Indoor Air Quality Update #4631

A Guide to the Practical Control of Indoor Air Problems, from **Cutter Information Corp.**

Circulation Office: 37 Broadway, Arlington, MA 02174-5539 U.S.A. (617) 648-8700 TLX: 650 100 9891 FAX: (617) 648-8707
Editorial Office: 2548 Empire Grade, Santa Cruz, CA 95060 U.S.A. (408) 425-3846

# Indoor Air Quality: Selected References

Prepared by the United States Department of Health and Human Services

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*IAQU* Document Code: 081

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# INDOOR AIR QUALITY

## Selected References

U.S. Department of Health and Human Services
Public Health Service
Centers for Disease Control
National Institute for Occupational Safety and Health

# INDOOR AIR QUALITY

Selected References

U.S. Department of Health and Human Services
Public Health Service
Centers for Disease Control
National Institute for Occupational Safety and Health
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September 1989

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## INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH) has compiled this document in response to an increasing number of requests for information about indoor air quality (IAQ), including "sick building syndrome." Included in this publication are:

1. NIOSH Congressional testimony that describes the NIOSH IAQ investigations program and summarizes the results of NIOSH research and findings on IAQ problems;

2. NIOSH guidance for conducting indoor air quality investigations;

3. NIOSH journal article on evaluating building ventilation systems; and

4. List of non-NIOSH publications on indoor air quality.

As the Federal agency responsible for conducting research and making recommendations for occupational safety and health standards, NIOSH limits its IAQ activities to the occupational environment. The U.S. Environmental Protection Agency (EPA) also conducts an IAQ program and can be contacted for information regarding both occupational and non-occupational settings. Several relevant EPA publications are included in Item 4 above and can be obtained from the EPA Public Information Center, 401 M Street S.W., Mail Code PM 211B, Washington, DC 20460, telephone 202-382-2080.

# CONGRESSIONAL TESTIMONY

TESTIMONY OF

J. DONALD MILLAR, M.D.

DIRECTOR

NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY AND HEALTH

CENTERS FOR DISEASE CONTROL

Before the

SUBCOMMITTEE ON SUPERFUND, OCEAN AND WATER PROTECTION

COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS

UNITED STATES SENATE

May 26, 1989

I am Dr. J. Donald Millar, Director of the National Institute for Occupational Safety and Health (NIOSH) of the Centers for Disease Control, in the Public Health Service of the Department of Health and Human Services. I appreciate this opportunity to report to you on the activities of NIOSH in the area of indoor air quality.

Our experience with evaluating and understanding indoor air quality problems is based on the research and technical assistance that we have conducted under the mandates of the Occupational Safety and Health Act (OSH Act). Our knowledge, therefore, relates to the health effects on workers in nonresidential and nonindustrial workplaces, including Federal buildings, schools, and other public buildings, commercial buildings and portions of commercial vehicles occupied by workers. In addition to dealing with air quality, this knowledge base includes data on ergonomic and psychosocial problems that also affect workers.

More specifically, most of our knowledge on indoor air quality problems has been generated on the "technical assistance side" of our responsibilities under the OSH Act. This assistance is conducted under Section 20(a)(6) of the OSH Act through our Health Hazard Evaluation (HHE) Program, where we respond to requests from employers, employees, employee representatives, State and local agencies and other Federal agencies. Presented below is a brief narrative of how the HHE Program is utilized for indoor air quality investigations, and what we have learned from these investigations in regard to the extent of the problem. Additional details are shown in Enclosure I.

In the 1970's, following the Arab oil embargo, energy conservation programs were encouraged throughout the United States. The operations of buildings changed in an effort to conserve fossil fuels and operating costs. Ventilation rates were reduced and buildings were sealed to prevent infiltration of untempered outside air (hot, humid air in the summer months and cold, dry air in the winter months). At the same time, there was a revolution occurring in buildings throughout the country. Computers forced a change in office procedures and productivity leading to ergonomic and organizational stress problems. Some of these new office technologies brought with them chemical and physical hazards.

We saw the effect of the conservation measures, as well as problems associated with the shifts in office automation (e.g. video display terminals, vision problems), and concern about asbestos and radiation, through increases in requests for assistance in the HHE Program. Of the 1,200 Health Hazard Evaluations between 1971 and 1978, NIOSH investigated six indoor air quality problems or 0.5% of the total. From 1978 to 1980, the percentage of HHE's have averaged 12% of all health hazard evaluations. More recently, on an annual basis, this has increased to approximately 20%. For example, in FY 1988 through the present, NIOSH's toll free information number has received an average of approximately 60 inquiries and requests for assistance per month on indoor air quality problems. In 1988, in addition to providing background information and a copy of NIOSH's indoor air quality guidance document (Enclosure I) to most of these callers, NIOSH researchers conducted 45 field investigations.

Table 1 presents the number of HHE investigations by building type since the Program was initiated in 1971. (These totals do not include complaints arising from asbestos contamination--the number of which also is significant--or complaints regarding radon.)

TABLE 1

NIOSH Indoor Air Quality
Investigations by Building Type
(through December 1988)

| Building Type | Number Completed | Percent of Total |
|---|---|---|
| Government and | | |
| Business Offices | 426 | 80 |
| Schools and Colleges | 68 | 13 |
| Health Care Facilities | 35 | 7 |
| Total: | 529 | 100 |

We have not seen a decrease in indoor air problems and we are concerned that as the U.S. moves more and more to a service and information economy, with increases in office workers, the problems will increase.

Indoor air quality problems may arise from a variety of sources including human metabolic activity, smoking, structural components of the building and contents, biological contamination, office and mechanical equipment, and outside air pollutants that enter the building. Commonly, the symptoms and health complaints reported by workers are diverse and not specific enough to readily identify the causative agent (Table 2). The workplace environment is implicated by the fact that these symptoms can be severe enough to result in missed work, reassignment, and even termination. This causes increased anxiety among the workers and, often times, makes the investigation of these problems even more difficult.

TABLE 2

Common Health Complaints

Eye Irritation
Dry Throat
Headache
Fatigue
Sinus Congestion
Skin Irritation
Shortness of Breath
Cough
Dizziness
Nausea
Sneezing
Nose Irritation

Although some of these episodes may be made up of several factors combined, we have classified the results found in our HHE Program by primary type of problem found: contamination from the building materials (4%); microbial contamination (5%); other contamination from inside the building (15%); contamination from outside the building (10%); inadequate ventilation (53%); and unknown (13%).

As mentioned above, in over half of our indoor air quality investigations, inadequate ventilation was found to be the cause of complaints. Heating, ventilating, and air conditioning (HVAC) conditions that can cause indoor air quality problems include migration of odors or chemical hazards between building areas, re-entrainment of building exhaust through heat recover devices or improper placement of exhaust and intake stacks, buildup of microorganisms in HVAC system components and poor odor and environmental control due to insufficient "fresh" outdoor air. The insufficient use of "fresh" outdoor air has been compounded by reduction in ventilation airflows because of energy conservation. The inadequacy of building ventilation can be evaluated by monitoring ambient carbon dioxide (CO2) concentrations, temperature, humidity, and airflow. However other chemical agents from sources other than human occupants also increase with adequate building ventilation.

In 20-25% of our indoor air quality surveys, sources inside the building have been identified as the major generators of indoor air pollution. To date, common sources that have been identified include: duplicators-methyl alcohol; signature machines - butyl methacrylate; blueprint copiers--ammonia; acetic acid; pesticides; boiler additives--diethyl ethanolamine; cleaning agents; tobacco smoke and combustion gases; foam insulation, particle board, plywood, construction glues and adhesives--formaldehyde, and organic solvents; lined ventilation ducts--fibrous glass; silicone caulking and curing agents. in these situations, we have found that low concentrations of agents need to be monitored since odor thresholds, comfort and unusual stimuli may be the significant factors rather than higher concentrations where health effects have been established. Also, in many instances no evaluation criteria exist and the investigators must compare areas where complaints are frequent with areas which have no complaints to search for chemical, biological, physical, and organizational factors which may be the cause. Given the problems with identifying emission sources and the need to measure at low levels, sensitive and specific direct-reading instruments need to be followed with highly specific, low level chemical analysis in the laboratory.

To complicate the investigations concerning poor air quality, ergonomics and psychosocial issues often are encountered. For example, our research teams, composed of behavioral scientists, physicians and industrial hygienists, have investigated a series of mass illness outbreaks in various work settings for which there was no apparent physical or chemical cause. The reported symptoms are typically vague and nonspecific, and frequently are described by workers as ill defined contaminants in the workplace (e.g., bad odors, stuffy or heavy air). Questionnaire surveys and interviews of both affected and unaffected workers suggest that the expression of the symptoms may have been exacerbated by a variety of ergonomic, organizational and psychosocial stresses which increase worker job and life-dissatisfaction.

Aside from NIOSH experiences discussed above, there have been considerable activities by other governmental and nongovernmental groups worldwide of which I am sure you are aware. Some major examples of these are as follows;

1. The National Research Council's Assembly of Life Science published "Indoor Air Pollutants" in 1981. The report lists a number of chemicals implicated in indoor air pollutant problems without assessing their importance. The Assembly also recommended that monitoring protocols and special instruments be developed to asses indoor air pollutants; that complaints of malaise, headache, stuffiness, and eye and throat irritation be studied; that the lowering of work productivity due to indoor pollution and associated discomfort be investigated; and that the influences of building design on the concentration of pollutants in commercial facilities be conducted.

2. The Environmental Protection Agency (EPA) published "EPA Indoor Air Quality Implementation Plan" in 1987 which not only described EPA's research agenda at that time, but dealt with those indoor air quality issues that concerned other Federal agencies. The document included a bibliography of indoor air quality literature containing over 2,000 entries.

3. In 1988, the Health and Safety Executive of Great Britain issued a report "Sick Building Syndrome: A Review." This report summarizes their experiences with "sick building syndrome," and discusses symptoms, common features of "sick buildings" and possible causes. Their experiences mirror that information found by our HHE Program.

4. A 1988 EPA publication, "Indoor Air Quality in Public Buildings" reported that concentrations of volatile organic compounds in new buildings were found to be as much as 100 times higher than those found outdoors.

5. Volume II of the Environmental Protection Agency's Report to Congress prepared in 1988/89 under Title IV of the Superfund Amendments and Reauthorization Act of 1986 highlights an up-to-date summary of the "Assessment and Control of Indoor Air Pollution." This volume discusses such issues as (a) factors affecting indoor air quality; (b) sources of pollutants and health effects; and (c) economic impacts.

These examples support the point that indoor air quality problems associated with worker health are significant and require continued vigilance.

In regard to your questions pertaining specifically to the Indoor Air Quality Act (S.657), the Administration has not yet taken a position on the specific contents of the proposed legislation.

Thank you for the opportunity to submit this testimony to the record.

ENCLOSURE I

# THE NIOSH APPROACH TO CONDUCTING INDOOR AIR QUALITY INVESTIGATIONS IN OFFICE BUILDINGS

National Institute for Occupation Safety and Health


## ABSTRACT

Since 1971, personnel from the National Institute for Occupation Safety and Health (NIOSH) have complete over 500 indoor air quality (IAQ) investigations in a variety of office building environments. Most of these investigations have been conducted since 1979, paralleling the energy conservation concerns of building owners and operators. These investigations have been conducted under the authority of the NIOSH Health Hazard Evaluation Program and have been in direct response to reported health complaints or illness. Therefore, these IAQ investigations are intended to establish the identity of a problem and to recommend solutions for its correction. Over time, we have developed a consistent methodology with a "solution-oriented" approach to conducting these IAQ investigations. To initiate the investigation, the NIOSH team gathers background information by telephone and then makes a site visit to interview the affected employees and establish symptom identity and prevalence. During this initial site visit, the investigators also attempt to identify sources of contaminants, evaluate comfort parameters, and assess ventilation system performance. A variety of applicable evaluation criteria may be used, including "rules-of thumb" gleaned from the current scientific literature and our own experiences. If specific problems cannot be identified through these initial means, follow-up visits are then used to pursue a continually narrowing range of possibilities. This "solution-oriented" approach has resulted in the best allocation of our resources and has allowed the most efficient use of in-field as well as analytical personnel. In the IAQ investigations completed to date, problems were found to result from building material contaminants in 4%, microbiological contaminants in 5%, contaminants brought in from outside the building in 10%, contaminants from inside the building in 15% and inadequate ventilation problems in 53%. The remaining 13% represent those investigations where no problem could be identified.


## INTRODUCTION

The sometimes questionable quality of indoor air and the potential for health risks have become major concerns of building occupants, especially office workers. Some potential indoor exposures, such as to the carcinogen, asbestos, have well-documented health implications. But, more commonly, the health risks of other indoor air exposures are poorly understood. Nevertheless, office workers experiencing indoor air quality (IAQ) problems often demand a complete evaluation of their work environment and of the effect it may have upon their health.

