to sort out whether the VOCs or the combination of high $CO_2$ and low relative humidity is causing problems. Frankly, we have not been overly concerned about VOCs to this point, because the solution to eliminating VOC contamination is usually the same as lowering $CO_2$ concentrations and increasing humidity (i.e., reduce recirculation and increase the fresh air flow). We have begun testing for the presence of VOCs and formaldehyde in IAQ surveys, however, and will publish a report if any interesting developments arise.

Formaldehyde sampling can be accomplished by hanging 3M 3721 passive dosimeters in the area for a couple days. There is yet to be a standard method for evaluating "total VOCs" since there are so many compounds present in low concentrations. One method uses a combination of gas chromatography and mass spectrometry to quantitatively identify each component. A less rigorous, but much less expensive, method is to use gas chromatography and flame ionization detection calibrated with a typical VOC such as toluene (Molhave et al., 1986).

In buildings with high levels of VOCs, Burge and Hoyer and others have advocated "baking out" the VOCs by raising the temperature above 26.6°C (80°F) for a week to a month during unoccupied periods. However, Offermann and Gilbertson (1991) have found baking out not to be that successful, and it tends to put cracks near windows and to damage the furnishings. Offermann and Gilbertson recommend ventilating the building with 100% outdoor air instead for at least a week.

Smoking

There have been many cases recently involving secondhand smoke and the effects it has on building occupants. NIOSH released an 18-page document in July 1991 titled "Current Intelligence Bulletin No. 54, Environmental Tobacco Smoke in the Workplace" (1991). This document states that occupants should not be exposed involuntarily to tobacco smoke in the workplace. Their study involved reviewing such research as a 1986 Surgeon General's report documenting a 30% increase in risk of lung cancer in nonsmokers exposed to tobacco smoke. AFR 30-27, Smoking in Air Force Facilities (July 1988), bans smoking inside Air Force facilities. According to our studies, this ban has greatly improved indoor air quality for the military.

Tobacco smoke has been associated with a number of acute responses. Effects include eye irritation, mucous membrane irritation, asthma and hypersensitivity reactions, headache, respiratory irritation, drowsiness, nausea, loss of appetite, an increased rate of respiratory illness, nonallergic rhinitis, and of course an unpleasant odor (Rajhans, 1989; Johnson et al., 1991; Burge and Hoyer, 1990). In addition, the International Agency for Research in Cancer (IARC) has concluded that passive smoke inhalation raises the risk of several forms of cancer (Rajhans, 1989).

The Ontario MOL, Lyles et al., Burge and Hoyer, and the Swedish Council for Building Research all advocate banning smoking from office buildings, and demand a separate ventilation system if smoking areas are allowed. Air Force Regulation 30-27 has the same requirements for all Air Force buildings.

Johnson et al. have determined that the concentration of carbon monoxide (CO) is a useful indicator of excessive tobacco smoke in buildings where people smoke. About 20% of the nonsmoking population suffers severe eye irritation from smoke particles whenever the CO concentration exceeds 2 ppm.

## Combustion Products

If there are boilers, fuel burning engines, parking garages, or busy streets inside a building or near the fresh air intake of an air handler, they are a potential source of IAQ complaints (Quinlan et al., 1989). The three likeliest combustion products are carbon monoxide (CO), nitrogen dioxide ($NO_2$) and sulfur dioxide ($SO_2$). Carbon monoxide is odorless and can cause fatigue or drowsiness, nausea, headache, and difficulty in breathing. The nitrogen and sulfur dioxides have annoying, characteristic odors and cause respiratory system irritation, plus eye and mucous membrane irritations.

When sampling for these combustion products, the most useful standards for comparison are the NAAQS published in 40 CFR 50 (1991) (annual averages of 0.03 ppm for $SO_2$ and 0.055 ppm for $NO_2$, a 24-h average of 0.14 ppm for $SO_2$, and an 8-h average of 9 ppm for CO). Comparison to the current outside concentration is also useful. If there is a problem with combustion products, the solution is to properly ventilate the combustion source or to move the fresh air intake.

## Other Contaminants and Contributors

Other contaminants that have been implicated in IAQ surveys are ozone, pesticides, asbestos, and radon (Burge and Hoyer, 1990). Although these contaminants are the least likely sources of problems, they are the contaminants most on the minds of building occupants. In addition, poor lighting and poor positioning of VDTs can cause "building-related" complaints not due to the air quality.

Ozone results from electrostatic reactions. The possible sources of ozone in an office environment are photocopy machines, electrostatic air cleaners, and electric motors badly out of tune. Ozone odor can be detected at 0.02 ppm, but it takes at least 0.1 ppm to cause discomfort in workers, such as respiratory irritation, eye and mucous membrane irritation, and headache.

Pesticide application will cause short-term irritant effects in some individuals, but if overused or used in a building with high recirculation of air, the irritation can last for months. When overused, pesticides and their inert carriers (often petroleum products) can be absorbed by carpets, wall fabrics, and ceiling tiles, and then will be desorbed back into the air at a later time (Burge and Hoyer, 1990).

Asbestos and radon have only long-term chronic effects, and, therefore, are of no concern from an IAQ perspective. However, it is important to educate the workers about the true health effects of these two contaminants to alleviate their concerns. Questions about asbestos exposure can be directed to the Industrial Hygiene Branch (AL/OEMI) and questions about radon assessment and mitigation can be directed to the Radiation Services Branch (AL/OEBS).

Insufficient light, glare, and problems with work station setup (such as an improper angle on the VDT screen or wrong height for the keyboard) can cause eye strain, headaches, and back pain from poor posture. Often these complaints are incorrectly attributed to the air quality. Questions about improving the ergonomic attributes of an office can be directed to the Occupational Medicine Branch (AL/OEMO).

Influence of Ventilation System

The design and maintenance of an HVAC system has primary influence over the air quality inside a building. The table on page 5 shows that in 70% of the buildings we surveyed, some aspect of the HVAC system played a major role in the symptoms experienced by workers. In addition, many of the comfort parameters and contaminants discussed earlier are made worse by the condition of the HVAC system. For instance, HVAC systems are ideal for promoting the growth of molds because they feed on dead organic matter (dirt) and grow most rapidly in wet, dark, undisturbed places (Rajhans, 1989). Burge et al. (1987) found that the design features of a building's ventilation system correlate well with the number of IAQ symptoms. Buildings with chillers, humidifiers, or extensive ductwork had higher complaint rates because greater maintenance man-hours are required but were not provided. Buildings with many local heating or cooling units had higher complaint rates than buildings with central heat and cooling.

Unfortunately, an emphasis on energy conservation efforts and budget cutbacks has lead many to forget that the primary function of office buildings is to provide workers with a comfortable and healthy environment in which to work. Providing this environment is largely dependent on the proper design, operation, and maintenance of a building's HVAC system (Morey and Shattuck, 1989). The Ontario Ministry of Labor has concluded that the single most effective solution to IAQ problems is an adequate fresh air supply from a properly designed, operated, and maintained HVAC system (Rajhans, 1989). Moffatt et al. (1991) state that the requirements of proper ventilation should dominate design and construction decisions, not the cost of heating, cooling, or equipment.

