

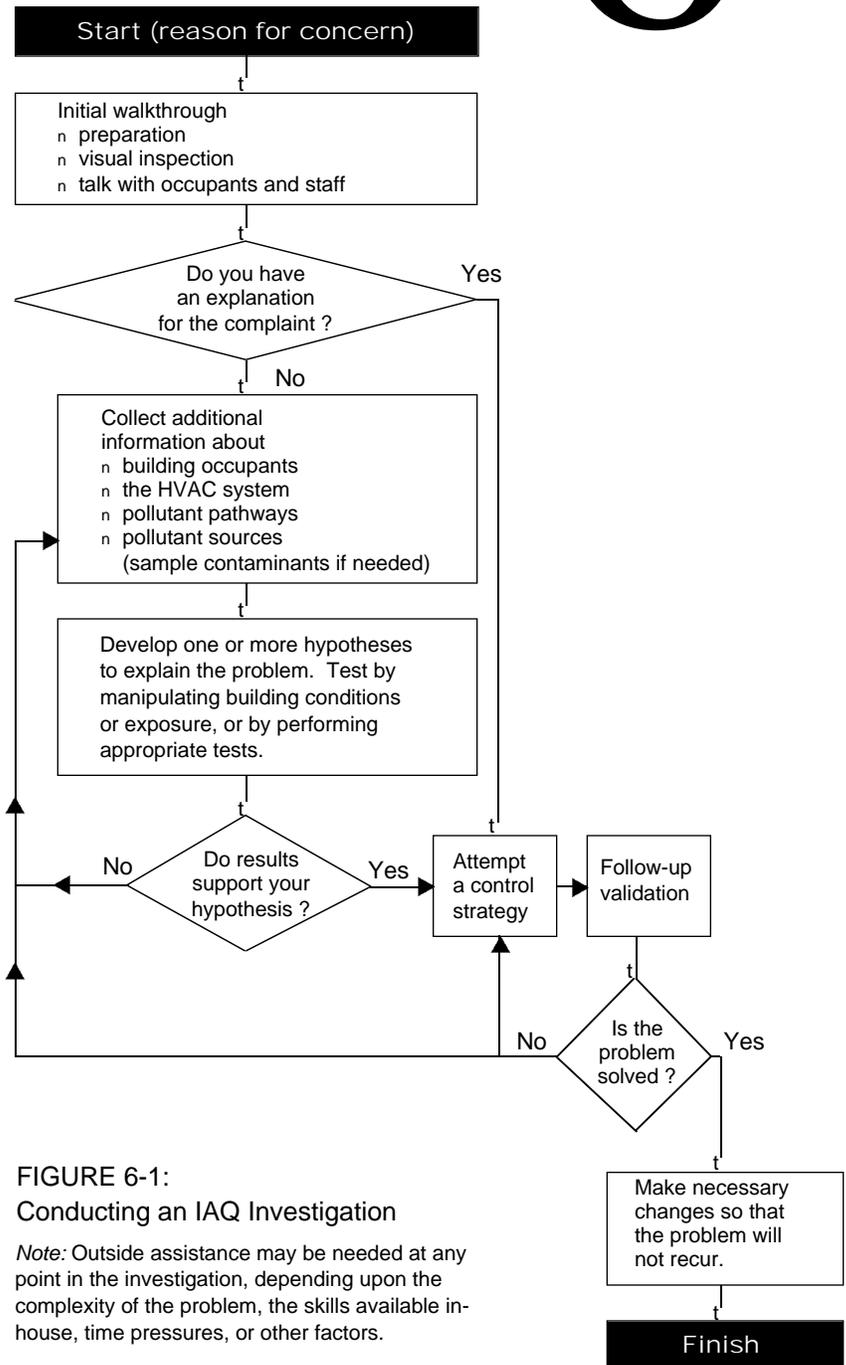
# Diagnosing IAQ Problems

# 6

The goal of the diagnostic building investigation is to identify and solve the indoor air quality complaint in a way that prevents it from recurring and that does not create other problems. This section describes a method for discovering the cause of the complaint and presents a “toolbox” of diagnostic activities to assist you in collecting information.

Just as a carpenter uses only the tools that are needed for any given job, an IAQ investigator should use only the investigative techniques that are needed. Many indoor air quality complaints can be resolved without using all of the diagnostic tools described in this chapter. For example, it may be easy to identify the source of cooking odors that are annoying nearby office workers and solve the problem by controlling pressure relationships (e.g., installing exhaust fans) in the food preparation area. Similarly, most mechanical or carpentry problems probably require only a few of the many tools you have available and are easily accomplished with in-house expertise.

The use of in-house personnel builds skills that will be helpful in minimizing and resolving future problems. On the other hand, some jobs may be best handled by contractors who have specialized knowledge and experience. In the same way, diagnosing some indoor air quality problems may require equipment and skills that are complex and unfamiliar. Your knowledge of your organization and building operations will help in selecting the right tools and deciding whether in-house personnel or outside professionals should be used in responding to the specific IAQ problem.



The IAQ investigation is often a repetitive cycle of information-gathering, hypothesis formation, and hypothesis testing.

## OVERVIEW: CONDUCTING AN IAQ INVESTIGATION

An IAQ investigation begins with one or more reasons for concern, such as occupant complaints. Some complaints can be resolved very simply (e.g., by asking a few common sense questions of occupants and facility staff during the walkthrough). At the other extreme, some problems could require detailed testing by an experienced IAQ professional. In this section “the investigator” refers to in-house staff responsible for conducting the IAQ investigation.

The flowchart on page 45 shows that the IAQ investigation is a cycle of information-gathering, hypothesis formation, and hypothesis testing. The goal of the investigation is to understand the IAQ problem well enough so that you can solve it. Many IAQ problems have more than one cause and may respond to (or require) several corrective actions.

### Initial Walkthrough

An initial walkthrough of the problem area provides information about all four of the basic factors influencing indoor air quality (occupants, HVAC system, pollutant pathways, and contaminant sources). The initial walkthrough may provide enough information to resolve the problem. At the least, it will direct further investigation. For example, if the complaint concerns an odor from an easily-identified source (e.g., cooking odors from a kitchen), you may want to study pollutant pathways as a next step, rather than interviewing occupants about their patterns of discomfort.

### Developing and Testing Hypotheses

As you develop an understanding of how the building functions, where pollutant sources are located, and how pollutants move within the building, you may think of many “hypotheses,” potential explana-

tions of the IAQ complaint. Building occupants and operating staff are often a good source of ideas about the causes of the problem. For example, they can describe changes in the building that may have occurred shortly before the IAQ problem was noticed (e.g., relocated partitions, new furniture or equipment).

Hypothesis development is a process of identifying and narrowing down possibilities by comparing them with your observations. **Whenever a hypothesis suggests itself, it is reasonable to pause and consider it.** Is the hypothesis consistent with the facts collected so far?

You may be able to test your hypothesis by modifying the HVAC system or attempting to control the potential source or pollutant pathway to see whether you can relieve the symptoms or other conditions in the building. If your hypothesis successfully predicts the results of your manipulations, then you may be ready to take corrective action. Sometimes it is difficult or impossible to manipulate the factors you think are causing the IAQ problem; in that case, you may be able to test the hypothesis by trying to predict how building conditions will change over time (e.g., in response to extreme outdoor temperatures).