At the National Institute for Occupation Safety and Health (NIOSH), the majority of our indoor air quality investigations are conducted as part of the Health Hazard Evaluation Program. We conduct these health hazard evaluations at the request of employee groups, unions, management, and local, State and Federal agencies. Generally, these requests are in response to existing worker health complaints and illness. Because we are essentially "invited" to conduct these investigations, the data presented here will not reflect a statistically valid cross-section of the indoor air quality problem. However, these findings are drawn from one of the largest single information bases currently available on the subject. In essence, this paper will summarize the NIOSH methodology currently used during IAQ investigations and some of the data from these IAQ investigations completed since the start of the Health Hazard Evaluation Program.

METHODOLOGY

We have found that investigating IAQ problems can present a formidable challenge which, in some ways, is more difficult than evaluating industrial environments. In an industrial situation, the evaluation will be directed by investigations of the materials used by, or in the vicinity of, the affected workers. These materials can usually be chemically analyzed which permits techniques and potential health effects using standard medical and epidemiologic techniques. Frequently there are exposure criteria which can be applied to help interpret the data obtained. This is rarely the case with an indoor air quality problem.

Indoor air quality investigations tend to become more complicated as time passes without identification of a cause. Frustrations result in highly charged emotions which only further impede continued evaluation efforts. These situations are further complicated by the fact that symptoms are not easily attributed to a single cause and the application of standard industrial hygiene, medical and epidemiologic techniques may prove to be inconclusive.

Over time, our approach in evaluating this situation has changed. We have developed a more consistent, solution-oriented approach that systematically excludes a continually narrowing range of possibilities. Generally, this exclusion hierarchy, which has come about based on our past experiences, involves evaluation of physical, chemical and microbiological factors, in the order presented. Each of these potential causation categories are discussed in more detail later in this presentation.

Since we anticipate that IAQ requests will continue to represent a substantial percentage of the total health hazard evaluation requests (currently about 20%), three response levels have been developed. Based on the information obtained during initial telephone with the requestor, the following responses are possible:

1. Provide "self-help evaluation" materials (attached). Remain available for consultation by telephone. Become more involved, if necessary.

2. NIOSH conducts an initial evaluation an provides recommendations to solve the problem or for further study on a "self-help" basis.

3. NIOSH conducts a full scale investigation.

The NIOSH investigation team commonly includes an industrial hygienist and physician/epidemiologist, but can also include other professionals such as an engineer. Most investigations contain the following parts: background assessment, initial site assessment, and, if necessary, additional site assessment.

BACKGROUND ASSESSMENT

For the background assessment, we initially obtain, by telephone, as much information on the building as practicable, an idea of symptoms being experienced, and a chronology of the problem. Much of this information can be collected using a standard questionnaire. We also request copies of other previous investigations which are relevant to the problem at hand. These data are then used to tailor the protocol for the initial site assessment so as to make it more efficient.

INITIAL SITE ASSESSMENT

For the initial site assessment, a common protocol includes five separate steps or parts: an opening conference, a walk-through evaluation, personal interviews, phase I of environmental monitoring, and a closing conference.

Opening Conference--The opening conference is attended by representatives of the employer and employees (where applicable) as well as someone who has knowledge of the operation, and maintenance of the building's heating, ventilating and air conditioning (HVAC) systems. This meeting serves to present NIOSH's role, discuss anticipated activities and arrange to receive copies of pertinent data not already received.

Walk-through Survey--The walk-through survey will involve all or part of the building including inspection of the HVAC systems with special attention given to the mechanism by which outside air enters each HVAC unit. Architectural plans and ventilation test and balance reports may also be reviewed during this phase. Potential sources of emission are identified so that each may be further evaluated, as needed.

Personal Interview--Personal interviews are often conducted to determine the extent, prevalence and character of reported symptoms. The use of a questionnaire, such as the one shown in Appendix 1, may be the most efficient means of collecting this type of information. It can be used as a guide during personal interviews or it can be self-administered

Phase I Environmental Monitoring--Phase I environmental monitoring is usually conducted on each initial survey. The scope of this effort may vary, but usually will either evaluate certain aspects of the building environment, which we have come to believe are important factors in all investigations, or explore any other possibilities made apparent from the background assessment. Evaluation of the ventilation system using both actual measurement and/or carbon dioxide (CO2) techniques, and monitoring temperature and relative humidity are useful procedures for all evaluations during the initial site assessment. Monitoring for formaldehyde is an example of a specific method which may be used if the background assessment indicates that respiratory system and eye irritation are prevalent complaints and the space has been recently built or renovated (a number of furnishings are potential sources of formaldehyde). Most of the monitoring accomplished on the initial survey is obtained using direct-reading instruments where possible because they provide results on-the-spot. Any deficiencies noted can be corrected and re-evaluated. Trace concentrations of hundreds of compounds could be identified depending on the extent of the sampling and analytical effort; however, the concentrations usually detected would not be expected to cause adverse health effects in a normal healthy individual. Other techniques which I will now discuss have been consistently more useful.

Evaluating HVAC Systems--HVAC systems can be complicated and most industrial hygienists have received very little or no training in the design, maintenance and trouble-shooting of building ventilation systems. The most important aspect of evaluating HVAC systems is to gain an understanding of how they are supposed to be working and then use some relatively simple methods to convince yourself that the system is performing up to the design specifications, and whether this is adequate with respect to the complaint areas in the building, return to the complaint area(s) and measure supply and return air flows using either a velometer or a flow hood and compare the results to the design quantities. Note that in variable-air-volume (VAV) systems the supply air flows may vary during the day.

A method which is gaining popularity, and which is currently used by NIOSH for evaluating the adequacy of ventilation to an area is the measurement of CO2 concentrations. Humans expire significant quantities of CO2. The higher the CO2 levels inside a building, the poorer the overall ventilation, in a general sense. We believe that complaints will not be prevalent if interior CO2 concentrations are maintained at twice or less the outdoor levels (usually 250-300 ppm). At CO2 concentrations above 1000 ppm, or 3 to 4 times the outdoor level, complaints of headaches tiredness, eye, nose and throat irritation may be more prevalent. It is important to realize that it is not the CO2 concentration that is causing the symptoms; but, if CO2 increase, so may all the other normal airborne contaminants and it may be some combination of all these substances that make people uncomfortable. Carbon dioxide measurement scan be obtained using standard detector tubes or portable CO2 monitoring instruments. The use of CO2 as an index of the general quality of indoor air is currently being evaluated by NIOSH as well as many other agencies.

Poor mixing of air is another potential problem sometimes found when air is delivered and returned through ceiling diffusers. Standard smoke tubes, and temperature and $CO_2$ measurements at 1 foot and 7 foot heights above the floor may be useful techniques in evaluating stratification resulting from poor mixing.

Monitoring Temperature and Relative Humidity--Temperature too cold, too warm or fluctuating can be a source of complaints. While individuals vary in their limits of thermal comfortability, if a significant number of workers in an area complain (more than 20%), then temperature and relative humidity may be creating an uncomfortable environment. If temperatures are too warm, complaints or tiredness, lack of concentration and headache may also be reported. Low relative humidities, not uncommon in the winter in a building or residence that is not humidified, can cause eye, nose and throat irritation.

CLOSING CONFERENCE

The closing conference of the initial site survey provides an opportunity to present the NIOSH activities accomplished, any results obtained and recommendations on corrective actions if potential problems were identified. If no problems were identified, recommendations may be made on how to continue studying the problem either on a self-help basis or through continued NIOSH involvement. Typical recommendations when we have not identified a probable explanation for the reported symptoms would include the formulation of a more formalized method of reporting worker symptoms on a daily basis and the generation of HVAC data logs to provide evidence that the HVAC system is performing in a consistent manner over time.

EVALUATION CRITERIA

Evaluation criteria used to interpret environmental measurements vary. In the classic industrial hygiene sense, the Occupational Safety and Health Administration's (OSHA) permissible limits [1], the American Conference of Governmental Industrial Hygienists' (ACGIH) Threshold Limit Values [2], and NIOSH's recommended exposure limits [3] are most commonly used in occupational exposure assessments. Because these criteria are based on health effects as they pertain to the manufacturing environment, they may not have the same relevance for workers in an office setting, whose primary concern may be for comfort or simply an absence of unusual sensory stimuli over their working period. The Environmental Protection Agency (EPA) has ambient air quality standards [4] for a variety of pollutants designed to protect the public over an entire day (not just an 8-hour workday). However, these, too, may not have relevance to an indoor office environment, especially from the perspective of problem-solving.

The American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc. (ASHRAE) guidelines for acceptable indoor air quality [5] have been developed for the indoor environment. We commonly use these as criteria in our office building evaluations, especially for assessing the performance of a ventilation system. We also use the ASHRAE comfort guidelines [6] as criteria for assessing the thermal performance of occupied space.

## ADDITIONAL SITE ASSESSMENTS

If the background assessment and the initial site visit identify a problem that need further definition, or if no problem can be isolated, an additional site assessment may be performed. During the additional site assessment, more specific and extensive monitoring may be conducted for chemical and/or microbiological contaminants of interest. Sampling for airborne microbiological contaminants is also outside of what is considered a standard industrial hygiene technique. Useful techniques are still under evaluation. Methodology is available; however, analytical support is somewhat limited. Nevertheless, the topic of potential microbiological contamination usually comes up as an investigation progresses. Close visual inspection of the various HVAC components will usually uncover a microbiological problem if present.

The condition most commonly associated with exposure to airborne organisms is hypersensitivity pneumonitis. This is a general term for a disease which occurs as a result of an immunologic inflammatory reaction to the inhalation of any of a variety of organic dusts. Terms like humidifier fever, ventilation pneumonitis, farmer's lung and cheese worker's lung are all the result of these exposures. Symptoms are usually described as a recurring "flu-like" syndrome. Diagnosis is based on a combination of characteristic symptoms, chest x-rays, pulmonary function abnormalities and sometimes immunologic studies [7].

Inspection of the HVAC system and confirmation of the diagnoses of hypersensitivity pneumonitis among workers may be more useful than air sampling for airborne microorganisms until investigative techniques are further refined.

## DISCUSSION

Through December 1988, 529 NIOSH indoor air quality health hazard evaluations have been completed (Table 1). These do not include our investigations of asbestos-in-building problems, but only those where the building occupants were actually experiencing ill health effects. The number of investigations has increased markedly since 1979. This is most probably due to a couple of factors: increased energy conservation measures and increased worker awareness of their office environment. We now average about two indoor air quality investigations per week.

TABLE 1

NIOSH INDOOR AIR QUALITY INVESTIGATIONS
BY YEAR (THROUGH DECEMBER 1988)

| Year | Number Completed | % |
|---|---|---|
| Pre-1978 | 6 | 1 |
| 1978 | 9 | 2 |
| 1979 | 12 | 3 |
| 1980 | 28 | 6 |
| 1981 | 82 | 18 |
| 1982 | 52 | 12 |
| 1983 | 61 | 14 |
| 1984 | 56 | 13 |
| 1985 | 81 | 18 |
| 1986 | 59 | 13 |
| 1987 | 38 | 8 |
| 1988 | 45 | 9 |
| Total: | 529 | 100 |

While the majority of our investigations have been conducted in government and private-sector office buildings (Table 2), we have also looked at problems in schools, colleges, and health care facilities.

TABLE 2

NIOSH INDOOR AIR QUALITY INVESTIGATIONS
BY BUILDING TYPE (THROUGH DECEMBER 1988)

| Building Type | # Completed | % |
|---|---|---|
| Government and Business Offices | 426 | 80 |
| Schools and Colleges | 68 | 13 |
| Health Care Facilities | 35 | 7 |
| Total: | 529 | 100 |

Commonly, the symptoms and health complaints reported by the office workers are diverse and not specific enough to readily identify the causative agent (Table 3). The workplace environment is implicated by the fact that these symptoms normally disappear on weekends away from the office. At times, these symptoms can be severe enough to result in missed work, reassignment, and even termination. This causes increased anxiety among the workers and, often times, makes the investigation of these problems even more difficult and frustrating.

TABLE 3

COMMON HEALTH COMPLAINTS

| | |
|---|---|
| Eye Irritation | Shortness of Breath |
| Dry Throat | Cough |
| Headache | Dizziness |
| Fatigue | Nausea |
| Sinus Congestion | Sneezing |
| Skin Irritation | Nose Irritation |

Although many of these problems may be multifactorial, we have classified our evaluations by primary type of problem found: contamination from the building material (4%); microbiological contamination (5%); contamination from outside the building (10%); contamination from inside the building (15%); inadequate ventilation (53%); and unknown (13%) (Table 4.) There are some shortcomings to these data, however, in that they may not represent a "true" cross-section of the indoor air quality problem as previously discussed. For example, we have not used a standard protocol for all these evaluations, as our methods and criteria have evolved with time and experience. Also, since many of these investigations were reviewed retrospectively, there may be some misclassification due to the vagueness of earlier reports. Lastly, we have little follow-up data on many of these evaluations to enable us to determine the efficacy of our recommendations[8].