Loftness and Hartkopf (1989) list the most notable HVAC failures as: (1) poorly maintained systems, (2) poor or nonfunctioning controls, (3) no fresh air intake, (4) no exhaust, and (5) poor placement or blockage of supply diffusers. Inevitably, these failures occur either because maintenance workers do not have the proper training or someone makes a decision without realizing the impact on the occupants. For instance, ASHRAE 62-1989, Offermann and Gilbertson (1991), and Morey and Shattuck (1989) agree that condensation pans underneath cooling coils should be designed and pitched to be self-draining. Yet, we have found countless condensation pans with standing water and microbial contamination because maintenance crews have never had the training or experience to see that pans drain properly. We often find thin fiberglass or metal screen prefilters used as the only particulate removal mechanism, because they are inexpensive. What is not considered is that prefilters are less than 20% efficient at dust removal.

Morey and Shattuck recommend paper pleated air filters or bag filters with at least 60% dust removal efficiency.

As another example, inadequate balancing of ventilation systems often leads to marked variations in temperature over short distances in a building. The temperature may vary so widely in the same location over short periods of time that the anticipation of the next cold blast after a hot period detracts from attention to work. Balancing problems of this nature occur because the control equipment responsible for directing air flow is positioned in places inaccessible for maintenance. After a time the controls become unresponsive to central control. Other obvious reasons for HVAC failures are reduction of the HVAC maintenance work force to save personnel costs and the creation of new rooms with floor-to-ceiling partitions which disrupt proper air flow patterns.

The IAQ impact of other common HVAC decisions is more subtle. For example, in many USAF buildings the HVAC system is turned off during unoccupied periods (evenings and weekends). Although this sounds like a good energy saving practice, Rajhans (1983), Morey and Shattuck, Johnson et al. and the NKB recommend against it. They cite the build-up of pollutants and humidity indoors because turning off the HVAC negatively pressurizes the building compared to the outdoors. As another example, a common design decision is to not provide operable windows in buildings. Most mechanical engineers believe that operable windows are incompatible with modern sealed, pressurized office buildings. On the contrary, windows that can be opened by the occupants have been effectively integrated with pressurized buildings and such designs can prevent a significant percentage of building IAQ problems, especially temporary temperature control or air contaminant problems (Loftness and Hartkopf, 1989).

In the near future, we intend to publish a joint report with the Air Force Civil Engineering Support Agency (AFCESA) describing common problems with HVAC systems and potential solutions.

## Energy Conservation and IAQ

Often, we find engineers from Civil Engineering resistant to increasing fresh air because this appears to defeat energy conservation efforts. Our response is two-fold: first, HVAC systems can be made energy efficient without compromising the fresh air quantity; and second, the cost of human productivity losses far outweigh any savings realized by minimizing fresh air.

### Energy Efficiency

There are at least three methods for improving energy efficiency while concurrently providing enough fresh air to a building. All three methods can be used in the same building, if desired. The least expensive to install is a carbon dioxide monitor which controls the amount of fresh air coming into a building. Moffatt et al. (1991) found that demand control ventilation of this type saved up to 10% in energy costs per year. A more effective, but more expensive, measure is to install heat exchanger equipment within the air handler. Johnson et al. state that a minimum of 50% of the heat or cooling in ventilation air can be recovered by heat exchangers. Finally, the most elaborate but effective method of energy efficiency is thermal storage (Offermann and Gilbertson, 1991). Thermal storage systems create ice during off-peak hours when energy costs little, then use this ice during peak hours to supplement the cooling capacity of the traditional air handler.

Even with a traditional HVAC system design, increasing the fresh air flow does not have as much impact on energy costs as one might suspect, assuming the system has the cooling capacity to treat the additional fresh air. The EPA found that the increase in annual energy costs by improving the fresh air flow from 2.5 L/s (5 cfm/person) to 10 L/s (20 cfm/person) was no more than 4% in any city of the U.S. and the average increase was only 2% (Teichman, 1991). Similar increases can be expected in going from 10 L/s (20 cfm/person) to 20 L/s (40 cfm/person).

## Productivity and Economic Impact

Lyles et al. (1991) summarize the overall effect of poor IAQ with the statement that "SBS is one of the most common and increasingly frequent afflictions of the office worker, leading to significant morbidity, decreased productivity, job dissatisfaction, and stress." Burge et al. (1987), in their study of over 4,000 office workers, conclude that IAQ problems are widespread throughout modern countries.

The World Health Organization has estimated that 30% of new or renovated office buildings have identifiable IAQ problems (Lyles et al., 1991). The general nature of this phenomenon translates into a huge productivity loss. Mudarri (1991) reports a New England study of 3,500 office workers in which 54% felt poor IAQ resulted in some productivity loss for themselves. Using the most conservative interpretation of this data, Mudarri estimated an overall 3% loss in national productivity, which equates to $60 billion in lost time per year. According to the National Center for Health Statistics, the average number of respiratory infections involving colds and flu is one per person per year. Tight buildings can increase that number to between 1.5 and 3.0 episodes per person per year which can double the cost of so-called energy efficient measures (Carpenter and Poitrast, 1990).

Wyon (1991) has reported some specific productivity losses. Typing productivity dropped by 30% at a room temperature of 23.8°C (75°F) compared to 20°C (68°F). His data also show assembly line production drops by 1% for each 1.1°K (2°F) variation from the ideal, and truck drivers miss 50% more signals at 26.6°C (81°F) compared to 21.1°C (70°F). Workers who had individualized control over their temperature had 69% fewer sick days than those under centralized temperature control. Wyon also found that persons not currently suffering from IAQ symptoms are 5% more productive than when they suffer two symptoms (an average figure in offices). In addition, persons suffering from 6 or more symptoms (not unusual) are 10% less productive than when they suffer from two symptoms.

This productivity loss can be directly compared to the costs of energy, operation, and maintenance for HVAC systems. Woods (1989) has figured that in an average building with "100 $ft^2$/person," the salary costs of employees are

"$\$237/\text{ft}^2$"; construction of the facility and equipping it for office work costs "$\$63/\text{ft}^2$" amortized over the life of the building; operation and maintenance costs are "$\$10/\text{ft}^2$"; and energy costs for the HVAC are "$\$2/\text{ft}^2$." A simple evaluation of the costs shows that a 5% savings in energy costs gained by reducing the amount of outside air is counterproductive if just 0.1% in productivity is lost (or 24 seconds per person per day). A 25% savings in operation and maintenance by reducing manning is counterproductive if 2.5% in productivity is lost (or 10 minutes per person per day). Mudarri (1991) and Offermann and Gilbertson (1991) have come up with very similar cost estimates for the general workforce, and we have found equivalent figures for USAF buildings.

In several buildings, we have calculated productivity loss figures based on sick leave. The average sickness absence rate reported by the Bureau of Labor Statistics is 3.6 days per person per year. Our data from "healthy" buildings in the USAF agrees with this figure. In a typical building with IAQ problems, we have found the sickness absence rate to be approximately 9 days per person per year. (Sickness absence rates are determined by collecting sick leave data from civilian timekeepers and subtracting out sick leave obviously unrelated to the building, such as pregnancy, injury, or alcohol abuse.) Based on sickness absence alone and 220 work days per year, the productivity loss in an average building with poor IAQ is (9 - 3.6)/220, or 2.5%. Add this time lost on the job suffering from IAQ symptoms, such as the 5% figure from Wyon (1991), and it becomes obvious that operating an HVAC system properly with the proper level of maintenance is more cost-effective than any attempt to save money by cutting down the fresh air or reducing the maintenance staff.