### Collecting Additional Information

If your hypothesis does not seem to be a good predictor of what is happening in the building, you probably need to collect more information about the occupants, HVAC system, pollutant pathways, or contaminant sources. Under some circumstances, detailed or sophisticated measurements of pollutant concentrations or ventilation quantities may be required. Outside assistance may be needed if repeated efforts fail to produce a successful hypothesis or if the information required calls for instruments and procedures that are not available in-house.

## Results of the Investigation

Analysis of the information collected during your IAQ investigation could produce any of the following results:

***The apparent cause(s) of the complaint(s) are identified.***

Remedial action and follow-up evaluation will confirm whether the hypothesis is correct.

***Other IAQ problems are identified that are not related to the original complaints.***

These problems (e.g., HVAC malfunctions, strong pollutant sources) should be corrected when appropriate.

***A better understanding of potential IAQ problems is needed in order to develop a plan for corrective action.***

It may be necessary to collect more detailed information and/or to expand the scope of the investigation to include building areas that were previously overlooked. Outside assistance may be needed.

***The cause of the original complaint cannot be identified.***

A thorough investigation has found no deficiencies in HVAC design or operation or in the control of pollutant sources, and there have been no further complaints. In the absence of new complaints, the original complaint may have been due to a single, unrepeated event or to causes not directly related to IAQ.

## Using Outside Assistance

Some indoor air quality problems may be difficult or impossible for in-house investigators to resolve. Special skills or instruments may be needed. Other factors can also be important, such as the benefit of having an impartial outside opinion or the need to reduce potential liability from a

serious IAQ problem. You are best able to make the judgment of when to bring in an outside consultant. See *Section 8* for a discussion of hiring professional assistance to solve an IAQ problem.

## INITIAL WALKTHROUGH

An investigation may require one or many visits to the complaint area. The amount of preparatory work needed before the initial walkthrough varies with the nature and scope of the complaint and the expertise of the investigator, among other factors. For example, an in-house investigator who is already familiar with the layout and mechanical system in the building may begin responding to a complaint about discomfort by going directly to the complaint area to check the thermostat setting and see whether air is flowing from the supply outlets.

If the investigator is not familiar with the building or is responding to complaints that suggest a serious health problem, more preparation may be needed before the initial walkthrough. The activities listed below can be directed at a localized “problem area” or extended to include the entire building:

***Collect easily-available information about the history of the building and of the complaints.***

***Identify known HVAC zones and complaint areas.***

Begin to identify potential sources and pollutants (e.g., special use areas near the complaint location). Having a copy of mechanical and floor plans can be helpful at this stage, especially if they are reasonably up-to-date.

***Notify the building occupants of the upcoming investigation.***

Tell them what it means and what to expect.

**Identify key individuals needed for access and information.**

A person familiar with the HVAC systems in the building should be available to assist the investigator at any time during the onsite phase. Individuals who have complained or who are in charge of potential sources (e.g., housekeeping, non-HVAC equipment) should be aware that their information is important and should be contacted for appointments or telephone interviews if they will not be available during the onsite visit.

The initial walkthrough provides an opportunity to question complainants about the nature and timing of their symptoms and to briefly examine the immediate area of the complaint. The investigator attempts to identify pollutant sources and types and observes the condition and layout of the HVAC system serving the complaint area. Facility staff can be asked

to describe the operating schedule of equipment. Obvious problems (e.g., blocked diffusers, malfunctioning air handlers) can be corrected to see if the complaints disappear. The walkthrough can solve many routine IAQ problems and will suggest directions for a more complex investigation, should one be necessary.

Some investigators avoid taking any measurements during the initial walkthrough so that they are not distracted from “getting the big picture.” Others find that using smoke sticks, digital thermometers, and direct reading CO<sub>2</sub> meters or detector tubes to take occasional measurements helps them develop a feel for the building.

It may help to keep the following questions in mind during the initial walkthrough:

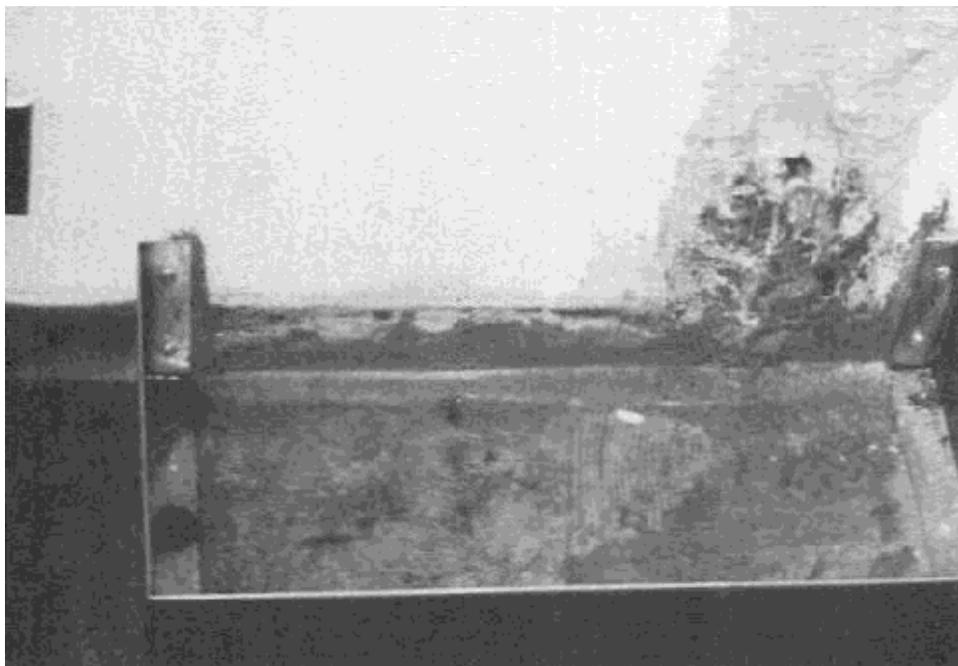
**Are there obvious pollutant sources? Do they appear to be adequately controlled?**

- n Are pollutant indicators present, such as odors, excessive dust, or staining?
- n Are there sanitation problems (e.g., debris near outdoor air intake, visible mold growth, major water damage) that could be introducing air contaminants?
- n Are there any conditions or activities occurring in or near the building that could be related in timing, location and health effects to the complaints?

**Are there any deficiencies in the HVAC system that serves the complaint area?**

- n Does equipment serving the area (e.g., thermostats, diffusers, fans, dampers, filters) appear to be operating, clean, and in good condition?
- n Do operating procedures exist, and does the staff follow them?
- n Do records indicate that the system was commissioned (set, tested, and balanced) after construction?
- n Do records indicate that system components are regularly inspected, calibrated, and adjusted?