TABLE 4

NIOSH INDOOR AIR QUALITY INVESTIGATIONS
BY PROBLEM TYPE (THROUGH DECEMBER 1988)

| Problem Type | # Completed | % |
|---|---|---|
| Building Materials Contamination | 21 | 4 |
| Microbiological Contamination | 27 | 5 |
| Outside Contamination | 53 | 10 |
| Inside Contamination | 80 | 15 |
| Ventilation Inadequate | 280 | 53 |
| Unknown | 68 | 13 |
| Total: | 529 | 100 |

BUILDING MATERIALS CONTAMINATION

Contamination from building materials and products was the major problem in 4% of our investigations. Formaldehyde can off-gas from urea-formaldehyde foam insulation, particle board, plywood, and some glues and adhesives commonly used during construction. Other building fabric contamination problems encountered included dermatitis resulting from fibrous glass, various organic solvents from glues and adhesives, and acetic acid used as a curing agent in silicone caulking.

MICROBIOLOGICAL CONTAMINATION

Five percent of our investigations have involved some type of microbiological contamination. Even though this is not a common cause of office problems, it can result in a potentially severe condition known as hypersensitivity pneumonitis. This respiratory problem can be caused by bacteria, fungi, protozoa, and microbial products that may originate from ventilation system components. A similar condition known as humidifier fever, most commonly reported in Europe, is also a result of microbiological contamination in ventilation systems. In our investigations, microbiological contamination has commonly resulted from water damage to carpets or furnishings, or standing water in ventilation system components.

OUTSIDE CONTAMINATION

Contamination from sources outside the office space was the major problem identified in 10% of our investigations. Problems due to motor vehicle exhaust, boiler gases, and previously exhausted air are essentially caused by re-entrainment. This is usually the result of improperly locked exhaust and intake vents or periodic changes in wind conditions. Other outside contamination problems include contaminants from construction or renovation such as asphalt, solvents, and dusts. Also, gasoline fumes infiltrating the basement and/or sewage system can sometimes be a problem and are usually caused by gasoline leaks from ruptured underground tanks at nearby service stations. One of the most common sources of outside contamination has been carbon monoxide fumes from basement parking garages being recirculated through the building ventilation system.

INSIDE CONTAMINATION

Contamination generated by sources inside the office space was the major problem identified in 15% of our investigations. Copying machines are often found to be a significant source. Examples of this type of problem would include methyl alcohol from spirit duplicators, butyl methacrylate from signature machine and ammonia and acetic acid from blueprint copiers. Still other inside contamination problems we have encountered include pesticides which were improperly applied; dermatitis from boiler additives such as diethyl ethanolamine; improperly diluted cleaning agents such as rug shampoo; tobacco smoke of all types; combustion gases from sources common to cafeterias and laboratories; and cross-contamination from poorly ventilated sources that leak into other air handling zones.

Contaminants from inside or outside the office space, and from the building fabric are essentially chemical contaminants. Many times odors are associated with some of these contaminants which may aid in source identification. Additionally, in most cases, these chemical contaminants were measured at levels above ambient but far below any existing occupational standard.

## INADEQUATE VENTILATION

In 53% of our investigations, the building ventilation has been inadequate. When evaluating building ventilation, we normally use ASHRAE standards for comparison. ASHRAE standards 62-1981, "Ventilation for Acceptable Indoor Air Quality" (ASHRAE 1981) and 55-1981, "Thermal Environmental Conditions for Human Occupancy" (ASHRAE 1981) are both used. Some of the ventilation problems we commonly encounter are: not enough outdoor air supplied to the office space; poor air distribution and mixing which causes stratification, draftiness, and pressure differences between office spaces; temperature and humidity extremes of fluctuations (sometimes caused by poor air distribution); and air filtration problems caused by improper or no maintenance to the building ventilation system. In many cases, these ventilation problems are created or enhanced by certain energy conservation measures. These include reducing or eliminating outdoor air; reducing infiltration and exfiltration; lowering thermostats in winter, raising them in summer; eliminating humidification or dehumidification systems; and early shut-down and late start-up of ventilation systems.

## CONCLUSION

The major problems identified in these NIOSH indoor air quality investigations can be placed into three general categories listed with decreasing frequency: inadequate ventilation, chemical contamination, and microbiological contamination. Inadequate ventilation is the single largest problem we have seen in buildings. Although varied, these ventilation problems commonly can allow a build-up of any contaminants present in the occupied space to the point that adverse health effects are experienced or allow the environment to become annoyingly uncomfortable to the office workers. As our experience increased over time, we developed a solution-oriented approach to conducting these evaluations which places a high priority on building ventilation. This approach has resulted in the best allocation of our resources and has allowed more efficient use of in-field as well as analytical time.

Increasing office worker awareness and the current shift to office-based, service-type employment will no doubt increase concerns about the indoor air quality in offices and other non-industrial settings. More research into office building ventilation and its effect on background levels of contaminants will be necessary to provide additional and more appropriate guidelines for the evaluation and control of indoor air quality problems in the future.

Early recognition of a problem, with a timely and systematic evaluation, are key factors to a quick and effective resolution.

REFERENCES


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APPENDIX I

INDOOR AIR QUALITY QUESTIONNAIRE

1. Complaints Yes _____ No _____
(If yes, please check)

_____ temperature too cold
_____ temperature too hot
_____ lack of air circulation (stuffy feeling)
_____ noticeable odors
_____ dust in the air
_____ disturbing noises
_____ other
(specify) ______________________________

2. When do these problems occur?

_____ morning
_____ afternoon
_____ all day
_____ no noticeable trend

_____ daily
_____ specific day(s) of the week
which day(s) ______________________________
______________________________

3. Health Problems or Symptoms

Describe in three words or less each symptom or adverse health effect you experience more than two times per week.

Example: runny nose

Symptom #1 ______________________________
Symptom #2 ______________________________
Symptom #3 ______________________________
Symptom #4 ______________________________
Symptom #5 ______________________________
Symptom #6 ______________________________

Do the above symptoms clear up within 1 hour after leaving work:
Yes _____ No _____

If no, which symptom or symptoms persist (noted at home or at work) throughout the week? Please indicate by drawing a circle around the symptom number below.

Symptom: #1 #2 #3 #4 #5 #6

Do you have any health problems or allergies which might account for any of the above symptoms? Yes _____ No_____

If yes, please describe. ______________________________
______________________________

# GUIDANCE FOR INDOOR AIR QUALITY INVESTIGATIONS

Hazard Evaluations and Technical Assistance Branch
Division of Surveillance, Hazard Evaluations and Field Studies
National Institute for Occupational Safety and Health

Cincinnati, Ohio 45226

January 1987

APPENDIX I (CONTINUED)

Do any of the following apply to you?

_____ wear contact lenses
_____ operate video display terminals at least 10% of the work day
_____ operate photocopier machine at least 10% of the work day
_____ use or operate special office machines or equipment (specify)
______________________________

5. Do you smoke? Yes _____ No _____

6. Do others in your immediate work are smoke? Yes _____ No _____

7. Your office or suite number is ______________________________

8. What is your job title or position? ______________________________

9. Briefly describe your primary job tasks. ______________________________
______________________________
______________________________

10. Can you offer any other comments or observations concerning your office environment? (optional)
______________________________
______________________________
______________________________
______________________________
______________________________
______________________________
______________________________

11. Your name? (optional) ______________________________

12. Your office phone number? ______________________________

## FOREWORD

This guidance was prepared by researchers in the Hazard Evaluations and Technical Assistance Branch, Division of Surveillance, Hazard Evaluations and Field Studies (DSHEFS), National Institute for Occupational Safety and Health (NIOSH). It is based upon our experience in conducting approximately 450 field investigations of indoor air quality problems in many types of buildings. Because indoor air problems have become increasingly common, and because it is more efficient in certain instances for employers and/or employees to evaluate or be directly involved in the evaluation of indoor air problems, we have developed this information to guide employers and employees in this endeavor.

This guidance is presented in three sections:

1. <u>OUR EXPERIENCE</u>: which provides the reader with information regarding our experience with indoor air quality problems and describes some of the most common causes of these problems.

2. <u>SELF-EVALUATION OF INDOOR AIR QUALITY PROBLEMS</u>: a "self-help" approach to assist the reader in evaluating an indoor air quality problem.

3. <u>INDOOR AIR QUALITY CONSULTATION SERVICES</u>: where the reader can go, in addition to NIOSH, for outside assistance if self-evaluation cannot resolve the problem.

This draft guidance was prepared to help you as an employer or employee evaluate or become directly involved in the evaluation of an indoor air quality problem.

The information provided was written in the hope that it would be self-explanatory. If, however, after reading the guidance you have questions, need clarification on any of the information, or would like to further discuss a given issue, feel free to contact one of our industrial hygienists.

We would also appreciate your comments and suggestions about this draft guidance, specifically, if it was helpful or more importantly, if it was not helpful. If you would like to share your comments or suggestions, or have questions, you can contact: Hazard Evaluations and Technical Assistance Branch, DSHEFS, NIOSH, 4676 Columbia Parkway, Cincinnati, Ohio 45226 (Phone 513-841-4374).

Section I

## OUR EXPERIENCE

Since 1971, investigators in the Hazard Evaluations and Technical Assistance Branch have responded to approximately 450 complaints of indoor air quality problems in a wide variety of office settings. The majority of these investigations have been conducted since 1979, paralleling the "energy efficiency" concerns of building operators and architects.

The majority of these indoor air quality investigations are part of the Health Hazard Evaluation Program. We conduct these evaluations upon request, from employee groups, unions, management, and local, state and Federal agencies. Generally, these requests are in response to existing worker health complaints and illness.

In this section, we have summarized our findings from indoor air quality investigations completed since the beginning of the Health Hazard Evaluation Program. Although these findings represent one of the single largest data and information bases that is currently available on the subject, the reader is advised that these findings should not be viewed as a statistically-valid cross section of the indoor air quality problem.

### A. METHODS

We have found that investigating indoor air quality problems is not an easy job. These problems can be very complicated due to highly charged emotions, the complexity of the buildings themselves, and the fact that standard epidemiology and industrial hygiene evaluation techniques may be inconclusive.

Over time, we have tried to develop a consistent, solution-oriented approach to conducting these investigations. Our approach is probably best described as one of exclusion, by which we try to eliminate and narrow-down the range of possible problem causes.

Our investigation teams have typically included an industrial hygienist and a physician or non-physician epidemiologist, although other professionals (such as an engineer) have been included as well. Most of our investigations have included: a background assessment; an initial site visit; and follow-up site visits if necessary.

#### 1. Background Assessment

The intent of the background assessment has been to obtain as much historical information as practical on the building itself, (when it was constructed, its fabric type, ventilation system, previous problems and previous investigations into air quality, recent renovations, etc.). In addition, to establish a chronology of the problems, we also have tried to obtain information about the kinds of symptoms employees have been experiencing and over what period of time. We have collected much of this information by using a questionnaire. Having access to these data prior to the initial site visit has allowed us to develop more effective strategies in dealing with these problems and has promoted more efficient use of investigator time during site visits.

2. Initial Site Visit

For the initial site visit, our typical protocol has been conducted in three separate steps: a walk-through evaluation, personal interviews, and environmental monitoring.

The walk-through evaluation is needed to obtain any additional background information not obtained during the Background Assessment (architectural plans, engineering reports, or previous environmental assessments, etc.) and to gain, first-hand, a visual appreciation for the building's design and floor plan. A critical inspection of the ventilation system is also important in order to thoroughly characterize the building with respect to potential sources of chemical and microbiological contaminants.

The personal interviews are needed to better characterize the building population and to determine the nature of the symptoms and complaints being reported. The personal interviews also have been critical in determining the magnitude of the problem, specifically if the problem is widespread throughout the building, or whether it is isolated in a particular section of the building or among a certain group of employees. In many of these instances, we again have used questionnaires, to collect this information.

On-site environmental monitoring is used to confirm or to rule-out a number of problem source possibilities identified from the background assessment, the walk-through evaluation, and the personal interview portions of the initial site assessment. During the initial site assessment, direct-reading monitoring methods have been most commonly used because they are excellent screening mechanisms that provide us with immediate results and thus, allows us to provide anxious employees immediate feedback. The most common instruments that we have used are: detector tubes for carbon dioxide, psychrometers for measuring temperature and humidity, and smoke tubes for determining air movement. We also, on occasion, have tested for specific chemical and microbiological contaminants, when appropriate. It has been our experience however, that standard industrial hygiene techniques for measuring chemicals may be inconclusive since most contaminants that we monitor are usually present at concentrations far below those known to cause health-related problems in industry. While this approach may be consistent with our solution-oriented philosophy, we recognize that the capability of substances to cause health effects in trace concentrations is not well understood.

Another limiting factor in understanding what environmental measurements mean, occurs with the Evaluation Criteria that are available to compare findings against, since these Criteria vary. In the classic industrial hygiene sense, the Occupational Safety and Health Administrations's (OSHA) permissible exposure limits (PELs), the American Conference of Governmental Industrial Hygienists' (ACGIH) Threshold Limit Values (TLVs), and NIOSH's recommended exposure limits (RELs) are most commonly used to assess exposures of workers in factories. Because these criteria are based on health effects that pertain to exposures in the manufacturing environment, they may not have the same relevance for workers in an office setting, whose primary concern may be for comfort or simply an absence of unusual sensory stimuli over their working period. The Environmental Protection Agency (EPA) has ambient air quality standards for a variety of pollutants designed to protect the public over an entire day (not just an 8-hour workday). However, these, too, may not have relevance to an indoor office environment, especially from the perspective of problem-solving.