## Steps in the Investigation

### Team Players

The quality of the surveys is a reflection of the capabilities of the survey team. We believe the best approach is the team approach, and that the BEE, Occupational Health Physician/Flight Surgeon, and MPHO have specific expertise to apply to the problem. They must work closely with HVAC engineers and technicians from Civil Engineering to identify and correct problems. With appropriate team effort, quality environments can be achieved and maintained. Quinlan et al. recommend that a team include members with expertise in medicine, industrial hygiene, epidemiology, microbiology, ventilation, and building maintenance. They also believe it is important to involve management, the building manager or owner, and employee representatives. In fact, Quinlan et al. state that the most important factor in the long-term solution of building-related problems is effective ongoing communication between the investigating team and the building manager and employees. Besch and Besch (1989) put it another way: an IAQ problem should be considered a crisis and should be managed as such.

### Investigation Protocols

Several authors have published protocols for conducting IAQ investigations. Quinlan et al. (1989) and the Ontario Ministry of Labour (Rajhans, 1989) have developed comprehensive protocols, including questionnaires and checklists. Burton (1991) has published a series of articles in simple language which includes an easy investigation protocol. Our recommended protocol, based on our experience and the protocols listed earlier, can be found in Appendix D.

Steps for a successful survey include an initial walk-through evaluation of the building, self-administered questionnaires, personal interviews with the employees, air sampling, a detailed report of findings, recommendations, and follow-up visits to assess the success of the recommendations (Quinlan et al., 1989). Quinlan et al. also recommend using a cross-sectional analysis of the interviews and air sampling results to develop conclusions and test hypotheses. A cross-sectional analysis determines frequencies of symptoms by area of a building, job description, or ventilation unit and compares to air sampling results in affected areas as well as control areas. Control areas can be "healthy" buildings, or unaffected parts of buildings. The outdoor air is also a useful control (Burge and Hoyer, 1990).

We have found that the most important functions of the BEE and MPHO in any IAQ survey are education and communication. Building occupants need to know what is causing their illness and what they can do (or avoid doing) to improve their environment. The Base Civil Engineer and his HVAC technicians and engineers need to realize the impact their decisions have on air quality, need to see that the affected workers are not just chronic complainers, and need to be reminded of the strong relationship between HVAC maintenance and the comfort of workers. Management (Base and Hospital Commanders, Unit Commander, or supervisor of affected workers) must be informed about the problems the workers are having and the difficulty the civil engineers are having in meeting the needs because of low manning, budget constraints, or inadequate facilities. When all three groups know the primary causes of problems, they can communicate effectively and achieve effective results.

Survey Steps

Prior to performing any type of survey, the team must have a point of contact (POC), usually the building manager. The POC needs to provide the survey team access to the mechanical rooms, HVAC systems, roofs and other areas pertinent to the survey. The POC must be fully informed of the team needs, time requirements, and general reasons for performing the survey.

The first step (after receiving health complaints from occupants of the building) is to initiate an IAQ questionnaire (see sample, Appendix B). It is best to hand out the questionnaire to the building occupants individually and at least 2 weeks prior to the actual survey. These questionnaires are self-administered and distributed to 100% of the building occupants if 200 or fewer, and 10% to 50% of the occupants, if more than 200. The goal is to have 100 to 200 questionnaires returned.

The second step is for the team to inbrief the commanders, supervisors and HVAC maintenance engineers of the facility in question. The ideal group consists of persons who are responsible for fixing problems, persons who will find the money to pay for the fixes, and persons who can relay the survey findings to the building occupants. The inbrief should give a general idea of what the team will be doing and an estimate of the time it will take. Suggest a joint walk-through of the building with all key personnel.

The third step is to proceed with the investigation, starting with the walk-through of the facility. This walk-through should be done by the BEE, MPHO, physician, building manager and HVAC maintenance engineers. A good working relationship is necessary to ensure a good survey.

The fourth step is the medical portion. This part of the survey includes interviews and collating data from the questionnaires. Interviews should be accomplished on numbers of occupants who chose not to answer the questionnaire equal to 10% of the total building population. If this number is too large to accommodate, then the number interviewed should be equal to the number of questionnaires. If that number is still too large, a number equal to at least 25% of the total number of questionnaires should be interviewed. Questions are asked about the individuals' health histories and working conditions.

After the questionnaires are entered into a database, the information can be analyzed and the correlations with $CO_2$ and relative humidity measurements can be performed. We use the EPI-INFO Program from CDC. We run the frequencies of complaints that are in the "often and always" categories.

The IAQ problem building is typified by numerous complaints (mentioned in the Medical Implications section of this report) at all times of the workday. If symptoms are related to an increase in $CO_2$ levels, they are more noticeable late in the morning and in the afternoon.

The fifth step requires the BEE to survey the HVAC system and monitor the environment. Prior to sampling in any part of a building, a review of the HVAC plans is necessary (see Appendix D). Blueprints and occupancy rates will help to compute accurate data. Appendix E has Troubleshooting Guidelines to aid in the recognition and evaluation of IAQ problems. Appendix F lists equipment that will be useful on an IAQ survey. If the equipment is not available on base, the Industrial Hygiene Equipment Loan Program at Brooks AFB can loan it out.

The sixth step of the survey is to compile data and compose the report. Information is given on medical symptoms and their frequency, discrepancies found with the ventilation system, and sampling results. The report gives conclusions as to the relationships between symptoms and the sampling results or other observations. The report should have recommendations on how best to resolve the problems (see Troubleshooting Guidelines in Appendix E). To maximize cooperation from Civil Engineering, they should be consulted during the report phase so that realistic recommendations are developed.

The seventh step of the survey is the outbrief. This step is one of the most crucial parts of the survey because the people who show an interest in this meeting will be the people who will ensure solutions are reached. Overhead slides of sampling results and photos from the survey can add support to the recommendations. Conclude the outbrief with a list of action items that each office of responsibility will accomplish.

The eighth step is to follow up on the action items. A month or so after the survey, call or visit the building and talk to some of the people. Find out if conditions have improved after recommended changes have been made. Follow up 6 months and a year later to check on the situation.

## CONCLUSIONS

We have found that the three most frequent sources of unacceptable IAQ are: inadequate design and maintenance of HVAC systems, insufficient fresh air, and low relative humidity. Assessment of the ventilation systems, identification and evaluation of the sources of contamination and correlation of the medical data should be done as a team. Occupancy complaints should be taken seriously and surveys performed with the utmost professionalism. The information from each survey should be documented and filed for future reference. Communication is critical for the success of a good indoor air quality program. We believe the cost of construction, operation, and maintenance of an ideal system is well worth the money.

All standards, whether ANSI, ASHRAE, ACGIH or government agency, are only guidelines. Professional judgment must supersede any criteria that are proving to be inadequate. The ultimate baseline, as ASHRAE states, is human health and acceptability. Through education and communication we are learning to balance the quality of the indoor environment, increase productivity and conserve our resources.

## RECOMMENDATIONS

Our experience with IAQ problems and our findings lead us to make the following recommendations:

1. Configure air handlers to maintain $CO_2$ levels below 600 ppm [a fresh air flow rate of 20L/s (40 cfm/person)].

2. Maintain relative humidity levels between 40% and 60%.

3. Maintain temperature between 20 and 23.8°C (68 and 76°F) and follow guidelines from ASHRAE Std. 55-1981 or its updates.

4. Use the survey protocol outlined in this report and work as a team with Civil Engineering and the building manager to achieve the maximum positive results.

5. Ensure the Air Force smoking policy is in effect and smoking areas are away from the building and the fresh air intakes.

6. Check the occupancy rates of the buildings and if overcrowding is a problem, call the Safety Office to verify and help resolve this issue.