*This improvised catch basin is intended to collect water seeping into the building from below grade. Although the catch basin “solves” the problem of uncontrolled water leakage, it also provides an indoor location that could support the growth of microbiologicals and create IAQ problems.*



***Are there pathways and pressure differences which could be moving contaminants into the complaint area from the outdoors or from other parts of the building?***

**COLLECTING ADDITIONAL INFORMATION**

Additional information will be needed if the initial walkthrough does not identify the cause of the problem. The following pages present techniques for collecting information about the occupant complaints, HVAC system, pollutant pathways, and pollutant sources and using that information to develop a hypothesis that could explain the problem. Common sense will suggest the appropriate sequence of steps during this part of the investigation. For example, if the complaint is limited to a single room, it makes sense to evaluate pollutant pathways into that room before attempting to inventory sources in locations outside of, but connected to, the complaint area. On the other hand, if the complaint involves a recognizable odor (e.g., exhaust fumes), it may be more practical to begin by locating the potential source(s) of the odor before trying to identify pollutant pathways.

Forms and checklists such as the samples provided in this document (modified if needed) can help investigators to record information in an organized way. Small copies of basic floor plans, such as fire evacuation plans, are convenient for noting locations of observations.

Any instruments that will be used should be inspected to make sure they are in working order and calibrated. IAQ investigations generally include the use of, at a minimum: heatless chemical smoke devices and instruments for measuring temperature and humidity.

Carbon dioxide measuring devices (detector tubes with a hand pump or a direct reading meter) are helpful for most investigations. Other instruments may be needed as the investigation progresses. See *Appendix A* for additional guidance on common IAQ measurements.

**Tools for Collecting Information**

The following pages present strategies, tools, and forms for the investigator to use during an in-depth investigation. The **Incident Log** shown below (and in Tab V) can be used to track the course of an investigation from the receipt of the original complaint.

SEE COMPLETE FORM PAGE 183

**Sample Form  
Incident Log**

File Number	Date	Problem Location	Investigation Record (check the forms that were used)									Outcome / Comments	Log Entry By (initials)
			Complaint Form	Occupant Interview	Occupant Diary	Log of Activities	Zone/Room Record	HVAC Checklist	Pollutant Pathway	Source Inventory	Hypothesis Form		

## COLLECTING OCCUPANT INFORMATION

### Strategies

Review existing information about complaints

Collect additional information from occupants

### Tools

- n Existing Records
- n IAQ Complaint Form
- n Incident Log

- n Occupant Interview
- n Occupant Diary



*An initial walkthrough may uncover problems such as this unsanitary condition in the HVAC system. Bird droppings have collected in an air supply plenum near an outdoor air intake that was not protected by a birdscreen.*

The discussion that follows has been divided into categories of occupant data, HVAC system data, pollutant pathway data, and source data. However, the suggestions for collecting and using information reflect the interdependence of these factors. For example, the operation of the air distribution system affects pollutant pathways, and the air distribution system can also be a source of pollutants.

Indoor air quality-related complaints may develop from a variety of causes. Neither the discussion of strategies for collecting information nor the suggestions for interpreting data can present the full range of possible situations encountered in

buildings. They are intended to present a problem-solving approach that can help facility staff to understand and resolve many common indoor air quality problems. If you decide to hire outside professionals to resolve your IAQ complaint, this discussion of strategies and tools should help you to understand and oversee their investigative work.

## COLLECTING INFORMATION ABOUT OCCUPANT COMPLAINTS

Occupant data falls into two categories: complaints of discomfort or other symptoms (e.g., teary eyes, chills) and perceptions of building conditions (e.g., odors, draftiness). Investigators can gather valuable information about potential indoor air problems from listening to occupants, and use that information for:

- n defining the complaint area within the building
- n suggesting directions for further investigation, either by identifying other events that seem to happen at the same time as the incidents of symptoms or discomfort, or by identifying possible causes for the types of symptoms or discomfort that are occurring
- n indicating potential measures to reduce or eliminate the problem

### Review Existing Records of Complaints

If there is a record of occupant complaints, a review of that record can help to define the location of the IAQ problem and identify people who should be interviewed as part of the investigation. Information about the history of complaints could also stimulate theories about potential causes of the problem.

### Interview Occupants

The most obvious way to collect information from building occupants is to talk to

them in person. If it is not possible to interview everyone who has complained about building conditions, the investigator should attempt to interview a group of individuals that reflect the concerns of the affected areas.

The investigation may also include occupant interviews with building occupants who do not have complaints. Then conditions in the complaint area can be compared to conditions in similar building locations where there are no complaints.

A sample **Occupant Interview** form is shown here (there is another copy in Tab V). It can also be presented in a written form in order to get information from more people than can be interviewed. The following key points will help interviews to be productive:

- n Read the discussion of evaluating occupant data before you conduct interviews, to be certain that you understand what sort of information is needed.
- n Make a copy of the interview form for each person you speak with, and use the form to record the answers to your questions.
- n Choose a location in which the person you are interviewing feels comfortable to speak freely.
- n Explain that the interview is intended to help discover and correct the cause of the complaints. Encourage the person you are interviewing to join in this cooperative problem-solving effort.
- n Give the person you are interviewing enough time to think about your questions.
- n If complainants are reluctant to answer questions about health symptoms, respect their desire for privacy. Planning for how to maintain this privacy is warranted, and in some cases may be mandated.
- n Feel free to expand the interview by adding questions that help to improve your understanding or explore their

## Sample Form Occupant Interview

### SYMPTOM PATTERNS

What kind of symptoms or discomfort are you experiencing?

Are you aware of other people with similar symptoms or concerns?  
Yes\_\_\_\_\_ No\_\_\_\_\_

If so, what are their names and locations?

Do you have any health conditions that may make you particularly susceptible to environmental problems?

### TIMING PATTERNS

When did your symptoms start?

hypotheses (or your own) about what may be causing the problem. Always be open to answers that may not fit your hypotheses.

- n You may sometimes need to clarify a question by giving examples of the sort of information you are interested in. Try to provide more than one example so that you don't seem to be telling the person the answer you want. Be particularly cautious about mentioning specific health effects.

The **Occupant Interview** includes many basic points that are found in questionnaires used by professional IAQ investigators. It is important to note, however, that this form is not called a "questionnaire." Formal questionnaires may be useful for quantitative epidemiology, IAQ research, complex IAQ investigations, or when litigation is a possibility. In these cases, questionnaires must be carefully designed and executed by people with an understanding of representative sampling and expertise in public health, industrial hygiene, or medicine. Use of questionnaires for such purposes is beyond the scope or expertise of most in-house investigations; if such questionnaire data is

SEE  
COMPLETE  
FORM  
PAGE 185

Sample Form  
Occupant Diary

On the form below, please record each occasion when you experience a symptom of ill-health or discomfort that you think may be related to an environmental condition in the building.

Time/Date	Location	Symptom	Severity/Duration	Comments

Sample Form  
Log of Activities and System Operations

On the form below, please record your observations of HVAC system operation, maintenance activities, and any other information that you think may be helpful in identifying the cause of IAQ complaints in this building. Please report any other observations (e.g., weather, other associated events) that you think may be important as well.