The American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE) guidelines for acceptable indoor air quality have been developed specifically for the indoor environment. We have commonly used these as our guidelines in office building evaluations, especially for assessing the performance of ventilation systems. We also use the ASHRAE comfort guidelines as criteria for assessing the thermal performance of occupied space.

In addition to the ASHRAE guidelines, we use "rule-of-thumb" measures gleaned from the current scientific literature and from our own experience. An example of these "rules-of-thumb" is the use of a carbon dioxide level of 1000 parts per million (ppm) indoors as a decision point for the determination of adequate amounts of outdoor air.

3. Follow-up Site Visit

If in the background assessment or during the initial site visit a problem has been identified that needs further definition, or if no problem can be isolated, an additional site assessment may be performed, but only in those cases where further work is most likely to result in meaningful recommendations. Subsequent site visits may result in more specific and extensive environmental monitoring for chemical and/or microbiological contaminants, and/or tracer gas monitoring to evaluate the ventilation system. In addition, follow-up site visits may be used to give building occupants a more detailed or widely distributed questionnaire or to conduct medical testing, if appropriate.

## B. DISCUSSION

Through December 1986, we had conducted 446 indoor air quality health hazard evaluations. These do not include our investigations of asbestos-related building problems, but only those where the building occupants were actually experiencing ill-health effects which appeared to be related to air quality. The number of investigations has increased markedly since 1979. This probably has been due to two factors: (1) increased energy conservation measures and (2) increased worker awareness of office environments. We now average about two Health Hazard Evaluation requests per week for indoor air quality investigations.

While the majority (~80%) of our indoor air investigations have been conducted in government and private-sector office buildings, we also have evaluated problems in schools, colleges, and health care facilities.

Commonly, the symptoms and health complaints reported by workers have been diverse and not specific to any particular medical diagnosis or readily associated with a causative agent. A typical spectrum of symptoms has included headaches, varying degrees of itching or burning eyes, irritations of the skin, including rashes, sinus problems, dry and irritated throats and other respiratory irritations. The workplace environment has been typically implicated by virtue of the fact that workers' symptoms normally disappear on weekends, when they are away from the office. At times, these symptoms have been severe enough to result in missed work, reassignment, and even termination. This has caused increased anxiety among the workers and, often times, has made the investigation of these problems even more difficult and frustrating.

Although some of these episodes may be multifactorial, we have been able to classify our evaluations by primary type of problem found: inadequate ventilation (52%); contamination from inside the building (17%); contamination from outside the building (11%); microbiological contamination (5%); contamination from the building fabric (3%); and unknown (12%).

### 1. Inadequate Ventilation

In 52% of our investigations, the building ventilation has been inadequate. When evaluating building ventilation, we normally use ASHRAE standards for comparison. ASHRAE standard 62-1981, "Ventilation for Acceptable Indoor Air Quality" and 55-1981, "Thermal Environmental Conditions for Human Occupancy" are both used. Some of the ventilation problems we commonly encounter are: not enough fresh outdoor air supplied to the office space; poor air distribution and mixing which causes stratification, draftiness, and pressure differences between office spaces; temperature and humidity extremes or fluctuations (sometimes caused by poor air distribution or faulty thermostats); and air filtration problems caused by improper or no maintenance to the building ventilation system. In many cases, these ventilation problems are created or enhanced by certain energy conservation measures applied in the operation of the building ventilation. These include reducing or eliminating fresh outdoor air; reducing infiltration and exfiltration; lowering thermostats or economizer cycles in winter, raising them in summer; eliminating humidification or dehumidification systems; and early afternoon shut-down and late morning start-up of the ventilation system.

2. Inside Contamination

Contamination generated by sources inside the office space is the major problem identified in 17% of our investigations. Copying machines are often found to be a significant source. Examples of this type of problem include; methyl alcohol from spirit duplicators; butyl methacrylate from signature machines; and ammonia and acetic acid from blueprint copiers. Still other inside contamination problems we have encountered include; exposures to pesticides; such as chlordane, which were improperly applied; dermatitis from boiler additives such as diethyl ethanolamine; improperly diluted cleaning agents such as rug shampoo; tobacco smoke of all types; combustion gases from sources common to cafeterias and laboratories; and cross-contamination from poorly ventilated sources that leak into other air handling zones.

Contaminants from inside or outside the office space, and from the building fabric are essentially chemical contaminants. Many times, odors are associated with some of these contaminants which may aid in source identification. In most cases, these chemical contaminants have been measured at levels above ambient (normal background) but far below any existing occupational evaluation criteria.

3. Outside Contamination

Contamination from sources outside the office space is the major problem identified in 11% of our investigations. Problems due to motor vehicle exhaust, boiler gases, and previously exhausted air are essentially caused by reentrainment of outside air. This is usually the result of improperly located exhaust and intake vents or periodic changes in wind conditions. Other outside contamination problems include contaminants from construction or renovation projects such as asphalt, solvents, and dusts. Also, gasoline fumes infiltrating the basement and/or sewage system can sometimes be a problem and these are usually caused by gasoline leaks from ruptured underground tanks at nearby service stations. One of the most common sources of outside contamination has been vehicle exhaust fumes from parking garages being drawn into the building ventilation system.

4. Microbiological Contamination

Five percent of our investigations have involved some type of microbiological contamination. Even though this is not a common cause of office problems, it can result in a potentially severe health condition known as hypersensitivity pneumonitis. This respiratory problem can be caused by bacteria, fungi, protozoa, and microbial products that may originate from ventilation system components. A similar condition known as humidifier fever, most commonly reported in Europe, is also the result of microbiological contamination in ventilation systems. In our investigations, microbiological contamination has commonly resulted from water damage to carpets or furnishings, or standing water in ventilation system components.

Although a variety of disorders (hypersensitivity pneumonitis, humidifier fever, allergic rhinitis, conjunctivitis) can result from microbiological exposure, we generally have not documented the existence of these disorders on the basis of medical or epidemiological data. However, even if visible microbial growth can not be directly related to the health complaints reported, it is a problem that needs to be addressed and corrected.

5. Building Fabric Contamination

Contamination from building materials and products is the major problem in 3% of our investigations. Formaldehyde can off-gas from urea-formaldehyde foam insulation, particle board, plywood, and some glues and adhesives commonly used during construction. Other building fabric contamination problems encountered include: dermatitis resulting from fibrous glass erosion in lined ventilating ducts; various organic solvents from glues and adhesives; and acetic acid used as a curing agent in silicone caulking.

C. CONCLUSION

The major problems[1] identified in our indoor air quality investigations can be placed into three general categories listed with decreasing frequency: inadequate ventilation, chemical contamination, and microbiological contamination. Inadequate ventilation is the single largest problem we see in buildings. Although varied, these ventilation problems commonly can allow a build-up of any contaminants present in the occupied space to the point that adverse health effects are experienced or allow the environment to become annoyingly uncomfortable to the office workers. As our experience has increased over time, we have developed a solution-oriented approach to conducting these evaluations which places a high priority on building ventilation.

1. Although not specifically mentioned, it is also important to recognize tobacco smoke as a potentially major contributor to indoor air quality problems. Tobacco smoke contains several hundred toxic substances, the more important are: carbon monoxide, nitrogen dioxide, hydrogen cyanide, formaldehyde, hydrocarbons, ammonia, benzene, hydrogen sulfide, benzo(a)pyrene, tars, and nicotine. Tobacco smoke can irritate the respiratory system and, in allergic or asthmatic persons, often results in eye and nasal irritation, coughing, wheezing, sneezing, headache, and other related sinus problems. People who wear contact lenses often complain of burning, itching, and tearing eyes when exposed to cigarette smoke. The ASHRAE ventilation guidelines for smoking areas recognize the need to provide additional ventilation (fresh outside air) to maintain air quality.

Section II

## SELF-EVALUATION OF INDOOR AIR QUALITY PROBLEMS

After reading the first section, you should have a good idea of what constitutes an indoor air quality problem and what we have found to be some of the common causes. The information in this section will provide guidelines on how to proceed to evaluate your specific question of indoor air quality. Many of these steps you can undertake by yourself or with the assistance of your building maintenance personnel. For some you may need to seek outside assistance from an industrial hygiene or ventilation consultant.

### A. INITIAL ASSESSMENT

#### 1. Documentation of Complaints

You will first need to obtain an estimate of the magnitude and distribution of the problem. This may be accomplished by questionnaire (example attached - Appendix I) or interview, or may be evident by how the problem was initially identified. A review of the interview/questionnaire data should help to better define what the complaints are, whether there is any localization of the problem in the building, and any particular circumstances of weather, time of day, day of week, building occupancy, or activity which improve or worsen the problem.

Some questions that you will want to include in the questionnaire or interview outline are:

a. What health complaints have been experienced?

b. When is the first time they were noticed?

c. Is there any specific incident or event that is linked with the initial onset of the complaints? (building renovations, new carpeting, new equipment, etc.)

d. How often do they occur? (several times per day/week, etc.)

e. How long do they last? (minutes/hours, all day)

f. Are there particular times of the day they occur? (morning vs. afternoon, etc.)

g. Do they occur in particular areas of the building vs. others?

h. Are there any specific activities, tasks or unusual circumstances that accompany the problem?

i. When do the health complaints go away? (soon after leaving the building, at home, on weekends)

As you review the data from the questionnaires, or your interviews, you will begin to get an idea of who has experienced health complaints and who has not. In addition, you should also begin to get a clearer picture of what symptoms and complaints are being reported. At this point, you may find it helpful to place individuals into categories to determine; those who definitely have health complaints, those who do not, and those who fall somewhere in between the first two categories. This exercise will at least provide you with numbers, to help determine the extent of the problem. You may also find it helpful to plot this information on a simply drawn sketch of the floor-plan, that identifies individuals in each category according to where their work stations are located. This will provide a graphic display of how complaints are distributed in the building and may help determine if the problem is wide-spread, or localized in a particular area.

You should also keep in mind as you review your data, that it's not unusual to have building occupants with health or comfort complaints from time-to-time; in fact it's normal! For example, the ASHRAE guidelines for thermal comfort strive to satisfy 80% of the building occupants. It would therefore not be unreasonable in a survey to find 20% of the occupants thermally "uncomfortable". Using the same reasoning, not every health complaint will necessarily be air quality related. In summary, your questionnaire data should be interpreted with care.

2. Building Characterization

Another important set of data to be obtained is associated with the building itself. What is known about the building composition and the ventilation system may provide important clues leading to problem solution. To assist you in gathering information about the building and the ventilation system, you should begin by filling in the answers to the questions listed below. (You may find it helpful and necessary to get assistance from persons who are responsible for building and ventilation system maintenance, or from an industrial hygienest or engineer. In addition, access to blue prints, diagrams, and specifications for the ventilation system etc., will also be valuable in answering the questions and assessing potential problem areas.)

a. What is the building's age?____________________

What is the basic construction?____________________

Number of floors?__________ No. square feet/floor__________

Type of windows?________________ Do they open?__________

b. Who is responsible for the functioning of the building systems? (i.e., ventilation)____________________

c. Who is responsible for cleaning the interior of the building?______

______________________________

How often is cleaning done?____________________

d. Have there been any major renovations or operating changes?________

What were they?____________________

When did they occur?____________________

e. Does the building have sprayed or foamed insulation?____________

When was it applied?____________________

f. What type of heating system is used?____________________

g. What type of cooling system is used?____________________

h. What type of humidification system is used?____________________

i. How is the total ventilation system operated?____________________

______________________________

j. What floors and rooms are served by each system?____________________

______________________________

k. What type of filtration system is used?____________________

How often is it changed/maintenanced?____________________

l. How much fresh air is being introduced into the ventilation system?

____________________

Does this amount meet system specifications?____________________

m. Where are the fresh air inlets and are they functioning properly?

______________________________

n. Are there any possible sources of contamination located in the general vicinity of the air inlets?____________________

o. How likely are contaminants to be drawn into the air inlets due to prevailing winds and inversions?____________________

p. How does exhaust air leave the building?____________________

q. Is the building being used for the same purpose(s) for which it was designed?______________________________

r. What type of activities are building occupants engaged in?______________________________

s. What processes or activities are present in the building that may serve as contaminant sources?______________________________

How are they vented?______________________________

3. Walk-Through Survey

A walk-through survey of the building is essential to ensure that information collected by interview and/or questionnaire is accurate. A walk-through survey of the building is also helpful to assess the overall condition of the building and to determine that systems are functioning properly.