7. Use common sense approaches to the problems in all of the above recommendations and if further studies for bioaerosols, VOCs, dust and fibers, etc., seem necessary, then do them.

## REFERENCES


1. ACGIH. 1991-1992 Threshold Limit Values for Chemical Substances and Physical Agents. American Conference of Governmental Industrial Hygienists. Cincinnati, OH, 1991.

2. Air Force Manual 86-2, Standard Facility Requirements. Chapter 13, Administrative Facilities. 1983.

3. Air Force Regulation 30-27, Smoking in Air Force Facilities. 19 July 1988.

4. Air Force Regulation 161-33, The Aerospace Medicine Program. 16 Nov 1987.

5. Anderson, R. Measuring Respiratory Irritancy of Emissions. Healthy Buildings--IAQ '91, Planning, Designing, Constructing, Renovating and Occupying Buildings: Recommendations and Benefits. Organized by ASHRAE and the International Council for Building Research, Studies and Documentation (CIB). Washington, D.C. Sept 5-8, 1991.

6. ASHRAE Standard 55-1981. Thermal Environmental Conditions for Human Occupancy. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. Atlanta, GA. January 29, 1981.

7. ASHRAE Standard 62-1989. Ventilation for Acceptable Indoor Air Quality. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. Atlanta, Ga. June 29, 1989.

8. Berglund, B., Lindvall, T. (ed.). Conclusions and Recommendations for Healthier Buildings. Healthy Buildings 1988; Vol 4: Swedish Council for Building Research. Stockholm, Sweden. June, 1991.

9. Besch, E.L. Regulation and Its Role in the Prevention of Building-Associated Illness. Occupational Medicine: State of the Art Reviews. 4: 741-752, Oct-Dec, 1989.

10. Besch, E.L., Besch, H.J. Managing an Indoor Air Quality (IAQ) Problem in a Public Building. Proceedings of the ASHRAE/SOEH Conference, IAQ '89, The Human Equation: Health and Comfort, Dec 1989.

11. Brundage, J.F., Scott, R., Lednar, W., et al. Building Associated Risk of Febrile Acute Respiratory Diseases in Army Trainees. JAMA; 259: 2108-2112, 1988.

12. Burge, H.A. Indoor Air and Infectious Disease. Occupational Medicine: State of the Art Reviews. 4: 713-721, Oct-Dec, 1989.

13. Burge, H.A., Hoyer, M.E. Focus on...Indoor Air Quality. Applied Occupational and Environmental Hygiene. 5: 84-93, Feb, 1990.

14. Burge, S., Hedge, A., Wilson, S., Bass, J.H., Robertson, A. Sick Building Syndrome: A Study of 4373 Office Workers. Annals of Occupational Hygiene. 31: 493-504, 1987.

15. Burton, D.J. Engineering Control, A Series of Columns on Indoor Air Quality. Occupational Health and Safety. June, 1990-July, 1991.

16. Carpenter, D.R., Poitrast, B.J.. Recommended Carbon Dioxide and Relative Humidity Levels for Maintaining Acceptable Indoor Air Quality. AFOEHL Report 90-169. October 1990.

17. DHHS-NIOSH. Indoor Air Quality, Selected References. May, 1989.

18. EPA. Building Air Quality: A Guide for Building Owners and Facility Managers. December 1991.

19. Fanger, P.O.. Ventilation to Handle Pollution from Building and Occupants. Healthy Buildings--IAQ '91, Planning, Designing, Constructing, Renovating and Occupying Buildings: Recommendations and Benefits. Organized by ASHRAE and the International Council for Building Research, Studies and Documentation (CIB). Washington, D.C., Sept 5-8, 1991.

20. Federal Register (56) 47892. OSHA Request for Information on Occupational Exposure to Indoor Air Pollutants. Sept 20, 1991.

21. Johnson, B.G., Kronvall, J., Lindvall, T., Pettersson, B., Wallin, A., Weiss Lindencrona, H. Buildings and Health: Indoor Climate and Effective Energy Use, Summary. Swedish Council for Building Research, Stockholm, Sweden; 1991.

22. Jones, W. Horizons: Sick Building Syndrome. Applied Occupational and Environmental Hygiene. 5: 74-83, February 1990.

23. Kreiss, K. The Epidemiology of Building Related Complaints and Illness. Occ. Med. State Art Rev. 4: 575-592, 1989.

24. Liebhaber, Frank, Capt, USAF, BSC. A Procedural Guide on Sick Building Syndrome. USAFOEHL Report 87-037; March 1987.

25. Loftness, V., Hartkopf, V. The Effects of Building Design and Use on Air Quality. Occupational Medicine: State of the Art Reviews. 4: 643-665, Oct-Dec, 1989.

26. Lyles, W.B., Greve, K.W., Bauer, R.M., Ware, M.R., Schramke, C.J., Crouch, J., Hicks, A. Sick Building Syndrome. Southern Medical Journal. 84: 64-72, Jan, 1991.

27. Moffatt, P., Moffatt, S., Cooper, K. Final Report: Demand Controlled Ventilation. A Research Report Submitted to Research Division, Canada Mortgage and Housing Corporation. March, 1991.

28. Molhave, L., Bach, B., Pedersen, O.F. Human Reactions to Low Concentrations of Volatile Organic Compounds. Environment International. 12: 167-175, 1986.

29. Morey, P.R., Shattuck, D.E.. Role of Ventilation in Building Associated Illness. Occ. Med. State Art Rev. 4: 625-642, 1989.

30. Morey, P.R., Woods, J.E. Indoor Air Quality in Health Care Facilities. Occ. Med. State Art Rev. 2: 547-563, 1987.

31. Mosher, C. et al. Unusually Aggressive Transmission Tuberculosis in a Factory. J. Occ. Med. 29: 29-31, 1987.

32. Mudarri, D. Quantifying Costs and Benefits of Healthy Buildings. Healthy Buildings--IAQ '91, Planning, Designing, Constructing, Renovating and Occupying Buildings: Recommendations and Benefits. Organized by ASHRAE and the International Council for Building Research, Studies and Documentation (CIB). Washington, D.C., Sept 5-8, 1991.

33. NIOSH. Current Intelligence Bulletin No. 54, Environmental Tobacco Smoke in the Workplace. Occupational Safety & Health Reporter; 7-24-91; pp. 232-234. 1991.

34. NIOSH 1989. Indoor air quality, selected references. Cincinnati: National Institute of Occupational Safety and Health. 1989.

35. NKB Publication No. 61E. Indoor Climate - Air Quality. Nordic Committee on Building Regulations. June, 1991.

36. Offermann, F.J. III, Gilbertson, T.A. How to Meet New Ventilation Standards: Indoor Air Quality and Energy Efficiency. Association of Energy Engineers (AEE) Seminar. Atlantic City, N.J. Nov 18-19, 1991.

37. Pritchard, J.A. A Guide to Industrial Respiratory Protection. NIOSH Pub. No. 76-189. Cincinnati, 1976.

38. Quinlan, P., Macher, J.M., Alevantis, L.E., Cone, J.E. Protocol for the Comprehensive Evaluation of Building-Associated Illness. Occupational Medicine: State of the Art Reviews. 4: 771-797, Oct-Dec, 1989.

39. Rajhans, G.S. Findings of the Ontario Inter-Ministerial Committee On Indoor Air Quality. Proceedings of the ASHRAE/SOEH Conference, IAQ '89, The Human Equation: Health and Comfort, 195-223, 1989.