Equipment and activities of particular interest:

Air Handler(s): \_\_\_\_\_

Exhaust Fan(s): \_\_\_\_\_

Other Equipment or Activities: \_\_\_\_\_

Date/Time	Day of Week	Equipment Item/Activity	Comments

needed, building owners and managers should use professionals.

Ask Occupants and Facility Staff to Keep More Detailed Records

Many events occur simultaneously in and around a complex building, and it can be very difficult to judge which of those events might be related to the IAQ complaints. In trying to resolve stubborn problems, professional investigators sometimes ask occupants and facility staff to keep day-by-day records. Occupants are asked to record the date and time of symptoms, where they are when the symptoms appear, and any other information that might be useful. Such information could include observations about the severity and duration of symptoms and comments on weather conditions, events, and activities that are happening at the same time. Facility staff are asked to record the date and time of events such as maintenance work, equipment cycles, or deliveries. If symptoms seem to occur at particular times of day, staff can focus their attentions on recording events that occur before and during those periods. Such records are likely to produce more accurate and detailed information than can be obtained by relying on memory. (Use the **Occupant Diary** and the **Log of Activities and System Operations** shown here and included in Tab V.)

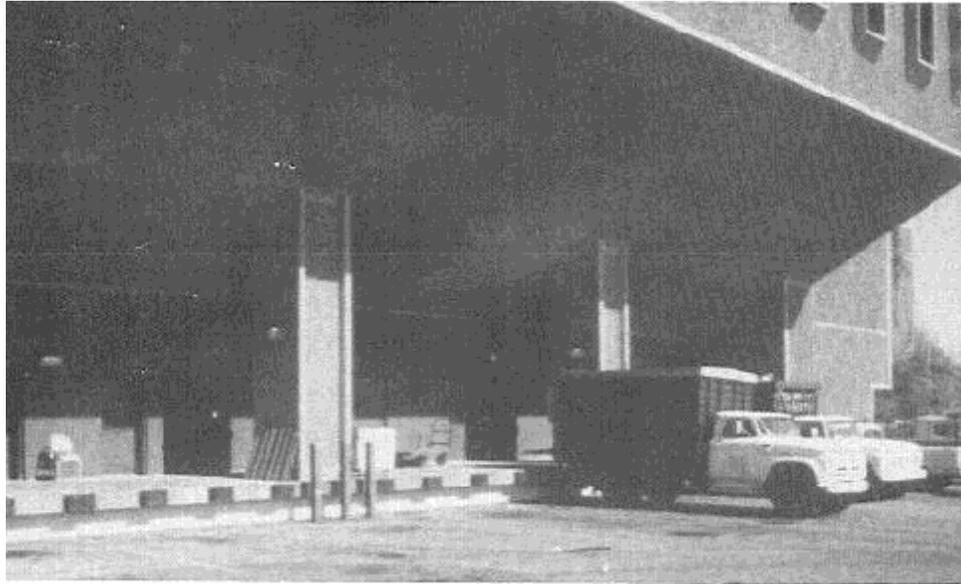
SEE  
COMPLETE  
FORMS  
PAGES 187  
AND 189

## USING THE OCCUPANT DATA

The pattern of complaints within the building helps to define the complaint area. The timing of symptoms and the types of symptoms reported may provide clues about the cause of the problem.

### *Strategies for Using Occupant Data*

- n Define the complaint area
- n Look for timing patterns
- n Look for symptom patterns



*Exhaust fumes are drawn into this building's outdoor air intake when trucks are idling at the nearby loading dock. Tools such as the Occupant Diary and Log of Activities and System Operation can help to identify intermittent pollutant sources such as this one.*

SPATIAL PATTERNS	SUGGESTIONS
Widespread, no apparent spatial pattern	<ul style="list-style-type: none"> <li>n Check ventilation and temperature control for entire building.</li> <li>n Check outdoor air quality.</li> <li>n Review sources that are spread throughout building (e.g., cleaning materials).</li> <li>n Consider explanation other than air contaminants.</li> </ul>
Localized (e.g., affecting individual rooms, zones, or air handling systems)	<ul style="list-style-type: none"> <li>n Check ventilation and temperature control within the complaint area.</li> <li>n Review pollutant sources affecting the complaint area.</li> <li>n Check local HVAC system components that may be acting as sources or distributors of pollutants.</li> </ul>
Individual(s)	<ul style="list-style-type: none"> <li>n Check for drafts, radiant heat (gain or loss), and other localized temperature control or ventilation problems near the affected individual(s).</li> <li>n Review local pollutant source(s) near the affected individual(s).</li> <li>n Consider that common background sources may affect only susceptible individuals.</li> <li>n Consider the possibility that individual complaints may have different causes that are not necessarily related to the building (particularly if symptoms differ among the individuals).</li> </ul>

### Define the Complaint Area

Use the spatial pattern (locations) of complaints to define the complaint area. Building locations where symptoms or discomfort occur define the rooms or zones that should be given particular attention during the initial investigation. However, the complaint area may need to be revised as the investigation progresses. Pollutant pathways can cause occupant complaints in parts of the building that are far removed from the source of the problems.

## Look for Timing Patterns

Look for patterns in the timing of complaints. The timing of symptoms and complaints can indicate potential causes for the complaints and provide directions for further investigation. Review the data for cyclic patterns of symptoms (e.g., worst during periods of minimum ventilation or when specific sources are most active) that may be related to HVAC system operation or to other activities in and around the building.

TIMING PATTERNS	SUGGESTIONS
Symptoms begin and/or are worst at the start of the occupied period	n Review HVAC operating cycles. Emissions from building materials, or from the HVAC system itself, may build up during unoccupied periods.
Symptoms worsen over course of occupied period	n Consider that ventilation may not be adequate to handle routine activities or equipment operation within the building.
Intermittent symptoms	n Look for daily, weekly, or seasonal cycles or weather-related patterns, and check linkage to other events in and around the building.
Single event of symptoms	n Consider spills, other unrepeated events as sources.
Recent onset of symptoms	n Ask staff and occupants to describe recent changes or events (e.g., remodeling, renovation, redecorating, HVAC system adjustments, leaks, or spills).
Symptoms relieved on leaving the building, either immediately, overnight, or (in some cases) after extended periods away from the building	n Consider that the problem is likely to be building-related, though not necessarily due to air quality. Other stressors (e.g., lighting, noise) may be involved.
Symptoms never relieved, even after extended absence from building (e.g., vacations)	n Consider that the problem may not be building-related.

*The following chart lists some common symptom groups that can be related to indoor air quality, along with possible sources or causes of those symptoms. Building managers are cautioned that this is only a partial listing.*

### Look for Symptom Patterns

Look for patterns in the types of symptoms or discomfort. IAQ investigations often fail to prove that any particular pollutant or group of pollutants are the cause of the problem. Such causal relationships are extremely difficult to establish. There is little information available about the health effects of many chemicals. Typical indoor levels are much lower than the levels at

which toxicology has found specific effects. Therefore, it may be more useful to look for patterns of symptoms than for specific pollutant and health effect relationships.

Investigators who are not medically trained cannot make a diagnosis and should not attempt to interpret medical records. Also, confidentiality of medical information is protected by law in some jurisdictions and is a prudent practice everywhere.