The following are some specific problem areas which may be identified and some possible solutions.

a. Specific equipment is giving off solvent fumes, ozone (older dry copiers or sparking electric motors) or heat which is not being adequately dissipated. If this type of problem needs better definition, assistance should be obtained from an industrial hygienist or manufacturing representative.

b. Improper cleaning procedures may be leaving irritating residues in the carpets. Underdilution of industrial strength cleaners can do this. Repeated steam or clean water cleaning can improve or eliminate the problem.

c. Equipment or cleaning products may be giving off solvent fumes (such as typewriter or duplicator cleaners). Also other use of solvent based materials in greater than minimal quantities may be a source of contaminants. Work practices may be able to be modified sufficiently to prevent a problem, or increased dilution ventilation, or local exhaust ventilation may be necessary.

d. Filters and wet areas (humidifiers, dehumidifiers, cooling coils) in the ventilating system may not be cleaned frequently enough. Wet areas may not be draining properly. The most unfortunate outcome can be excessive fungal spores being distributed through the system with some individuals becoming hypersensitive to them and developing hay fever like symptoms or hypersensitivity pneumonitis. Because assessment of spore counts is neither simple nor cheap, cleaning up the system is the preferred first step.

e. The air intake for the ventilating system may be located where it brings in contaminated air. Perhaps it only happens during rush hour traffic, or under specific weather conditions. If it appears to happen only under specific circumstances of short duration, one solution may be to shut off the air intake during the specific time. If it is a more general problem and the major contaminant is carbon monoxide (CO) from auto exhaust or a chimney, a general assessment using low range CO detector tubes can be made. If other substances appear important an industrial hygienist should be consulted. Correction of a building's air intake problem will probably require some structural modification and/or changing traffic patterns.

f. There may be adequate exhaust ventilation with inadequate make-up air. This reduces the efficiency of the exhaust ventilation and may lead to reverse flow in some vents. Under more extreme conditions this may show up as an inrush of outside air whenever a door or window is opened. This condition can also lead to the back-drafting of flue gases from vented natural gas appliances such as hot water heaters and boilers. Such situations will require that more make-up air be supplied. Outside environmental conditions will dictate how much treatment the additional outside air will need. It may be necessary to get professional engineering help to correct this problem.

g. The ventilating system may be out of balance or the temperature control may be inadequate. The feed-back from the building occupants should be quite helpful in pin-pointing these problems. Poor temperature control may be due to inadequate recovery time after the ventilating system has been shut down over night or over the weekend. Another possibility is that windows allow given rooms to pick up a greater solar heat load than the ventilation system can handle. Professional help may be necessary to correct this problem. The desirable temperature is dependent on customary dress, level of physical activity, amount of air movement, and individual variation. There is no one "ideal" temperature, however, ASHRAE guidelines state the operative temperature for thermal acceptability of sedentary or slightly active persons at 50% relative humidity is 73 to 79°F.

h. During winter in the colder climates, indoor air can become excessively dry when heated to comfortable temperatures. This can lead to drying and irritation of mucus membranes of the eyes, nose and throat. It may be necessary to humidify the air in excess of the water vapor added by the occupants' respiration. If the air is to be humidified (ASHRAE guidelines recommend 20-60%), remember the necessity of adequately cleaning the humidifier. Also, recirculating or independent steam humidification is preferable to filter plate type humidifiers.

i. A few individuals may be excessively sensitive, perhaps on an allergic basis, to some substance in the environment (cigarette smoke included). Increased ventilation may handle this, but it may be necessary to either modify the environment more drastically, or to move the worker(s).

j. The pressures of work, interpersonal stresses, management-labor stresses, home-demand vs. work-demand stresses, etc. may result in the workforce being aggravated by minor problems in the work environment which otherwise might simply be ignored.

At this stage of the evaluation, it is quite possible that specific problems such as non-functioning ventilation equipment, poor temperature control, etc. will become evident as a major factor in the problem. If this is the case, the problem or problems should be corrected before the evaluation continues. Correction of problems may or may not require assistance from outside contractors.

In other instances the cause or causes of an indoor air quality problem may not be so easily determined. In such instances we advise initially using a simple approach to evaluating the effectiveness of the ventilation system, including temperature and humidify factors.

B. INTERMEDIATE ASSESSMENT

1. Guidelines

a. Carbon Dioxide Levels

Carbon dioxide ($CO_2$) is a normal constituent of exhaled breath and, if monitored, can be used as a screening technique to evaluate whether adequate quantities of fresh outdoor air are being introduced into a building or work area. The outdoor, ambient concentration of $CO_2$ is usually 250-350 ppm. Usually the $CO_2$ level is higher inside than outside, even in buildings with few complaints about indoor air quality. However, if indoor $CO_2$ concentrations are more than 1000 ppm (3 to 4 times the outside level), there is probably a problem of inadequate ventilation and complaints such as headaches, fatigue and eye and throat irritation are frequently found to be prevalent. The $CO_2$ concentration itself is not responsible for the complaints. However, a high concentration of $CO_2$ may indicate that other contaminants in the building may also be increased and could be responsible for occupant complaints. If $CO_2$ concentrations are maintained below 600 ppm, with comfortable temperature and humidity levels, complaints about air quality should be minimal. If $CO_2$ levels are greater than 1000 ppm, widespread complaints may occur and thus 1000 ppm should be used as an upper limit guideline. This does not mean that if this level is exceeded the building is hazardous or that it should be evacuated, but rather this level should be a guideline that helps maximize comfort for all occupants. Levels between 600 ppm and 1000 ppm are less clearly interpreted.

b. Temperature

ASHRAE has published guidelines describing thermal environmental conditions, (ASHRAE Standard 55-1981, Thermal Environmental Conditions for Human Occupancy). These guidelines are intended to achieve thermal conditions in a given environment, that at least 80% of the persons who occupy that environment will find acceptable or "comfortable." The following is an example of the guideline that ASHRAE recommends for a building environment that is occupied by sedentary or slightly active persons, during the summer season, and when the relative humidity is at 50%: The operating temperture to achieve thermal acceptibility (comfort zone) should be 73° to 79°F. If the operating temperature is outside this range, (at either end-point), then more than 20% of healthy people occupying the area are likely to experience some degree of discomfort.

c. Humidity

The majority of references addressing temperature and humidity levels as they pertain to human health frequently appear in the context of assessing conditions in hot environments. Development of a "comfort" chart by ASHRAE presents a comfort zone considered to be both comfortable and healthful. This zone lies between 73 and 77°F (23 and 25°C) and 20 to 60 percent relative humidity. ASHRAE's recommended design conditions are an effective temperature and dry bulb temperature of 76°F (24.5°C), a relative humidity of 40 percent, and an air circulation rate of less than 45 feet per minute. Effective temperature is an index of relative comfort determined by successive comparisons of individuals to different combinations of temperature, humidity, and air movement. Relative humidity levels below 20 percent are associated with increased discomfort and drying of the mucous membranes.

d. Provision of Adequate Amounts of Outside Air

ASHRAE Standard 62-1981 (Ventilation for Acceptable Indoor Air Quality) recommends guidelines for a wide variety of commercial, institutional, and industrial facilities, including office buildings. For general offices where smoking is not permitted, indoor air quality is considered adequate if outside air is provided at the rate of 5 cubic feet per minute (CFM) per occupant. Higher ventilation rates are recommended for areas where smoking is permitted because tobacco smoke is one of the most difficult air contaminants to control. Thus, where smoking is allowed, a minimum of 20 CFM of outdoor air per occupant should be provided (ASHRAE 62-1981, Table 3, Section 3.1).

2. Sampling Techniques for Carbon Dioxide, Temperature, Humidity and Air Flow

$CO_2$ concentrations can easily be determined by using direct reading detector tubes which indicate concentration as a function of length of color change on a sampling tube. Tubes and their associated sampling pumps can be obtained from most local industrial safety equipment supply houses. (See example - Figure 1.)

Plan your sampling locations. Include some areas where there are problems and some where there are not. If there is no difference between areas, pick some from each area of the building.

Start sampling first thing in the morning. You should be among the first people in the building that day. Get baseline samples at all your major sample spots including an outside sample. During the day get representative samples in all your major sampling locations, the frequency determined by the variety and duration of activities. You will probably want to get samples just before the lunch break, particularly if there is a significant decrease in building occupancy at lunch. You will want samples again at the end of the work day just before everyone starts leaving (a lot of in-out traffic would allow more air exchange than during the major part of the day). Depending on the number of sampling sites and activities involved, you may want additional samples at other locations. Record all $CO_2$ measurements in ppm, by specific location and time of day.

To round out the monitoring, temperature and humidity should be checked at various times and places throughout the day, and if necessary, air flow at vents and return air grills should be evaluated as well. Although wet bulb, dry bulb thermometers can be used, that degree of accuracy is unnecessary. A desk thermometer and relative humidity meter should be adequate. Measurements for air flow are intended to assure that vents are functioning (perhaps intermittently) and to possibly see if the airflow is directed in a suitable direction. Air movement from vents is easily checked with smoke tubes, which are also available from any safety supply house. (See example - Figure II.) Exact measurements are less important at this stage of the evaluation.

3. Interpretation of Results

Your decision to take further action will be determined by what you have found during your day of sampling. The following, represent some of the possible general trends and recommendations for followup, that have been identified through $CO_2$ monitoring.

a. Initial $CO_2$ readings inside the building are close to outside readings (250-350 ppm). During the day there are a few rises and falls, but by quitting time readings are still close to initial readings. This suggests that fresh air intake is sufficient. Perhaps the first approach to improving the livability of the building will be to look at temperature and humidity, and check for imbalances in the ventilating system.

b. Initial $CO_2$ readings inside the building are close to outside readings. During the day levels rise and are definitely elevated by the close of work. This suggests that over 24 hours the air intake is sufficient, but may not be sufficient during the hours the building is occupied.

c. Initial $CO_2$ readings inside the building are appreciably higher than outside readings. This may simply be due to the shutdown of the ventilating system when the building is unoccupied, or it may be due to underventilation which will require provision of significantly more fresh air. In this case it will be necessary to arrange to have the system left on for several hours after the occupants leave.

d. Temperature, humidity and air flow readings compare unfavorably with specified guidelines. Steps should be taken to adjust systems to comply with the guidelines.

4. Contaminant Sources

Additional evaluation of point sources of contaminants also may be necessary. If point sources such as copy machines, blue print machines, solvents, etc. are suspected to be causing the problem, the assistance of an industrial hygienist, or a manufacturing representative, may be necessary.

5. General Recommendations for the Correction and Prevention of Indoor Air Quality Problems

a. Ensure an Adequate Fresh Outdoor Air Supply

This has been shown to be the single most effective method of correcting and preventing problems and minimizing complaints related to poor indoor air quality. Even if a specific contaminant is identified (such as formaldehyde) dilution may be the most practical way of reducing exposures.

(1) If mechanical ventilation is on, check that the outdoor air supply louvers are open. They may have been closed deliberately to save energy, or automatically by a faulty control system.

(2) Fresh, outdoor air should be adequately distributed to all office areas during the entire time they are occupied, at a minimum rate of 5 cubic feet per minute (cfm) of fresh air per person. In areas where smoking is permitted this rate should be increased to 20 cfm per person. These levels are specified in the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 62-1981, "Ventilation for Acceptable Indoor Air Quality." If the exact number of occupants is not known, an estimate of 7 persons per 1000 $ft^2$ may be used to calculate ventilation requirements. Fresh air ventilation rates should be measured on a regular basis to ensure they remain at optimal levels.

(3) During occupancy periods it should be assured that outdoor air dampers (vents) do not close, nor do fans of air handling units turn off at certain times of the day or within certain temperature ranges. These problems may mean that modifications must be done on the ventilation system so that it can handle very cold or very warm air.

(4) All air vents (diffusers) should be checked to ensure they are open and unobstructed, providing for adequate air mixing in each supplied area. Also the diffusers should be adjusted so that occupants are not sitting in a direct stream of air. Often the air stream temperature will be less than body temperature and be uncomfortably cool.

(5) If the office layout has been changed (e.g., by erecting partitions, room dividers, or new walls), care must be taken that adequate air flow is still being provided.

(6) An insufficient supply of make-up (fresh) air can cause the building to be at a negative pressure with respect to the outdoor atmosphere, creating a situation where untreated air and/or contaminants can infiltrate from outside. This can be determined by observing the direction of air movement at windows and doors. In order to prevent this problem, particular attention must be paid to proper balancing of the air supply and exhaust systems.

(7) A program of preventive maintenance must be in place for all ventilation equipment, including checking; damper positions and functioning belts, baffles, ductwork, and system balance. Actual air flow supplied to occupied areas must be measured and any necessary maintenance or repairs done to comply with the original design specification and the ASHRAE Guidelines.

(8) If possible, gauges should be installed to provide information on air volumes delivered by supply and return fans, and maintenance people should be trained to read them and respond appropriately.

(9) Filters on air handling units must be replaced at regular intervals. Permanent static pressure gauges are helpful in deciding when to change filters. Filters should have a moderate efficiency rating, as measured by the ASHRAE atmospheric dust spot test, and should be of an extended surface type. Pre-filters (e.g., roll type) should be used before air passage through higher efficiency filters.

b. Eliminate or Control all Known and Potential Sources of Chemical Contaminants

(1) Use local exhaust where appropriate to capture and remove contaminants generated by specific processes. In some instances, the manufacturer of office machines will advise whether exhaust ventilation is recommended.