40. Rajhans, G.S. Indoor Air Quality and $CO_2$ Levels. Occupational Health in Ontario. 4:160-167, 1983.

41. Shelton, B.G., Morris, G.K. Bacteria and Fungi in Indoor Environments: Pathogens and Other Microorganisms Requiring Immediate Remedial Action. 1991 American Industrial Hygiene Conference and Exposition, Salt Lake City, UT; Paper # 69.

42. Stolwijk, Jan A. J. Shelter and Indoor Air. Environmental Health Perspective. 86:271-274, 1990.

43. Strindehag, O., Norell, L., Kvarnstrom, S. Improved Indoor Air Quality by Supervision of the $CO_2$ Content. Indoor Air '90, The Fifth International Conference on Indoor Air Quality, Toronto; 4: 437-442, 1990.

44. Sundell, J. Comments during Workshop on Performance Guidelines for Controlling IAQ by Ventilation. Healthy Buildings--IAQ '91, Planning,

Designing, Constructing, Renovating and Occupying Buildings: Recommendations and Benefits; Organized by ASHRAE and the International Council for Building Research, Studies and Documentation (CIB). Washington, D.C., Sept 5-8, 1991.

45. Teichman, K. ASHRAE 62-1989. An Environmental Health Perspective. Healthy Buildings--IAQ '91, Planning, Designing, Constructing, Renovating and Occupying Buildings: Recommendations and Benefits. Organized by ASHRAE and the International Council for Building Research, Studies and Documentation (CIB). Washington, D.C., Sept 5-8, 1991.

46. Wallingford, K. M. NIOSH Indoor Air Quality Investigations in Non-industrial Workplaces, Update '86. American Industrial Hygiene Conference, paper #18. 1986.

47. Woods, J.E. Cost Avoidance and Productivity in Owning and Operating Buildings. Occupational Medicine: State of the Art Reviews. 4: 753-770, Oct-Dec, 1989.

48. Wyon, D. Overcoming Barriers to Productivity in Healthy Buildings. Healthy Buildings--IAQ '91, Planning, Designing, Constructing, Renovating and Occupying Buildings: Recommendations and Benefits. Organized by ASHRAE and the International Council for Building Research, Studies and Documentation (CIB). Washington, D.C., Sept 5-8, 1991.

## ADDITIONAL SUGGESTED READING

1. Alexander, R.W., Nedords, M.J. Epidemic Psychogenic Illness in a Telephone Operator's Building. J. Occ. Med. 28:42-45, 1986.

2. ASHRAE Conference. Engineering Solutions to Indoor Air Problems. Proceedings of the ASHRAE Conference IAQ 88. Atlanta, Georgia. April 88.

3. Bardena, E.J. Office Epidemics. The Sciences. Nov/Dec 1986.

4. Boxer, P.A. Occupational Mass Psychogenic Illness. J. Occ. Med. 27:867-872, 1985.

5. Douglas, W. et al. Proliferation of Pneumocyte II Cells in Prolonged Exposure to 1% $CO_2$. Undersea Biomedical Research. 6: S135, 1979.

6. Fanger, P.O. Introduction of the Olf and Decipol Units to Quantify Air Pollution Perceived by Humans Indoors and Outdoors. Energy and Buildings. 12:1-6, 1988.

7. Fanger, P. et al. Air Pollution Sources in Assembly Halls Quantified by the Olf Unit. Energy and Buildings. 12: 7-19, 1988.

8. Fisk, W. Air Exchange Effectiveness of Conventional and Task Ventilation for Offices. Healthy Buildings--IAQ '91, Planning, Designing, Constructing, Renovating and Occupying Buildings: Recommendations and Benefits. Organized by ASHRAE and the International Council for Building Research, Studies and Documentation (CIB). Washington, D.C., Sept 5-8, 1991.

9. Guyton, A.C. Textbook of Medical Physiology. 7th ed. W.B. Saunders Co. Philadelphia, 1986 pg 508.

10. Janssen, J., Wolff, A. Subjective Response to Ventilation. Proceedings of the ASHRAE Indoor Air Quality Conference '86. 161-170, 1986.

11. Lairson, D.R., et al. Identifying Families at High Risk of Cardiovascular Disease: Alternative Worksite Approaches. J. Occ. Med. 32:586-593, July 1990.

12. Landrigan, P.J., Miller, B. The Arenyattah Epidemic. The Lancet. Dec 24/31, 1474-75, 1983.

13. Modan, B. et al. The Arenyattah Epidemic. The Lancet. Dec 24/31, 1983, 1472-74.

14. NIOSH. Hazard Evaluations and Technical Assistance Branch Division of Surveillance, Hazard Evaluations and Field Studies, National Institute for Occupational Safety and Health (NIOSH); Guidance for Indoor Air Quality Investigations. January 1987.

15. Pfeffer, J.M. Hyperventilation and the Hyperventilation Syndrome. Postgraduate Med. J. 60(supp 2):12-15, 1984.

16. Roach, S.A., Rapport, S.M. But They Are Not Thresholds: A Critical Analysis of the Documentation of Threshold Limit Values. Am. J. Ind. Med. 17:727-753, 1990.

17. Roy, M., Courtay, C. Daily Activities and Breathing Parameters for Use in Respiratory Tract Dosimetry. Radiation Protection Dosimetry. 35: 179-186, 1991.

18. Schaefer, K. Physiological Stresses Related to Hypercapnia During Patrols in Submarines. Undersea Biomedical Research. 6:S15-S48, 1979.

19. Schaefer, K. et al. Effect of Prolonged Exposure to 0.5% $CO_2$ on Kidney Calcification and Lung Ultrastructure. Undersea Biomedical Research. 6:S-155, 1979.

20. Sterling, T.D., Mueller, B. Concentrations of Nicotine, RSP, CO, and $CO_2$ in Nonsmoking Areas of Offices Ventilated by Air Recirculated from Smoking Designated Areas. American Industrial Hygiene Association Journal; 49:423-426.

21. Travis, C. Coping with Anxiety. Science Digest. February 1986, 46-51, 80-81.

## APPENDIX A

## ACUTE EFFECTS OF IAQ PARAMETERS

## Acute Effects of IAQ Parameters

A cross-reference chart of IAQ-related contaminants and their acute effects is provided on the next three pages. The information for the chart was extracted from our own experience and ten literature sources. For each combination of contaminant and effect, number(s) are given corresponding to the literature source. The numbers correspond to the following references. See the reference section in the body of the report for the full citation.

1. AL/OEM (Our own observations)
2. Rajhans (1983)
3. Burge and Hoyer (1990)
4. Quinlan et al. (1989)
5. Rajhans (1989)
6. Johnson et al. (1991)
7. Jones (1990)
8. Anderson (1991)
9. Lyles et al. (1991)
10. Molhave (1986)
11. Pritchard (1976)

Each contaminant is represented by an alphabetical character in the chart. The contaminant, its alphabetical character, and a concentration at which the effects begin is provided below. Not all literature sources agree on the same concentration. Therefore, the most conservative concentration is given.