SYMPTOM PATTERNS	SUGGESTIONS
THERMAL DISCOMFORT	<ul style="list-style-type: none"> <li>n Check HVAC condition and operation.</li> <li>n Measure indoor and outdoor temperature and humidity (see Figure 6-2 on page 57). See if extreme conditions exceed design capacity of HVAC equipment.</li> <li>n Check for drafts and stagnant areas.</li> <li>n Check for excessive radiant heat gain or loss.</li> </ul>
<b>COMMON SYMPTOM GROUPS</b> Headache, lethargy, nausea, drowsiness, dizziness	If onset was acute, arrange for medical evaluation, as the problem may be carbon monoxide poisoning. <ul style="list-style-type: none"> <li>n Check combustion sources for uncontrolled emissions or spillage. Check outdoor air intakes for nearby sources of combustion fumes.</li> <li>n Consider evacuation/medical evaluation if problem isn't corrected quickly.</li> <li>n Consider other pollutant sources.</li> <li>n Check overall ventilation; see if areas of poor ventilation coincide with complaints.</li> </ul>
Congestion; swelling, itching or irritation of eyes, nose, or throat; dry throat; may be accompanied by non-specific symptoms (e.g. headache, fatigue, nausea)	May be allergic, if only small number affected; more likely to be irritational response if large number are affected. <ul style="list-style-type: none"> <li>n Urge medical attention for allergies.</li> <li>n Check for dust or gross microbial contamination due to sanitation problems, water damage, contaminated ventilation system.</li> <li>n Check outdoor allergen levels (e.g., pollen counts).</li> <li>n Check closely for sources of irritating chemicals such as formaldehyde or those found in some solvents.</li> </ul>
Cough; shortness of breath; fever, chills and/or fatigue after return to the building	May be hypersensitivity pneumonitis or humidifier fever. A medical evaluation can help identify possible causes. <ul style="list-style-type: none"> <li>n Check for gross microbial contamination due to sanitation problems, water damage, or contaminated HVAC system.</li> </ul>
Diagnosed infection	May be Legionnaire's disease or histoplasmosis, related to bacteria or fungi found in the environment. <ul style="list-style-type: none"> <li>n Contact your local or State Health Department for guidance.</li> </ul>
Suspected cluster of rare or serious health problems such as cancer, miscarriages	<ul style="list-style-type: none"> <li>n Contact your local or State Health Department for guidance.</li> </ul>
<b>OTHER STRESSORS</b> Discomfort and/or health complaints that cannot be readily ascribed to air contaminants or thermal conditions	<ul style="list-style-type: none"> <li>n Check for problems with environmental, ergonomic, and job-related psychosocial stressors.</li> </ul>

Figure 6-2 shows the range of temperatures and relative humidities that fall within the comfort zone for most individuals dressed in “typical” clothing and involved in light, mostly sedentary activity. Recent research suggests that indoor air quality is judged to be worse as temperatures rise above 76°F, regardless of the actual air quality.

There is considerable debate among researchers, IAQ professionals, and health professionals concerning recommended levels of relative humidity. In general, the range of humidity levels recommended by different organizations seems to be 30% to 60%. Relative humidities below this level may produce discomfort from dryness. On the other hand, maintaining relative humidities at the lowest possible level helps to restrict the growth of mold and mildew. The concerns (comfort for the most part) associated with dry air must be balanced against the risks (enhanced microbiological growth) associated with humidification. If temperatures are maintained at the lower end of the comfort range (68 - 70°F) during heating periods, relative humidity in most climates will not fall much below 30% (also within the comfort range) in occupied buildings.

### COLLECTING INFORMATION ABOUT THE HVAC SYSTEM

IAQ complaints often arise because the quantity or distribution of outdoor air is inadequate to serve the ventilation needs of building occupants. Problems may also be traced to air distribution systems that are introducing outdoor contaminants or transporting pollutants within the building.

The investigation should begin with the components of the HVAC system(s) that serve the complaint area and surrounding rooms, but may need to expand if connections to other areas are discovered. Your goal is to understand the design and operation of the HVAC system well

FIGURE 6-2: Acceptable Ranges of Temperature and Relative Humidity During Summer and Winter <sup>1</sup>

Relative Humidity	Winter Temperature	Summer Temperature
30%	68.5°F - 76.0°F	74.0°F - 80.0°F
40%	68.5°F - 75.5°F	73.5°F - 79.5°F
50% <sup>2</sup>	68.5°F - 74.5°F	73.0°F - 79.0°F
60%	68.0°F - 74.0°F	72.5°F - 78.0°F

<sup>1</sup> Applies for persons clothed in typical summer and winter clothing, at light, mainly sedentary activity.

<sup>2</sup> See left for discussion of relative humidities.

SOURCE: Adapted from ASHRAE Standard 55-1981, Thermal Environmental Conditions for Human Occupancy

enough to answer the following questions:

- n Are the components that serve the immediate complaint area functioning properly?
- n Is the HVAC system adequate for the current use of the building?
- n Are there ventilation (or thermal comfort) deficiencies?
- n Should the definition of the complaint area be expanded based upon the HVAC layout and operating characteristics?

An evaluation of the HVAC system may include limited measurements of temperature, humidity, air flow, and CO<sub>2</sub>, as well as smoke tube observations. Complex investigations may require more extensive or sophisticated measurements of the same variables (e.g., repeated CO<sub>2</sub> measurements taken at the same location under different operating conditions, continuous temperature and relative humidity measurements recorded with a data logger). A detailed engineering study may be needed if the investigation discovers problems such as the following:

- n airflows are low
- n HVAC controls are not working or are working according to inappropriate strategies
- n building operators do not understand (or are unfamiliar with) the HVAC system

### WHAT DO YOU KNOW SO FAR?

- n Use the Hypothesis Form on page 223 to make brief notes after reviewing the occupant data.
- n Decide whether you have a hypothesis that might explain the complaints. If so, test it. (See page 78 for a discussion of hypothesis testing.)
- n Decide what else you need to know. Consider whether in-house expertise is sufficient or outside assistance is needed (See Section 8 for guidance on hiring outside assistance.)