(2) General room air from areas where contaminants are generated (e.g., a printing area where solvents are used) should be exhausted directly outdoors rather than recirculated into the rest of the building's air supply.

(3) Check to be sure outside air intakes or other building vents or openings are not located in close proximity to potential sources of contamination (e.g., places where motor vehicle emissions collect, downwind of exhausts, cooling towers, etc.). If necessary, raise stacks or relocate intakes or exhausts.

(4) Isolate areas of renovation, painting, carpet laying, etc., from occupied, non-construction areas through use of physical barriers and separation of involved ventilation systems. If possible, perform this type of work on evenings and weekends. Supplying a maximum amount of ventilation to the areas initially on a 24 hour basis can assist in rapid dispersion of contaminant levels.

(5) Pesticides should be applied only while the building is unoccupied, and the building should be thoroughly ventilated before reoccupation.

(6) Eliminating or reducing contamination of the air supply with cigarette smoke is a recognized method of improving the indoor environment. Cigarette smoke contains many substances (e.g., carbon monoxide, formaldehyde, particulates) that pollute the air and may build up in poorly ventilated areas. Bans on smoking or restriction of smoking to designated areas (preferably that have their air supply exhausted rather than recirculated) are methods of dealing with this pollution source.

c. Eliminate or Control all Known and Potential Sources of Microbial Contaminants

(1) Promptly detect and permanently repair all areas where water collection or leakage has occurred.

(2) Maintain relative humidity at less than 60% in all occupied spaces and low-air-velocity plenums. During the summer, cooling coils should be run at a low enough temperature to properly dehumidify conditioned air.

(3) Check for, correct, and prevent further accumulation of stagnant water under cooling deck coils of air handling units, through proper inclination and continuous drainage of drain pans.

(4) Use only steam, not water, as the moisture source for humidifiers in the ventilation systems. Steam should not be contaminated with volatile amines (sometimes used as rust inhibitors).

(5) Once contamination has occurred (through dust or dirt accumulation or moisture-related problems) downstream of heat exchange components (as in ductwork or plenum), additional filtration downstream may be necessary before air is introduced into occupied areas.

(6) Water-damaged porous furnishings, including carpets, upholstery and ceiling tiles, should be discarded rather than disinfected, to effectively eliminate microbial contamination.

(7) Air handling units should be constructed so that equipment maintenance personnel have easy and direct access to both

heat exchange components and drain pans for checking drainage and cleaning. Access panels or doors should be installed where needed.

(9) Non-porous surfaces where moisture collection has promoted microbial growth (e.g., drain pans, cooling coils) should be cleaned and disinfected with detergents, chlorine-generating slimicides (bleach), and/or proprietary biocides. Care should be taken to insure that these cleaners are removed before air handling units are reactivated.

## C. CONCLUSIONS AND FOLLOW-UP ASSESSMENTS

If sufficient information has been obtained to identify the problem or problems, corrective action can be taken. Depending on the complexity of the problem, it may or may not be necessary to call in expert help, such as that of an engineering/ventilation consultant or an industrial hygienist. Keep in mind that early recognition of a problem, with a timely and systematic evaluation, are key factors to a quick and effective resolution.

In summary:

1. Make a log of employee complaints.
2. Assess the ventilation system for the building, including temperature and humidity factors.
3. Identify and evaluate sources of contaminants.
4. Correct identified deficiencies and control or eliminate identified sources of contaminants.
5. Monitor complaints after remedial action has been taken.

Section III

## INDOOR AIR QUALITY CONSULTATION SERVICES

If further evaluation is needed to resolve the problem or if technical expertise is needed to complete any of the self-evaluation steps outlined above, on-site assistance is available from the following sources.

1. Local or State Health Departments or Consulting Programs (Availability and expertise vary with locality and state)

2. Private Consultants (availability and expertise vary)

   a. A list of industrial hygiene consultants who are members of the American Industrial Hygiene Association (AIHA) is available from the AIHA:

      American Industrial Hygiene Association
      475 Wolf Ledges Parkway
      Akron, Ohio 44311-1087

   b. A list of engineering firms certified by the National Environmental Balancing Bureau (NEBB) is available from the NEBB:

      National Environmental Balancing Bureau
      8224 Old Courthouse Road
      Vienna, Virginia 22180

3. NIOSH - Health Hazard Evaluation Program:

      National Institute for Occupational Safety and Health
      Hazard Evaluations and Technical Assistance Branch
      4676 Columbia Parkway
      Cincinnati, Ohio 45226

Additional background information concerning indoor air quality can be obtained from the following sources.

1. Environmental Protection Agency
   820 Quincy Street, N.W.
   Washington, D.C. 20011

2. Consumer Product Safety Commission
   Washington, D.C. 20207

3. Office of Scientific and Technical Information
   Department of Energy
   P.O. Box 62
   Oak Ridge, Tennessee 37830

6. Federal Employee Occupational Health Program (contact your regional Public Health Service Office)

Appendix I

## INDOOR AIR QUALITY QUESTIONNAIRE

1. Complaints Yes ____ No ____
(If yes, please check)

____ temperature too cold
____ temperature too hot
____ lack of air circulation (stuffy feeling)
____ noticeable odors
____ dust in air
____ disturbing noises
____ other (specify) ____________________

2. When do these problems occur?

____ morning
____ afternoon
____ all day
____ no noticeable trend

____ daily
____ specific day(s) of the week
which day(s)? ____________
____________

3. Health Problems or Symptoms

Describe in three words or less each symptom or adverse health effect you experience more than two times per week.

Example: runny nose

Symptom #1 ____________________

Symptom #2 ____________________

Symptom #3 ____________________

Symptom #4 ____________________

Symptom #5 ____________________

Symptom #6 ____________________

Do the above symptoms clear up within 1 hour after leaving work?
Yes ____ No ____

If no, which symptom or symptoms persist (noted at home or at work) throughout the week? Please indicate by drawing a circle around the symptom number below.

Symptom: #1 #2 #3 #4 #5 #6

Do you have any health problems or allergies which might account for any of the above symptoms? Yes ____ No ____

If yes, please describe. ____________________

____________________

____________________

4. Do any of the following apply to you?

_____ wear contact lenses
_____ operate video display terminals at least 10% of the work day
_____ operate photocopier machines at least 10% of the work day
_____ use or operate other special office machines or equipment (specify)

_______________________________________________

_____ currently taking medication
reason for taking medication (specify) ____________________

_______________________________________________

5. Do you smoke? Yes_____ No_____
6. Do others in your immediate work area smoke? Yes_____ No_____

7. Your office or suite number is ____________________

8. What is your job title or position?____________________

9. Briefly describe your primary job tasks. ____________________

_______________________________________________

_______________________________________________

10. Can you offer any other comments or observations concerning your office environment? (optional)

_______________________________________________

_______________________________________________

_______________________________________________

_______________________________________________

_______________________________________________

_______________________________________________

_______________________________________________

_______________________________________________

11. Your name? (optional) ____________________

12. Your office phone number? (optional)____________________

Am. Ind. Hyg. Assoc. J. 47(4):207-213 (1986)

# Evaluation of Building Ventilation Systems

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**Over the past several years, NIOSH has responded to health hazard evaluation requests from workers in dozens of office environments. Typically, the employees have complained of headache, eye and upper respiratory tract irritation, dizziness, lethargy and the inability to concentrate. Most often "inadequate ventilation" has been blamed for these complaints. Of paramount importance in the evaluation and correction of these problems is an effective evaluation of the building's ventilation system. Heating, ventilating and air-conditioning conditions that can cause worker stresses include: migration of odors or chemical hazards between building areas; reentrainment of exhaust from building fume hoods or through heat wheels; buildup of microorganisms in the HVAC system components; and poor odor or environmental control due to insufficient "fresh" outdoor air or system heating or cooling malfunction. The purpose of this paper is to provide an overview of building ventilation systems, the ventilation problems associated with poorly designed or operating systems, and the methodology for effectively evaluating system performance.**

## Introduction

Man has constructed buildings to protect himself and his possessions from the elements. Enclosures, however, may not protect man from various sources of pollution. Sterling and Kobayashi[1] have reviewed studies on pollution in enclosed living and working places and have come to the following conclusions: "Buildings do not protect their inhabitants from pollution. To the contrary, the body burden of toxic vapors and dusts in the 'inside' may very well exceed the burden of pollution in the 'outside'."

Pollutants in an office-type environment may arise from multiple sources: human metabolic activity, smoking, structural components of the building, biological contamination, cooking, office equipment and outside air pollution.

Metabolic activity produces a variety of by-products: carbon dioxide, water, feces, flatus, urine, breath, sweat, glandular secretions and organic dust particles from hair, skin, mucus and dead cells. From breath come acetic acid, acetone, volatile oils, methane and hydrogen sulfide; from urine come volatiles, ammonia and ethereal sulfates; from sweat and glandular secretions come urea, lactic and other organic acids.[1]

In studies of smoking in test rooms and in public buildings, measureable (and in some cases excessive) levels of particulate matter, carbon monoxide, nicotine, acrolein, acetaldehyde and benzo(a)pyrene[1] have been found.

Materials of construction have been shown to cause measurable levels of contamination in office environments. Formaldehyde can be released from urea formaldehyde insulation materials. Low vapor pressure solvents may evaporate over extended periods of time from paints and adhesives.[1]

Air conditioning and heating systems can become contaminated with many types of microorganisms. Then these systems in turn pollute the indoor environment with these microorganisms.[2,3]

Cooking is a major source of hydrocarbons and particulate matter. Gas appliances also can produce carbon dioxide, carbon monoxide and nitrogen oxides.[1]

A typical office may use equipment which may liberate other contaminants; *i.e.*, mimeograph machines — methyl alcohol; blueprint machines — ammonia; office copiers — ozone, toner chemicals.[1]

### *Tight Building Syndrome*

Public and private residential and commercial buildings consume about one-fourth of the total end-use energy produced in the United States. Thus, increasing attention has been directed to the design of new structures and the modifications of existing ones to minimize the consumption of energy.

Typical energy reduction strategies include:

1. Modification of the chiller cycling to operate equipment near capacity;
2. Reduction of the outdoor air component of the office supply system to a minimum;
3. Reduction of the total air circulation to the minimum value needed to maintain design space ventilation conditions;
4. Elevation of cooling coil discharge temperature with a concurrent increase in relative humidity at the design room temperature;
5. Periodic shutdown of ventilation system components.[4]

Energy reduction strategies also may include use of sealed windows, lower winter and higher summer room temperatures and centralized control of air conditioning, heating and lighting. These strategies may give office employees the feeling that they are not in control of their work environment.

Over the past several years, NIOSH has conducted health hazard evaluations in response to requests from workers in numerous office environments.[5-7] Typically, the employees have complained of headache, eye and upper respiratory tract irritation, dizziness, lethargy and the inability to concentrate. Most often "inadequate ventilation" has been blamed for these complaints. In the majority of these cases, measurements for airborne contaminants have failed consistently to identify toxic contaminants as a probable cause

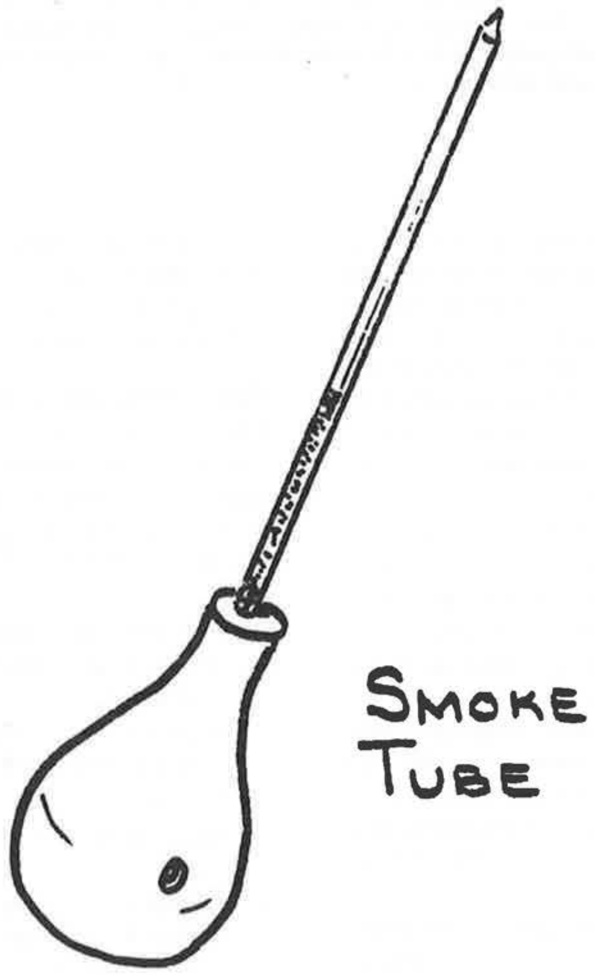



**Figure II**

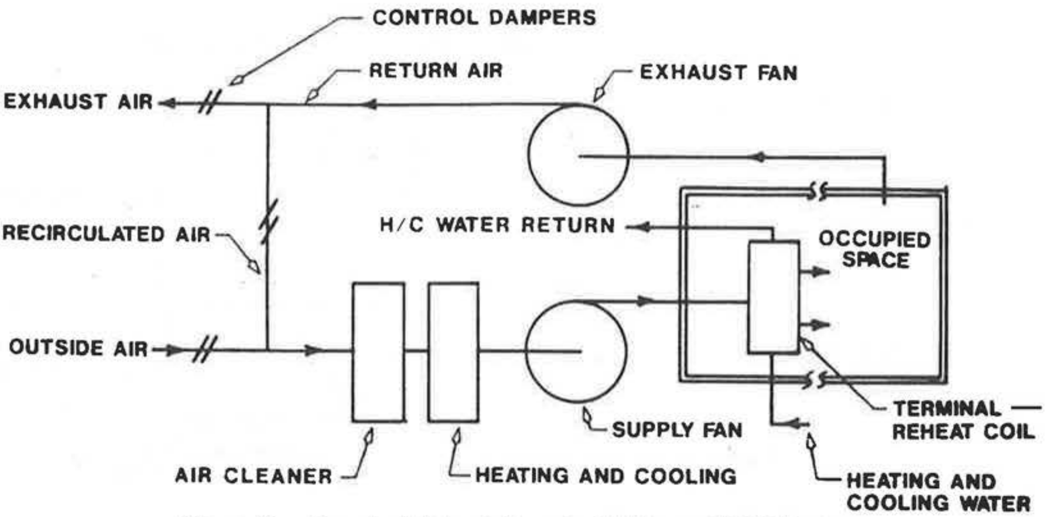



Figure 3 — Terminal Reheat Constant Volume HVAC System.