A - $CO_2$ > 600 ppm

B - Relative Humidity < 40%

C - Relative Humidity > 70%

D - Temperature > 24.4°C (76°F)

E - Temperature < 20°C (68°F)

F - Air Flow > 50 fpm (15.24 m/min) Assymmetry of Radiant Temperature

G - Bioaerosols > 200 colony forming units (cfu)/$m^3$

H - Dust, Fibers > 0.25 mg/$m^3$

I - VOCs > 10 ppm (or > 5 mg/$m^3$)

J - Miscellaneous Chemical Irritants

K - Formaldehyde > 0.1 ppm

L - Carbon Monoxide > 9 ppm

M - Ozone > 0.1 ppm

N - $NO_2$ > 3 ppm

O - Tobacco Smoke (CO > 2 ppm)

P - Poor Lighting, Poor Position of VDT, Other Ergonomic Difficulties

| Effects | Contaminants | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P |
| Drowsiness | 1,2<br>3 | | | | | | | | | | | 4 | | | 5 | |
| Fatigue, Lethargy, Feeling Tired | 1,2 | | | 6 | | | | | 4 | 7,8 | | 3,9 | 3 | | | |
| Difficulty Concentrating | 1,3<br>4 | | | | | | | | 4,9<br>10 | | | | | | | |
| Sensation of Breathing Difficulty, Chest Tightness, Shortness of Breath | 1,3<br>11 | | | | | | | | | 8 | | 3 | 3 | | | |
| Stuffy/Stale Air | 1,2<br>4 | | | | | | | | | | | | | | | |
| Temperature Too Warm | 1 | | | 1,6 | | | | | 10 | | | | | | | |
| Temperature Too Cold, Drafty | | | | | 1,6 | 6 | | | | | | | | | | |
| Clumsiness | | | | | 6 | | | | | | | | | | | |
| Eye Irritation (dry, itchy, burning) | 2 | 1,4 | | | | | 6 | 1,4<br>5,9 | 10 | 7,8 | 4 | | 3 | | 3,5<br>6 | |
| Dry or Irritated Nose/Throat/ Mucous Membrane | | 1,4 | | | | | | 4,6 | 4,<br>10 | 7 | 4,5 | | 3 | | 3,6 | |
| Sinus Congestion | | 1 | | | | | | | | | | | 3 | | | |

| Effects | Contaminants | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P |
| Dry, Itchy Skin Rash/Irritation | 1,9 | | | | | | 5 | 1,4 5,9 | | | | | | | | |
| Contact Lens Discomfort | 1,4 | | | | | | | | | | | | | | | |
| Nose Bleeds | 1,4 | | | | | | | | | | | | | | | |
| Headache | 3,4 | 1 | | 6 | | | | | 4 | 7 | 4 | 2,3 4,9 | 3 | | 3,5 | |
| Increased Colds, Respiratory Illness | * 9 | 1 | | | | | 3 | | | | | | | | 5,6 | |
| Mold Growth, Musty Odor | | | 1,4 | | | | 1,4 6 | | | | | | | | | |
| Asthmatic or Allergic or Hypersensitivity Reactions | | | 1,4 | | | | 1,4 5,9 | | | | | | | | 3,5 6 | |
| Humidifier Fever | | | 1 | | | | 1,4 9 | | | | | | | | | |
| Hypersensitivity Pneumonitis | | | 1 | | | | 1,3 4,5 7,9 | | | | | | | | | |
| Allergic Rhinitis | | | | | | | 3,5 7,9 | | | | | | | | | |
| Allergic Asthma | | | | | | | 3,7 | | | | | | | | | |
| Nausea | 2 | | | | | | 6 | | 9 | 7 | | 3,4 | | | 5 | |
| Respiratory Sys. Irritation | | | | | | | 6 | 1,4 9 | | 8 | | | 3 | 4 | 5 | |

* Reference 9 links an increase in respiratory illness with high recirculation of air.

Four of the effects listed above are clinical diagnoses.
- Humidifier Fever symptoms include: fever, malaise, headache, joint and muscle pain, and decreased pulmonary function.
- Hypersensitivity Pneumonitis symptoms include: shortness of breath, malaise, dry cough, fever, chills, decreased pulmonary function, and fibrosis.
- Allergic Rhinitis symptoms: runny/itchy nose and eyes, and sinus congestion.
- Allergic Asthma symptoms include: wheezing and chest tightness.

| Effects | Contaminants | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P |
| General Complaints | 4 | | | | | | | | 9, 10 | | | | | | | |
| Dizziness | 3 | | | | | | | | 4,9 | 7 | | | | | | |
| Noticeable, Unpleasant Odor | | | | | | | | | 10 | | | | 3 | | 6 | |
| Wheezing, Pain in Deep Breath | | | | | | | | | | | | | 3 | | | |
| Coughing | | | | | | | | | | | | | 3 | | 3 | |
| Appetite Loss | | | | | | | | | | | | | | | 5 | |
| Eye Strain, Back Pain, Posture | | | | | | | | | | | | | | | | 6 |

APPENDIX B

QUESTIONNAIRE

NAME:____________________(optional) SEX M F AGE_____ [$CO_2$_____ RH_____]
(leave blank)

BASE/CITY____________________ BUILDING____________ ROOM #/LOCATION_______

This questionnaire is being distributed to assess the satisfaction of building occupants with building conditions. Your cooperation in giving us accurate data is appreciated. Please answer the questions positively if you have any of the following symptoms or conditions and you believe they are caused or aggravated by the building environment. Place the number describing the frequency next to the condition. Only one answer per condition.

A. 0 - Never, 1. - sometimes, 2. - often, 3. - always

1.___ Aching joints
2.___ Nasal problems, sinusitis
3.___ Back Pain
4.___ Problems with your ears
5.___ Eye irritation/itching
6.___ Dizziness
7.___ Dry, itchy skin/rash
8.___ Headache
9.___ Fatigue
10.___ Drowsiness/sleepiness difficulty concentrating
11.___ Shortness of breath
12.___ Chest tightness
13.___ Coughing
14.___ Sneezing
15.___ Wheezing
16.___ Hayfever/allergies
17.___ Colds
18.___ Bronchitis
19.___ Asthma
20.___ Temperature too warm
21.___ Temperature too cold
22.___ Other (Please use other side if necessary.)

B. When do these symptoms occur?

1. Morning 2. Afternoon 3. Night 4. All the time

C. Do the symptoms get worse as the week progresses?

1. Yes 2. No 3. Does not apply

D. When do you experience relief from these symptoms?

1.____Upon leaving building
2.____When you get home
3.____On weekends only
4.____Only on extended absences (vacations, etc.)

E. Do you smoke? 1. Yes 2. No If so, how many packs per day? 1/2 1 2 3

F. Where are you located in the building? Floor____ Wing/Area_____________

G. Are you near office equipment? 1. Yes 2. No If so, what type?

H. Any other comments you wish to make may be written on the reverse.

# APPENDIX C

# BIOAEROSOL SAMPLING PROTOCOL

## BIOAEROSOL SAMPLING PROTOCOL

The decision to perform biological sampling should be made only when all four of the following are true:

1. There is medical evidence of an allergic or infectious incidence.
2. There are suspicious sources (high humidity, musty smell, signs of water damage on ceiling tiles or carpet, standing water in a ventilation system, trash near an outdoor air intake, etc.).
3. A specific pathogen is present, or you have exhausted all efforts to convince mechanical maintenance personnel to fix or clean the source.
4. All persons involved in the analysis (BEE, 907, Microbiologist) have time to perform the sampling, culturing and evaluation.

AL/OE, Equipment Loan (DSN 240-2142), has Andersen 2-stage samplers and Mattson-Garvin slit-to-agar samplers.