## COLLECTING HVAC SYSTEM INFORMATION

Strategies	Tools
Review existing documentation on HVAC design, installation, and operation	<p>Collect:</p> <ul style="list-style-type: none"> <li>n design documents, testing and balancing reports</li> <li>n operating instructions, control manufacturer's installation data</li> </ul>
Talk to facilities staff	<p>Ask facilities staff to record their observations of equipment cycles, weather conditions, and other events using <i>Log of Activities and System Operations</i></p>
Inspect system layout, condition, and operation	<p>Use:</p> <ul style="list-style-type: none"> <li>n Zone/Room Record</li> <li>n HVAC Checklist - Short Form and/or</li> <li>n HVAC Checklist - Long Form</li> <li>n thermometer and sling psychrometer (or electronic equivalent) to measure temperature and humidity</li> <li>n micromanometer (or equivalent) to measure pressure differentials               <ul style="list-style-type: none"> <li>l 0-2" and 0-10" water gauge (w.g.) to measure at fans and intakes</li> <li>l 0-.25" w.g. with pitot tube to check airflow in ducts</li> </ul> </li> <li>n chemical smoke for observing airflow patterns</li> <li>n a device to assess airflow from diffusers               <ul style="list-style-type: none"> <li>l rough quantitative: anemometer; velometer</li> <li>l accurate quantitative: flow hood</li> </ul> </li> <li>n carbon dioxide measurement devices               <ul style="list-style-type: none"> <li>l detector tubes with a hand pump</li> <li>l direct reading meter</li> </ul> </li> </ul>
Use additional instruments as appropriate	<p>Instruments often used by professional IAQ consultants include:</p> <ul style="list-style-type: none"> <li>n a hygrothermograph to log temperature and humidity</li> <li>n tracer gas and measurement equipment</li> <li>n a device to measure airborne particulates</li> <li>n measurement devices for carbon monoxide and other contaminants of interest</li> </ul>

## Review Documentation on HVAC Design, Installation, and Operation

A review of existing documentation (e.g., plans, specifications, testing and balancing reports) should provide information about the original design and later modifications, particularly:

- n the type of HVAC system (e.g., constant volume, VAV)
- n locations and capacities of HVAC equipment serving the complaint area
- n the planned use of each building area
- n supply, return, and exhaust air quantities
- n location of the outdoor air intake and of the supply, return, and exhaust registers, diffusers, and grilles that serve the complaint area

The most useful way to record this information is to make a floor plan of the complaint area and surrounding rooms. You may be able to copy an existing floor plan from architectural or mechanical drawings, fire evacuation plans, or some other source.

If there is no documentation on the mechanical system design, much more on-site inspection will be required to understand the HVAC system. The HVAC system may have been installed or modified without being commissioned, so that it may never have performed according to design. In such cases, good observations of airflow and pressure differentials are essential. In addition, load analyses may be required.

## Talk to Facility Staff

Facility staff can provide important current information about equipment operating and maintenance schedules and breakdowns or other incidents. There may be inspection reports or other written records available for review. Staff members who are familiar with building systems in general and with the specific features of the

building under investigation can be very helpful in identifying conditions that may explain the indoor air quality complaints. Some facility operators have extensive preventive maintenance programs. On the other hand, discussion could reveal that facility staff are not operating the building according to its design, because:

- n they do not understand the design logic of the HVAC system
- n they have been asked to run the HVAC system at the lowest possible energy cost
- n they do not have the manpower to operate the building properly
- n the HVAC system has not been modified to accommodate changes in the use of space or increases in the occupant population

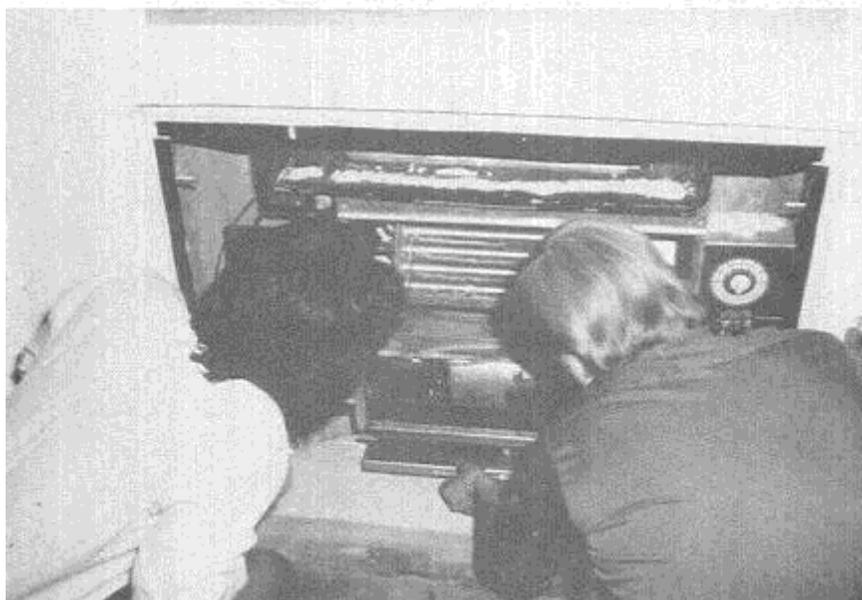
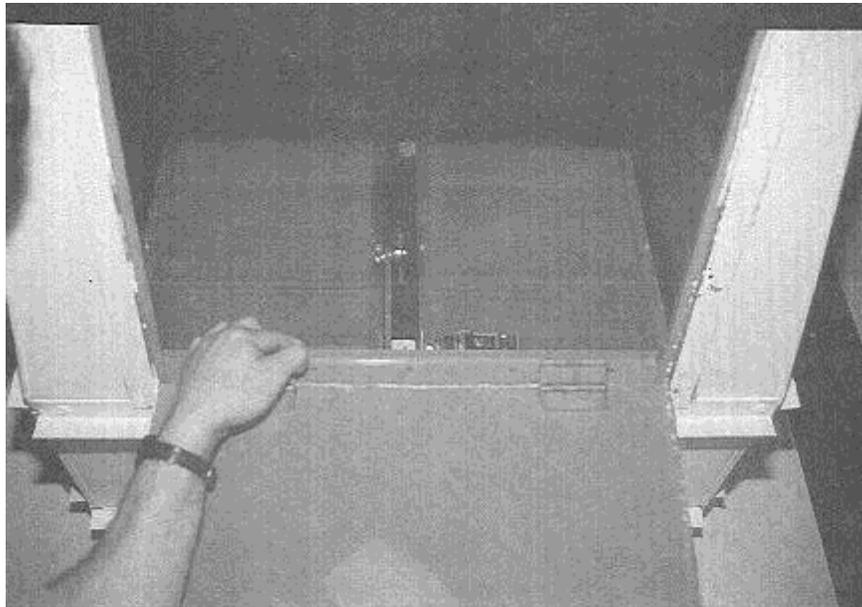
Staff may have noticed occupant activities that are indicators of inadequate ventilation or poorly-controlled temperatures, such as:

- n desktop fans, heaters, or humidifiers
- n supply diffusers blocked off with tape or cardboard
- n popped-up ceiling tiles
- n interference with thermostat settings