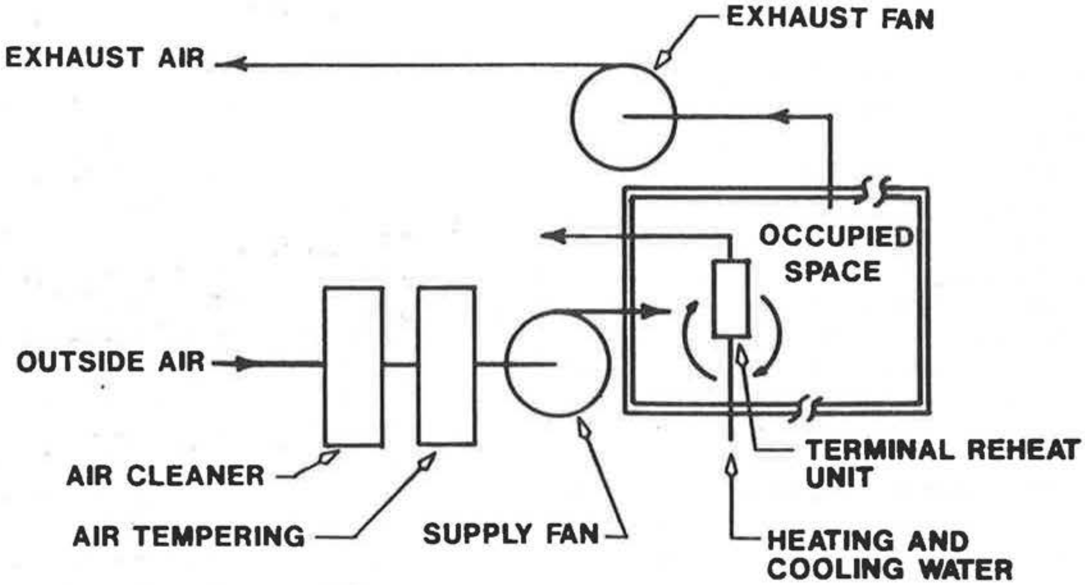



Figure 4 — All Water HVAC System.

Both systems can utilize outside air to assist in temperature control and to assure that an appropriate amount of outside air is circulated throughout the building. In limited cases, the entire airflow may consist of outside air (single pass system). Most systems, however, will incorporate recirculation of the return air as an energy conservation feature. The quantity of outside air in recirculated air systems can vary from 10% (which may approach the minimum required for odor and contaminant control) to 100% of the system supply flow. The actual quantity is determined by the indoor/outdoor air temperature relationship and in many cases by the overall energy conservation requirements.

***Air and Water Systems***

Air and water (also known as terminal reheat) systems are similar to the single duct all-air systems described previously. Before discharge into the room, however, the air passes through a terminal (fan coil) unit supplied with heating/cooling water. A typical system is depicted in Figure 3. Some initial heating or cooling may be performed. Like all-air systems, these systems typically recirculate a portion of the building air.

***All-Water Systems***

All-water systems normally use a number of self-contained fan coil units (same as terminal retreat), which distribute heated or cooled air to the work space. Unlike the air and water systems, all of the heating or cooling airflow is recirculated from the work space. Outside air still is required for ventilation and is introduced through a separate duct system with some initial tempering. A schematic of a typical all-water system is shown in Figure 4.

All three types of HVAC systems may incorporate humidification and dehumidification operations. Dehumidification usually will be required during the cooling season and

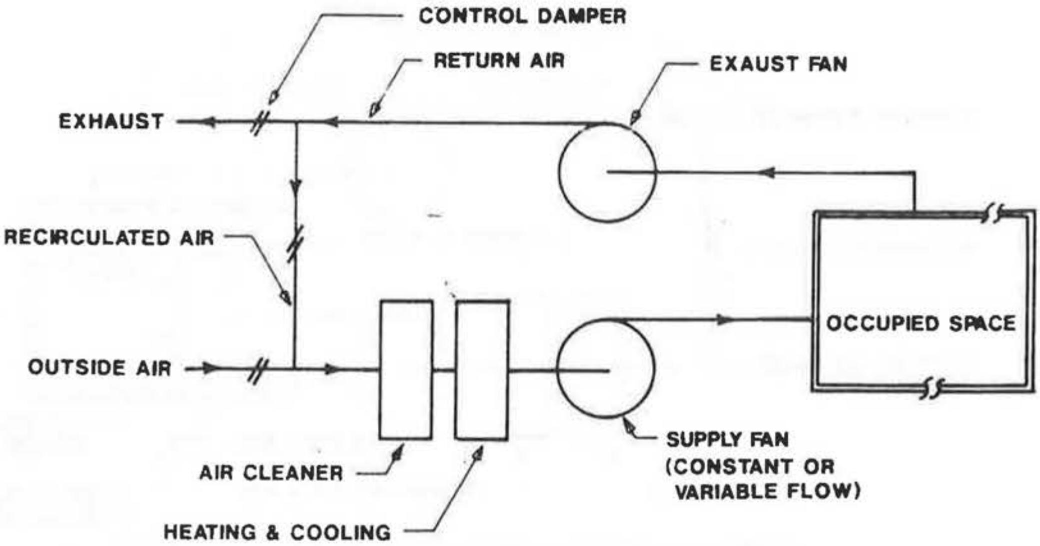


Figure 1 — Constant or Variable Air Volume HVAC System.

for employee symptoms; NIOSH investigators repeatedly have documented insufficient (or total lack of) fresh air in these same environments. Extremes in temperature and relative humidity have been noted also.

Of paramount importance in the evaluation and correction of these problems is a thorough analysis of the building's ventilation system. The purpose of this document is to provide an overview of building ventilation systems, the ventilation problems associated with poorly designed or poorly operating systems and the methodology for effectively evaluating system performance.

**Heating, Ventilating and Air Conditioning (HVAC) Systems**

There are three basic types of heating, ventilating and air conditioning (HVAC) systems: the all-air system; the air and water system; and the all-water system.[8]

***All-Air Systems***

All-air systems may exist as large central units serving an entire building or small unitary systems serving small areas or zones within a building. These systems heat or cool the air at a central location and transmit it to the room(s) as indicated in Figure 1. The air may be tempered to the desired condition and transmitted through a single duct or hot and cool air may be transmitted separately *via* a dual duct system and appropriately mixed just prior to discharging into the room. A dual duct system is illustrated in Figure 2. All-air systems may be further classified as constant air volume (CAV) or variable air volume (VAV). The CAV system is operated at a fixed flow rate and varies the temperature only. The VAV system operates in the same manner relative to the heating, cooling and transmission of air, but has the additional capability of varying the air volume as well as temperature depending upon the space heating or cooling load.

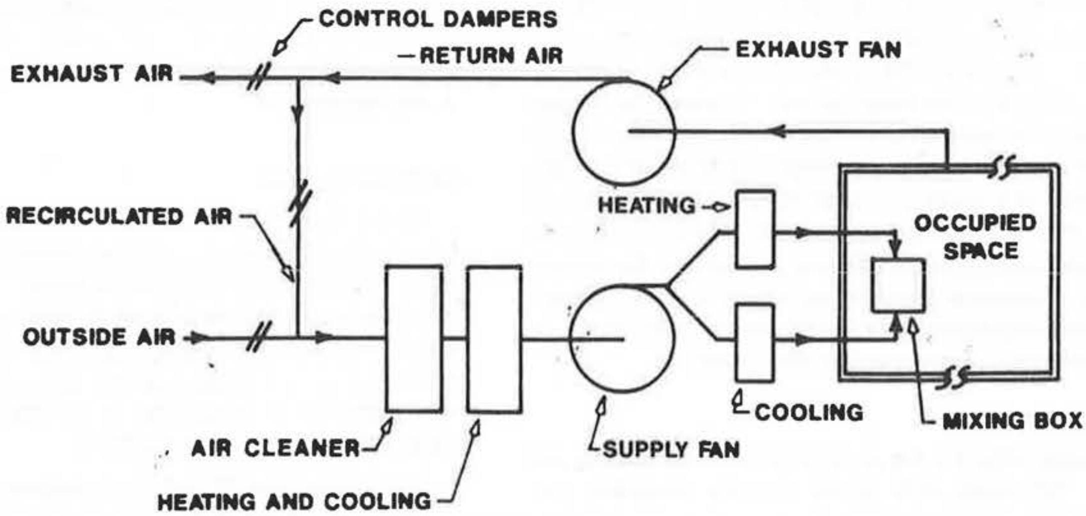
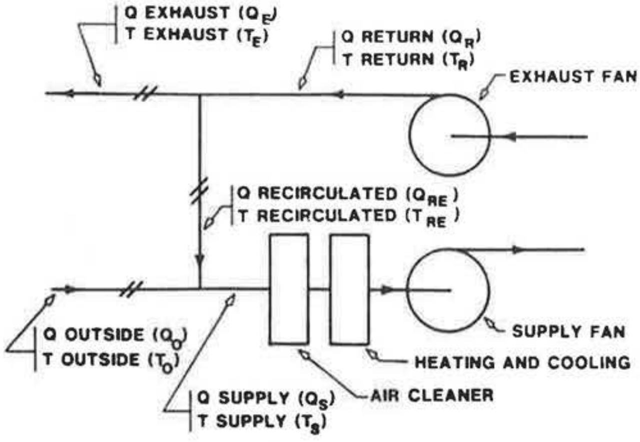


Figure 2 — Constant Air Volume Dual Duct HVAC System.




NOTE: $T_R = T_E = T_{RE}$ IF MEASURED AT OR NEAR AIR HANDLING SYSTEM AND % OUTSIDE AIR = $\frac{Q_O}{Q_S} \times 100$

Figure 6 — Determination of Outside/Supply Air Rates by Temperature Measurement.

heated discharge air through the wheel, which is packed with a heat absorbing material. The wheel rotates permitting the cooler incoming air to pick up heat from the wheel material. Contaminants may be transferred to the incoming air *via* leakage or carry-over in the wheel heat absorbing material.

**4. Poor Odor or Environmental Control Due to Insufficient Ventilation**

There are two requirements for HVAC system airflow: to provide for adequate heating, cooling and humidification (or dehumidification) of a space and its occupants and contents and to provide sufficient outdoor air for odor and/or contaminant control. Heating or cooling airflow requirements usually are the dominant consideration, and it is common to recirculate most of the air. A small fraction of the airflow is vented to the outside and replaced with fresh air to prevent a buildup of odors or other air contaminants. Malfunction of system inlet dampers, improper settings or poor initial design can reduce the volume of outside air below requirements needed for control of odor and contaminants. This problem may be difficult to identify as the total airflow into the space may appear to be sufficient.

**5. Microorganisms as Contaminants in HVAC Systems**

Practically all HVAC systems will incorporate filtration, dehumidification and humidification to some degree. Filter media are composed of fabric or fibrous materials. These materials can harbor microorganisms if not kept clean and moisture-free. Water from humidification systems may drain into sumps within the system. If not treated or replenished adequately with fresh water, biological growth may occur. Dehumidification systems, while removing water from the air, incorporate drain pans which may become contaminated and cause similar problems. In all cases these microorganisms may be carried into the occupied building space by the ventilation air.