Sampler Operation: The principle of operation of both types of samplers is the same. Each consists of a sampling platform and a sampling pump. The system is designed to sample 28.3 liters/min (1 cfm) air. The Andersen sampler has a critical orifice, so it's not important to calibrate its pump on a regular basis. The sampling technique is simple with only a few important points: keep an accurate sampling time, make sure the sampling platform is sealed before sampling and be sure to clean the sampler between uses.

Cleaning: To decontaminate the sampler, wash with soap and water before the first sample, dry with sterile gauze and wipe with isopropyl alcohol pads. Between samples, rinse all surfaces exposed to the sampled air with deionized water, dry, and wipe with alcohol pads. Make sure the holes are not clogged with water from the rinse. If they are, use a clean air blasting source such as a can of compressed air to dry them.

Sampling: The sampling media we use is Saboraud Dextrose agar in 150-mm petri dishes for molds, Blood agar (100-mm dishes) for gram positive bacteria, and MacConkey agar (100-mm dishes) for gram negative bacteria. However, it's important to discuss media with the mycologist or bacteriologist who will analyze your plates. They may have a preference for a specific type of agar. All of the above agars are available commercially already poured into disposable petri dishes (except Sabaraud which is in 150-mm size), but the analyst may provide you with the media you need. The maximum sampling time should be 30 minutes to avoid drying out the media. In most cases, use 15 minutes for a relatively clean area and 5 minutes for suspected contaminated areas. Take control samples for comparison (outside and in other parts of the building on a separate ventilation system). Sample as close to the suspected source as possible.

Results: Compare individual genera and their concentrations to the control samples, and total colony concentrations to a criterion of 200 colonies/$m^3$. A large number of colonies of a specific genus not found in the control sample indicates a potential problem. For total colony counts, we have either collected fewer than 100 colonies/$m^3$, or collected so many colonies that they overlapped on the agar and were too numerous to count. This means no gray area; either there's an obvious problem or there's not.

## APPENDIX D

## SURVEY PROTOCOL

**AL/OE Protocol for Comprehensive Indoor Air Quality Investigation**

1. The Military Public Health Office should distribute the questionnaire in Appendix B and compile the results. In buildings with fewer than 200 workers, ask all workers to fill out one. In buildings with more than 200 workers, evenly distribute the questionnaires to 10% to 50% of the workers with a goal of 100 to 200 questionnaires returned. An epidemiology program (software) may speed up the compilation. The questionnaire allows occupants to select symptoms they feel are building related. As a control measure, some of the symptoms they are allowed to choose are unrelated to IAQ. Occupants are asked to rank the occurrence of each symptom as Never, Sometimes, Often, or Always. Consider only IAQ-related items marked Often or Always when calculating percentage of occurrence. Any occurrence rate above 20% is an indication of unacceptable Indoor Air Quality, as defined by the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) in 62-1989, Ventilation for Acceptable Indoor Air Quality.

2. The Military Public Health Officer or a physician should interview affected workers. This serves two purposes. First, the interviews will independently check the questionnaire results and help narrow down the cause of the problem and the most affected building areas. Second (and just as important), the workers will perceive that someone cares and understands, thus reducing anxiety over the problem.

3. Concurrent with gathering medical data, the Bioenvironmental Engineer should tour the building and inspect each air handler with an engineer from Civil Engineering who specializes in HVAC systems. Visually verify HVAC conditions. Often, conditions are different (worse) than the HVAC engineer believes; but be tactful. The cooperation of the HVAC engineer is needed to get positive results. Some of the items to look at in each air handler are:

a. Are the fresh air intakes located away from pollution sources, such as busy streets, loading docks, or exhaust vents?
b. What is the designed minimum outdoor air flow rate? Does the system currently meet this minimum?
c. Are the fresh air dampers really open during normal operation? Are the damper controls connected and functional?
d. Do the temperature controls work as they should?
e. Is there a comprehensive maintenance schedule, and is enough manpower available to perform it?
f. Is the HVAC system reasonably free of dust, oil, and fibers, including the cooling coils, duct work, all plenums and chambers?
g. Do the air filters have an Atmospheric Dust Spot Efficiency of at least 60% for 1 micron particles? Are they inspected and replaced routinely? (Do not be confused by an Arrestance Rating of 60% or more. Arrestance is a measure of capture efficiency for large particles (10 microns). Filters with an Arrestance Rating of 60% have less than 20% Dust Spot efficiencies.)
h. Is the HVAC system free of standing water?
i. Are the drip pans under the cooling coils pitched so the water drains? Is the drain mounted flush to the bottom of the pan so that no water accumulates in the pan? Are the drip pans free of growth and evidence of past growth? Is the drain J-trapped?

j. Is there a return fan? If so, are the air handlers positively pressurizing the building (i.e., is the supply fan stronger than the return fan)? If the supply fan speed can vary, is there fan tracking control so the return fan is never stronger than the supply fan? Does it seem to work?
k. Are contaminants from the mechanical room (e.g., heater) exhausted so they cannot enter the air handler? If the mechanical room acts as a return air plenum, is it free of trash, dirt, standing water, and chemical storage?
l. If insulation is used inside air handlers, is it fixed so fibers cannot enter the air handler? Is it kept dry?
m. Do all rooms have supply air vents? Do they deliver the designed air flow?
n. Are the supply and exhaust vents in rooms free of dust, dirt, and obstructions?
o. Does the diffuser distribute supply air evenly? Does the office setup (room dividers, etc.) allow supply air to reach workers?
p. If there are mechanical dampers for the room supply vents, are they open wide enough? If there are automatic dampers, such as variable air volume (VAV) boxes, do they work and are they calibrated? (There are various types of VAV boxes. Some open and close the damper based on room thermostat readings. Others work on a pressure principle. Ask the HVAC engineer to explain the ones you encounter -- when they open, how wide, etc. Then, verify they work as described.)
q. Is the ceiling free of water stains? If not, what caused the stain? Has it been fixed?
r. Is this a smoking-free building? If not, is the tobacco smoke prevented from getting into the main air handlers?

4. To back up the medical interviews and walk-through of the air distribution system, measure the carbon dioxide concentration, relative humidity, and temperature. When these "comfort" parameters fall outside their ideal range, complaints begin. The ideal ranges are: 600 ppm $CO_2$ or less, relative humidity between 40% and 60%, and temperature from 20 to 24.4°C (68 to 76°F). Take measurements in several representative rooms for each air handler (both affected and unaffected rooms). Also take measurements outside (for comparison), and in the return air plenum if possible. A $CO_2$ meter with datalogger should be run for 24 hours in the return air plenum and in an affected area. Make sure the meter is calibrated. The $CO_2$ concentration will rise exponentially as the workday begins and will usually stabilize 3 to 4 hours later. At least four readings per representative room are recommended for each comfort parameter. Spread the measurements throughout a day when the air handlers are in their usual operating mode. If there are two (or more) modes, sample when the outside air is minimized and when the fresh air dampers are open the widest.

5. If there are complaints of odor or irritation, find and remove the source. Typical sources are: untrapped drain lines connected to the sewer, gas-fired heater exhaust, new furniture or carpet, stagnant air, insulation fibers, and diesel trucks idling outside the building fresh air intakes. Possible screening samples to collect are methane, hydrogen sulfide, carbon

monoxide, hydrocarbons, ammonia, formaldehyde, particulates (dust and fibers), sulfur dioxide, nitrogen dioxide, and ozone. Make sure direct reading instruments are calibrated. If any of these are significantly above outdoor levels, trace the source and remove it. If the samples are not above outdoor levels, use the data for negative documentation.