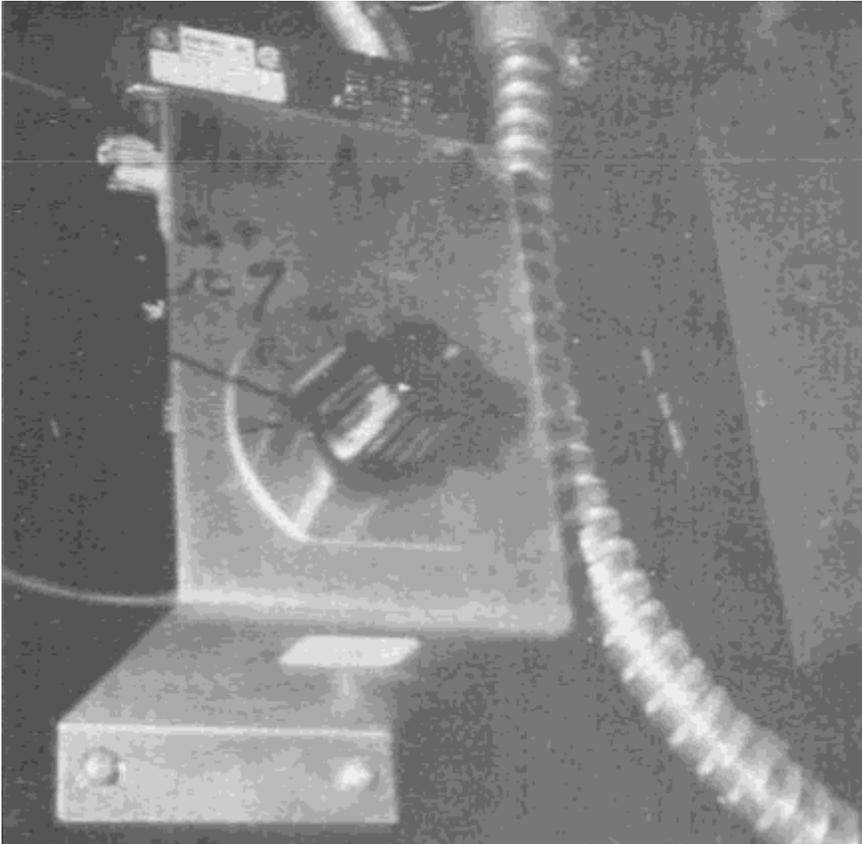
IAQ complaints are often intermittent. Discussions with staff may reveal patterns that relate the timing of complaints to the cycles of equipment operation or to other events in the building such as painting, installation of new carpeting, or pest control. These patterns are not necessarily obvious. Keeping a day-to-day record may help to clarify subtle relationships between occupant symptoms, equipment operation, and activities in and around the building. (See **Occupant Diary** and **Log of Activities and System Operations** on page 52 and in Tab V.) Staff members may have theories about the cause of the problem.

### Inspect System Layout, Condition, and Operation

If the building is new or if there is a preventive maintenance program with recent



*Above: An investigation of this building revealed no problems with the HVAC system, although the amount of outdoor air was very low. In a more thorough inspection of the HVAC system, investigators found that the wiring to this outdoor air damper motor had never been connected. No outdoor air was entering the building through the intake controlled by this damper. Below: These investigators are examining a perimeter fan-coil unit. Self-contained heating or cooling units such as this one are often overlooked during routine maintenance. There may be many such units in a single building, sometimes in remote or inaccessible locations.*



*The design specifications for this building called for a minimum 20% setting on the outdoor air damper control. Facility staff lowered the minimum outdoor air setting to 10% in order to save energy and reduce operating costs. As a result, the building was underventilated whenever outdoor temperatures were either very hot or very cold.*

test and balance reports, it is possible (but not necessarily likely) that the HVAC system is functioning according to its original design. Otherwise it is probable that one or more features of building usage or system operation have changed in ways that could affect indoor air quality.

Elements of the on-site investigation can include (but are not limited to) the following:

***Check temperature and/or humidity to see whether the complaint area is in the comfort range.***

Take more than one measurement to account for variability over time and from place to place. Compare to Figure 6-2 on page 57 (see also *Appendix B*).

- n Check thermostat operation.
- n Check whether the supply air temperature corresponds to the design criteria.
- n Use a hygrothermograph (if available) to log temperature and humidity changes in the complaint area.

***Check for indicators of inadequate ventilation.***

- n Check supply diffusers to see if air is moving (using chemical smoke). If it is not, confirm that the fan system is operating, and then look for closed dampers, clogged filters, or signs of leaks.
- n Compare design air quantities (if available) to building codes for the current occupancy or ventilation guidelines (e.g., ASHRAE 62-1989, see *Appendix B*). If the HVAC system, performing as designed, would not provide enough ventilation air for current needs, then there is good reason to believe that actual ventilation rates are inadequate.
- n Measure carbon dioxide (CO<sub>2</sub>) in the complaint area to see whether it indicates ventilation problems. (See *Appendix A* for a discussion of techniques for measuring and interpreting CO<sub>2</sub> concentrations.)
- n Measure air quantities supplied to and exhausted from the complaint area, including calculation of outdoor air quantities (see *Appendix A* for further guidance). Be aware of damper settings and equipment cycles when you are measuring (e.g., are you evaluating minimum outdoor air, “normal” conditions, or maximum airflow?). Note that evaluation of variable air volume (VAV) systems requires considerable expertise. Compare the measured air quantities to your mechanical system design specifications and applicable building codes. Also compare ventilation rates to ASHRAE 62-1989. Some of the ventilation recommendations of ASHRAE 62-1989 are reproduced in *Appendix B*.

***Check that equipment serving the complaint area (e.g., grilles, diffusers, fans) is operating properly.***

- n Confirm the accuracy of reported operating schedules and controls sequences; for example, power outages may have disrupted time clocks, fans reported as “always running” may have been accidentally switched off, and controls can be in need of calibration.

- Check to see that equipment is properly installed. For example, look for shipping screws that were never removed or fans that were reversed during installation, so that they move air in the wrong direction.

**Compare the current system to the original design.**

- Check to see that all equipment called for in the original design was actually installed.
- See whether original equipment may have been replaced by a different model (i.e., a model with less capacity or different operating characteristics).

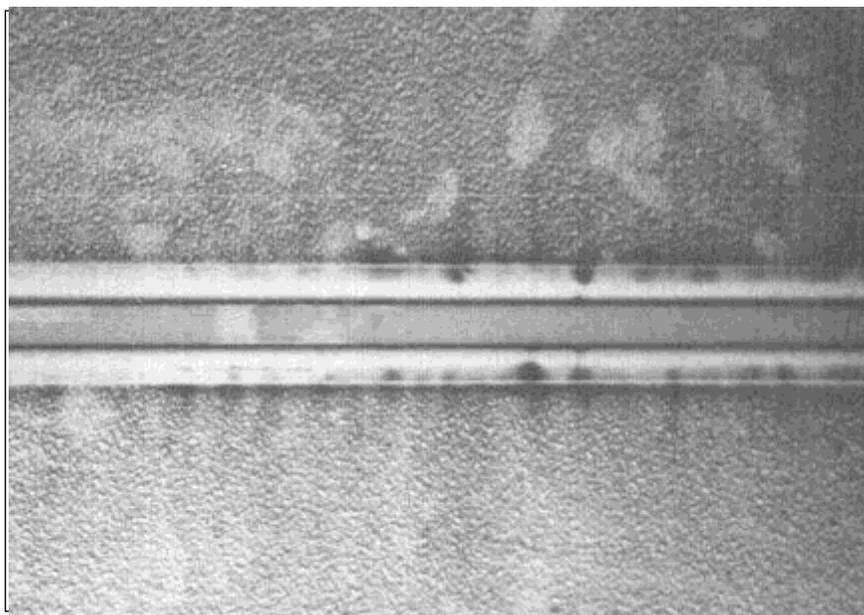
**See whether the layout of air supplies, returns, and exhausts promotes efficient air distribution to all occupants and isolates or dilutes contaminants.**

(See *Appendix A* for guidance on using chemical smoke to study airflow and mixing patterns and CO<sub>2</sub> to help determine the adequacy of ventilation.)