## Evaluation of HVAC Systems

The first step in evaluation of a system is to obtain design drawings and to determine the type and configuration of components, including the number, location, type and size of fresh air intakes and building exhausts, and the areas served by each part of the system. This may be difficult if the building is large, modifications have been made, or the system is otherwise complex. In such cases, it may be necessary to consult the building architect/engineer. As a minimum, it will be necessary to define the system with relation to the problem, *i.e.*, How is the suspected (or actual) source area ventilated and how is the complaint area ventilated?

It is not feasible to provide a specific evaluation procedure, which will provide answers to all problems; instead, the guidelines presented below should enable the reader to evaluate many of the common problems described earlier.

### *Reentrainment of Air From Building Exhaust*

Reentrainment problems usually manifest themselves by detection of odors or contaminants in an area remote from the source. If there are a number of inlets, detection in any number of areas may occur with shifts in the wind direction.

Evaluation can be accomplished by one of two procedures. In both cases, the physical characteristics of the exhaust and intake systems must be determined. Specific attention should be given to the perceived migration path of the contaminant. Where does the alleged contaminant originate? Where is it exhausted? Where is the air intake serving the complaint area located?

Release of smoke (by use of a smoke candle or grenade) in the discharge stack can provide visual evidence of the flow path. This method is not quantitative, but in many cases can identify the problem. A tracer can be released at a known rate into the exhaust system in the source area with measurements taken at a supply discharge grille or supply point in the detection area. If the tracer is present, it confirms the reentrainment. By knowing the tracer release rate and the airflow rate, the tracer concentration in the exhaust air can be calculated. By comparison of this value to the concentration in the detection area supply air, the dilution of the exhaust contaminant can be determined. Detection of the tracer in the supply air will verify reentrainment; determination of the relative concentration will quantify the severity.[11,12]

Sulfur hexafluoride ($SF_6$) has been used as a tracer gas. It is chemically inert and is present normally in the environment. Measurements can be made with infrared detection devices or gas chromatography with the use of electron capture detectors. Infrared devices will provide satisfactory results but require rather large quantities of the tracer due to their low sensitivity. Gas chromatography proves more satisfactory by being able to detect $SF_6$ in concentrations as low as 1 ppb. Other racer materials may be used provided that they are not present normally in the areas of concern and detection instrumentation is available.[11]

### *Migration Within a Building*

Migration of odors or contaminants within a building is caused by differences in pressure between building areas.

**TABLE I**
**Outside Air Requirements for Ventilation[A]**
**(cfm/Person)**

| | Smoking | Non-Smoking |
|---|---|---|
| Office space | 20 | 5 |
| Meeting space | 35 | 7 |
| Classrooms | 25 | 5 |
| Libraries | - | 5 |
| Hospital operating room | - | 40 |
| Photo dark room | - | 20 |
| Retail store show room | 25 | 5 |
| Dry cleaning storage area | 35 | 10 |

[A]From ASHRAE 62-1981 Table III.

normally is accomplished at the system cooling coils. Conversely, humidification usually is required during the heating season. Humidification typically is performed by spraying water or steam into the supply airflow, or by passing the air through water-soaked media.

Air-moving systems usually incorporate filtration for the removal of dust particles but also may include charcoal beds for odor control. Particle removal usually is accomplished by fabric filtration although some use of electrostatic precipitation may be found.

Actual system configuration may be a combination of more than one type. The systems described are used primarily for environmental control of the core portion of a building. Perimeter heating and cooling units may be used also. These may be small individual steam or water units occasionally incorporating fans to circulate air with the room. Some of these units provide for introduction of outside air.

### *HVAC System Problems Relating to Employee Health*

HVAC problems may be an adverse impact on employee health and well-being. HVAC conditions which may cause worker stresses include: migration of odors or chemical hazards throughout the building; reentrainment of exhaust from building fume hoods or through heat wheels; buildup of microorganisms in the HVAC system components; and inadequate environmental control which results from an insufficient supply of "fresh" outdoor air or malfunctions in heating or cooling components. It is not unusual for several of these problems to occur simultaneously.

#### 1. Migration of Odors

Odors or chemicals may migrate from their origin in one part of a building to another in a number of ways. If the HVAC system serving the area of origin is common to others and if air is recirculated (as is the common case), the contaminant will migrate quickly *via* the recirculated air.

If the building area is served by more than one HVAC system, pressure imbalances may occur between zones. This will cause air to move from the higher pressure zone into the lower pressure zone. The movement may be from one area to an adjacent area or can be from floor to floor. Pressure imbalance also can occur within a single ventilation system if the room supply and exhausts are not balanced properly.

#### 2. Reentrainment of Building Exhaust

Wind currents flowing over a building create a turbulent recirculating flow pattern over the roof area and a turbulent wake on the downstream building side.[9,10] The size of these patterns will vary with the shape of the building, but they always exist. If the exhaust discharge is within the roof flow pattern, exhaust air will be dispersed at roof level and into the downstream wake. Exhaust air contaminants may be taken into any air inlet located in the recirculation and wake area. Low profile building exhaust discharge and inlets are common due to aesthetic design considerations. The net result may be the inadvertent recirculation of contaminants into the building air intakes.

#### 3. Reentrainment Through Heat Recovery Wheels

Heat recovery wheels absorb heat from discharge air and transfer it to incoming air. They function by passing the

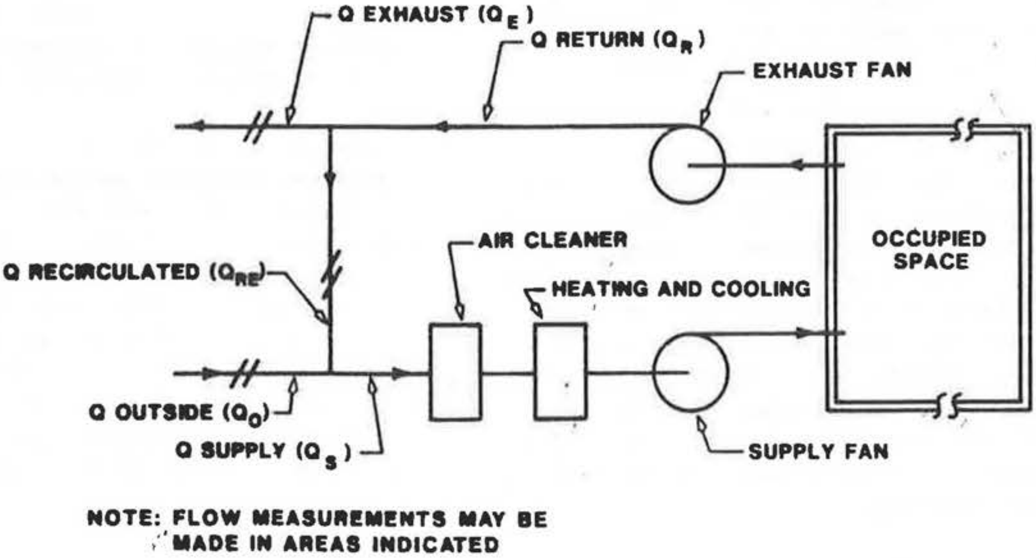



Figure 5 — HVAC System AirFlow Measurement.

The percentage of outside air in the supply system therefore equals

$$Q_O / Q_S \times 100.$$

Caution must be used so that the temperature measurements are taken at points that are representative of the respective airflow. Also, the supply air temperature must be taken upstream of the supply blower and any heating or cooling apparatus.

A third method, which does not require flow or temperature measurements, uses a tracer gas.[14] A tracer gas is released at a steady rate into the system, either *via* the outside air or the main supply until a steady state concentration is achieved in the room or area under investigation. Then the release is stopped, and the concentration decay is measured. Then the room ventilation rate is determined from

$$I = \frac{1}{t} \ln \frac{C_o}{C}$$

where I = ventilation rate, (room air changes per hour)
t = time, (hours)
$C_o$ = concentration of tracer at time = 0
C = concentration of tracer at time = t

### *Biological Contaminants*

Evaluation of any HVAC system should include a thorough check of filters and sumps for cleanliness.[2,3] Water draining from the humidification components may stagnate and will often foster the growth of biological contaminants. These systems should be designed to permit complete drainage of the collected water. If the water is recirculated, sufficient replacement must be provided to preclude stagnation. Filters must be checked for cleanliness also since these components may harbor microorganisms and reduce airflow as well. Dirt allowed to collect in ducts and in perimeter HVAC systems can provide the substrate which fosters the growth of microorganisms.

## Summary

Evaluation techniques described in this paper help to provide an effective measure of the flow rates and overall performance of building ventilation systems. The tracer techniques described are very effective in determining flow patterns or migration of building contaminants.

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Unfortunately, equal pressures are difficult to maintain in multi-story and multi-area buildings, especially when more than one ventilation system is used. In certain cases such as laboratory buildings, pressure differentials serve useful purposes by containing contaminants within the low pressure area.

To evaluate possible migration of air contaminants, it is first necessary to determine the physical characteristics of the building ventilation system(s). The existence of pressure differentials can be determined by use of smoke tubes at doors and hallways. The direction of smoke travel will be in the direction of higher to lower pressure. This method provides more of an indication of migration than a quantitative assessment. The use of a tracer gas also can provide accurate documentation of a contaminant migration. Here the tracer would be released into the room air in the source area while sampling is conducted in other building areas.

### *Reentrainment Through Heat Recovery Wheels*

Contaminants may be transferred to an incoming air stream *via* leakage or carry-over in the wheel heat absorbing material. Contamination through leakage can be evaluated by use of the tracer gas technique. The tracer is released in the exhaust air inlet to the heat wheel and measured in the heat wheel outside or make-up air discharge duct. Comparison of the mass flow of the tracer in the two ducts can provide a quantitative measure of the problem.

### *Insufficient Outside Air*

Fresh (outside) air ventilation rates are recommended by the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHR AE62-1981)[13] for occupied spaces (Table 1). For example, 20 cfm per person is recommended where there is smoking, and 5 cfm per person where there is no smoking. These rates are designed to provide for normal odor and contaminant control. These flow rates usually are much lower than the airflow required for heating and cooling. If the HVAC system does not recirculate, the supply air will be from the outside and the ventilation rules should be satisfied. Single pass systems, however, are outnumbered greatly by HVAC systems which recirculate return air directly to the supply side inlets. Provision for outside ventilation air then must be incorporated into the system. This usually is accomplished by a series of dampers as diagrammed schematically in Figure 5.

The level of recirculation usually is dependent upon the indoor/outdoor temperature relationship. One typically observes higher levels of recirculation when the temperature difference is great and lower when the temperature difference is small. The level of outside ventilation air should not fall below that recommended by ASHRAE. Unfortunately, this minimum level is not always maintained for a number of reasons. The initial design may have not been adequate either in determination of the proper value or in specification of system components. Deterioration or malfunction of system components may have occurred. A final and all too common reason is an arbitrary reduction or elimination of outside air to conserve energy.

The initial step in evaluating the ventilation of a building or area is to determine the system configuration (*i.e.*, single-pass, variable air volume, recirculation, *etc.*). The specific approach to evaluation will depend on this configuration.

For a single-pass system the ventilation rate will be the same as the total airflow rate. Airflow measurements may be taken at grilles or in ducts if accessible. Evaluation of a recirculating system is more difficult. Outside airflow to a space may range from 0 to 100% of the total airflow. For example, if the ratio of outside air to the total flow is 10%, then the cfm/person would be determined by the product of this ratio and the total space airflow divided by the number of people occupying the space.

Obtaining the fresh air and total system flow rates can be difficult depending on the physical complexity of the HVAC system. There are three general approaches that may be used. The first is direct measurement of the appropriate airflows. Such measurements can be made with pitot tubes and/or direct-reading instruments such as hot wire anemometers or rotating vane anemometers. The three principal streams to measure are the outside airflow, the HVAC system main supply airflow and the airflow to the space under investigation. While some buildings will contain well defined ductwork with accessible measurement points, many will not. It may be necessary to measure average velocity over the face of a grille to determine airflow. Duct measurements may be made in any convenient place as long as the measurement represents the total flow of interest. Room air usually will be supplied from grilles or through slots incorporated into light fixtures. Special portable flow measuring hoods for measuring total air volume from various shaped outlets are available commercially which greatly speed these measurements.

In many situations, there may not be sufficient access to permit airflow measurements with standard techniques. Where this occurs a temperature balance may be appropriate. This technique is a thermal energy balance between the recirculated air, outside air and the supply air streams. The sum of the products of the recirculated air and the outside airflows and their respective temperatures should equal the product of the supply air and its temperature. Since the supply airflow is the sum of the recirculated and outside airflows, the percent of outside air in the supply can be calculated.

Referring to Figure 6 shows:

$$Q_{RE}\,T_{RE} + Q_O\,T_O = Q_S\,T_S$$

and

$$Q_{RE} + Q_O = Q_S$$

Solving these equations yields

$$Q_O/Q_S = \frac{T_S - T_{RE}}{T_O - T_{RE}}$$

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Additional References

The following non-NIOSH references provide additional information on indoor air quality. These references may be obtained from your local public or university library, or from the issuing organization or government agency.


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