6. In about 40% of buildings with IAQ problems, mold or bacteria contamination is a significant contributor. Allergic responses are the most common complaint. Air sampling to confirm the presence of microbes is unnecessary -- signs of contamination such as growths in the drain pan, a mold odor, or water-stained ceiling tiles is enough. If the decision to sample is made anyway, follow the guidance given in the protocol in Appendix C.

7. Compare results of the inspections and air sampling to questionnaire and interview data. Compile the collected data plus conclusions and recommendations into a report. Use the report to generate action items. Use the troubleshooting guideline in Appendix E to aid in the recognition, evaluation, and control of IAQ problems.

## APPENDIX E

## TROUBLESHOOTING GUIDELINES

## IAQ Troubleshooting Guidelines

| Cause | Symptom/Complaint | Observation | Recommendation |
| --- | --- | --- | --- |
| Low Relative Humidity (RH) | Dry, scratchy eyes, nose or throat<br>Sore throat<br>Can't wear contacts<br>Dry, itchy, flaking skin<br>Headache or bodyache<br>Bleeding nose<br>Sinusitis<br>Bronchitis<br>Increase in respiratory illness | RH less than 40% | Re-humidify air in air handlers |
| High $CO_2$ Conc. | Sleepiness<br>Fatigue<br>Poor concentration<br>Restlessness<br>Stuffy feeling<br>Sensation of breathing difficulty | $CO_2$ more than 600 ppm esp. in afternoon<br>Fresh air dampers nearly closed<br>No supply air in room or supply air blocked | Increase fresh air rate<br>Open dampers<br>Decrease density of occupants<br>Add supply vents<br>Rearrange office |
| Negative Pressure Building | Too hot in some places/ too cold in others<br>Dusty | Wide temperature variations<br>Doors slam shut/ hard to open<br>Supply flow rate less than return<br>Humidity damaged paint, wallpaper | Increase supply air fan to 5% greater than return fan<br>Open supply air intakes wider |
| Fiberglass, Insulation, Dust | Irritative cough<br>Dermatitis | Dust/fibers in room, or air handler<br>Exposed insulation in air handler unit (AHU) | Replace or remove insulation<br>Vacuum ducts<br>Clean AHU |
| Bio-aerosols | Allergy confined to building<br>Musty smell<br>Nausea/diarrhea | Water-stained ceiling<br>Drip pans w/undrained water<br>Mold smell<br>Visible mold growth<br>RH more than 70% | Clean and disinfect whole system<br>Replace filters<br>Eliminate water source |

**IAQ Troubleshooting Guidelines (cont.)**

| Cause | Symptom/Complaint | Observation | Recommendation |
|---|---|---|---|
| Work at VDT | Facial skin irritation | Dusty<br>RH less than 40% | Rehumidify air<br>Replace filters<br>Treat VDT with anti-static wipe<br>Ground VDT |
| Pollution Source | Smells<br>Headaches<br>Nausea/diarrhea | Fresh air intake located near loading dock/road/ water tower<br>Combustion source in return air<br>No J-traps on drains or traps are dry | Relocate fresh air intake<br>Remove combust. source<br>Add J-traps and fill with water<br>Absorb offending chemical |
| Cigarette Smoke | Tobacco smell<br>Complaints about smokers | CO more than 2 ppm<br>Tobacco smoke gets in return air | Move smoking area<br>Ban smoking |
| Air Handler Neglect | Any of above complaints<br>Legionella | No air filters<br>Clogged air filters<br>Ductwork or coils oily or dirty<br>Standing water in air handler<br>Exhaust/supply air grills dirty<br>Less than 20°C (68°F) or more than 24.4°C (76°F) | Add or replace air filters<br>Clean and disinfect whole system<br>Begin maintenance schedule<br>Calibrate controls<br>Balance system |

# APPENDIX F

# EQUIPMENT CHECKLIST

**Basic Equipment for Indoor Air Quality Survey**

Carbon Dioxide, Temperature and Relative Humidity:

- ____ Indoor Air Quality Monitors (Metrosonics AQ-501 or equivalent) OR
- ____ $CO_2$ Monitors with strip chart recorders or dataloggers
- ____ sling psychrometers or hygrothermographs

Velocity and Air Flow Measurements:

- ____ Flow Hood (for supply and exhaust vent air flow)
- ____ Rotating vane anemometer (for air velocity)

Contaminant Screening:

- ____ Flame Ionization Detector (FID) OR Photoionization Detector (PID) (calibrated with hexane for organic detection)
- ____ Color Detector Tubes for carbon monoxide, ammonia, sulfur dioxide, nitrogen dioxide, hydrogen sulfide, and ozone

Volatile Organics (Total VOCs & Formaldehyde):

**NOTE: Coordinate VOC sampling in advance with the AL/OE analytical lab**

- ____ Charcoal Tubes (100mg/50mg, charcoal shell)
- ____ Sampling Pumps (calibrated at 200 cc/min)
- ____ 3M 3721 Passive Dosimeters for Formaldehyde

Biological Sampling:

- ____ Anderson Sampler (2 stage)
- ____ Mattson-Garvin Slit-to-agar Samplers, w/15-min motors
- ____ Sampling Media. (Use the media recommended by the microbiologist who will analyze the samples.) The media we use are:
  - Blood Agar (gram positive bacteria, Anderson Sampler)
  - MacConkey Agar (gram negative bacteria, Anderson Sampler)
  - Saboraud Dextrose (mold, Slit-to-agar sampler)
- ____ Wipes/Isopropyl Alcohol
- ____ Deionized Water and Basin

Supplies:

- ____ Flashlight (it's dark inside an air handler)
- ____ Tape Measure
- ____ Tool Kit (screwdrivers, hexnut wrenches)
- ____ Extension Cords
- ____ Labels for Samples

Notes:

- You may not need all the equipment on the list for each survey. Results from the questionnaires, walk-through and professional judgment will determine what equipment to use. Other equipment may be necessary for special surveys.

- Equipment you do not have can be obtained from Armstrong Lab Equipment Loan.

- The FID and PID are excellent tools for the detection of organic material leaks, but they are not absolutely necessary. A PID cannot detect methane.

## APPENDIX G

## FRESH AIR FLOW RATE CALCULATION

## Fresh Air Flow Rate Calculation

Workers are the only significant source of $CO_2$ in an office environment, so it is fairly simple to relate $CO_2$ concentration to fresh air flow using tracer gas theory. Using the steady state $CO_2$ concentration, the relation is

$$Q = \frac{11{,}500\ n}{C_s - C_a}$$

where $Q$ = fresh air flow rate (cubic feet per minute, cfm),

$n$ = the number of persons served by the air handler,

$C_s$ = steady state $CO_2$ concentration in the work space (ppm),

$C_a$ = the concentration of $CO_2$ in the ambient (outdoor) air (ppm),

and 11,500 is a constant based on the average human $CO_2$ generation rate of 0.0115 cfm per office-worker. This constant comes from ASHRAE 62-1989, which assumes a breathing rate of 9 liters of air per minute and a concentration of $CO_2$ in the expired breath of 37,000 ppm.

We have verified this equation in several buildings. We use this equation to calculate the fresh air flow required per person to keep the $CO_2$ concentration at 600 ppm or below. The average outdoor concentration of $CO_2$ we find on surveys is 325 ppm. Thus, Q/n = 11,500/(600-325) = 42 cfm/person.



*U.S. GOVERNMENT PRINTING OFFICE 1992-0-661-049/60017