- If supplies and returns are close together, heatless chemical smoke can be used to check for short-circuiting (supply air that does not mix properly with air in the breathing zone, but moves directly to the return grille). CO<sub>2</sub> can also be used to evaluate air mixing.
- Use heatless chemical smoke to observe airflow patterns within the complaint area and between the complaint area and surrounding spaces, including outdoors. Compare airflow directions under various operating conditions.
- If the system layout includes ceiling plenums, look above the ceiling for interruptions such as walls or full-height partitions.

**Consider whether the HVAC system itself may be a source of contaminants.**

- Check for deterioration or unsanitary conditions (e.g., corrosion, water damage or standing water, mold growth or exces-



- sive dust in ductwork, debris or damaged building materials in ceiling plenums).
- If the mechanical room serves as a mixing plenum (i.e., return and outdoor air are drawn through the room into the air handler), check very carefully for potential contaminants such as stored solvents and deteriorated insulation.

**Use the forms provided in this document to inspect the HVAC system.**

- Use the **Zone/Room Record** to describe the ventilation system serving the complaint area and surrounding rooms or zones. The **Zone/Room Record** is reproduced on page 62 and in Tab V.
- Use the HVAC Checklist (short and/or long form) to evaluate the condition of HVAC system components that affect air distribution and IAQ in the complaint area. A portion of the **HVAC Checklist-Short Form** is reproduced on page 62. **The HVAC Checklist - Long Form** is useful for more detailed examination of the system. Complete copies of both forms can be found in Tab V.

*The dark streaks at the outlet of this supply diffuser could indicate a filtration problem. Poorly maintained or improperly sized filters can allow dirt to be distributed through the building.*

Sample Form

Zone/Room Record

This form is to be used differently depending on whether the goal is to prevent or diagnose IAQ problems. During development of a profile, this form should be used to record more general information about the entire building; during an investigation, the form should be used to record more detailed information about the complaint area and areas surrounding the complaint area or connected to it by pathways.

PROFILE AND DIAGNOSIS INFORMATION					DIAGNOSIS INFORMATION ONLY		
Building Area (Zone/Room)	Use**	Source of Outdoor Air*	Mechanical Exhaust? (Write "No" or estimate cfm airflow)	Comments	Peak Number of Occupants or Sq. Ft. Floor Area*	Total Air Supplied (in cfm)**	Outdoor Air Supplied per Person or per 150 sq. Ft. Area****

Sample Form

HVAC Checklist — Short Form

Sections 2, 4 and 6 and Appendix B discuss the relationships between the HVAC system and indoor air quality.

MECHANICAL ROOM

- n Clean and dry? \_\_\_\_\_ Stored refuse or chemicals? \_\_\_\_\_
- n Describe items in need of attention \_\_\_\_\_

MAJOR MECHANICAL EQUIPMENT

- n Preventive maintenance (PM) plan in use? \_\_\_\_\_
- Control System \_\_\_\_\_
- Type \_\_\_\_\_
- System operation \_\_\_\_\_

USING THE HVAC SYSTEM DATA

As you review the HVAC data, consider whether the system is adequate to serve the use of the building and whether the timing, location, and impact of apparent deficiencies appear related to the IAQ complaint. Deficiencies in HVAC design, operation, or maintenance may exist without producing the complaint under investigation; some defects may not cause any apparent IAQ problems.

**Strategies for Using the HVAC System Data**

- n Compare the original design to the current system.
- n Compare the original uses of space to current uses.
- n Consider the condition of the HVAC system.

SEE COMPLETE FORMS PAGES 177 AND 191

## HEALTH AND SAFETY CONSIDERATIONS FOR IAQ INVESTIGATORS

Normal safety precautions observed during routine operation of the building must be followed closely during IAQ inspections. When the IAQ investigator is not familiar with the mechanical equipment in that particular facility, an operator or engineer should be present at all times in equipment areas. Potential safety hazards include:

- n electrocution
- n injury from contacting fans, belts, dampers or slamming doors
- n burns from steam or hot water lines
- n falls in ventilation shafts or from ladders or roofs

Investigators evaluating building IAQ generally do not encounter situations in which specific personal protection measures (e.g., protective garments and respirators) are required. However, safety shoes and eyeglasses are generally recommended for working around mechanical equipment. When severe contamination is present (e.g., microbiological, chemical, or asbestos), IAQ investigators may need additional protection in the vicinity of certain building areas or equipment. Such decisions are site specific and should be made in consultation with an experienced industrial hygienist. General considerations include the following:

**Microbiological:** Care must be taken when serious building related illness (e.g., Legionnaire's disease) is under investigation or when extensive microbiological growth has occurred. Investigators with allergy problems should be especially cautious. The array of potential contaminants makes it difficult to know what sort of personal protection will be effective. At a minimum, investigators should minimize their exposure to air in the interior of ducts or other HVAC equipment unless respiratory protection is used. If there is reason to suspect biological contamination (e.g., visible mold growth), expert advice should be obtained about the kind of respiratory protection to use and how to use it. Possible protective measures against severe microbiological contamination include disposable coveralls and properly fitted respirators.

**Chemical:** Where severe chemical contamination is suspected, specific precautions must be followed if OSHA action levels are approached. Such instances rarely occur in IAQ investigations. One possible exception might be a pesticide spill in a confined space. In this case, an appropriate respirator and disposable coveralls may be needed.

**Asbestos:** An IAQ investigation often includes inspection above accessible ceilings, inside shafts, and around mechanical equipment. Where material suspected of containing asbestos is not only present, but also has deposited loose debris, the investigator should take appropriate precautions. This might include disposable coveralls and a properly fitted respirator.

*Note: The requirements for proper fit, physical condition of the wearer, and other considerations involved in selection of the proper respirator must be evaluated by an occupational safety and health specialist. There is a NIOSH Respirator Decision Logic for proper respirator selection, and OSHA has regulations for an appropriate respirator protection program.*

When the IAQ investigator is not familiar with the mechanical equipment in that particular facility, an operator or engineer should be present at all times in equipment areas.

ALL SYSTEMS	SUGGESTIONS
Ventilation and temperature control zones	<ul style="list-style-type: none"> <li>n Revise definition of complaint area (if needed) to add spaces linked to the original complaint area by ductwork or controls.</li> <li>n Check to see that thermostats are properly located and function properly.</li> </ul>
Changes in equipment	<ul style="list-style-type: none"> <li>n Note equipment changes that could be affecting the system's performance (e.g., removal or addition of equipment, replacement by a different model).</li> </ul>
Operating cycles	<ul style="list-style-type: none"> <li>n Review operating procedures for occupied and unoccupied periods.</li> <li>n Compare timing of occupied/unoccupied periods to equipment cycles and occupant complaints. Confirm that time clocks are reading the actual time. See ASHRAE 62-1989 for suggested lead times to allow proper flushing before occupants arrive. In some cases (e.g., warm, humid climates), fans may need to operate during unoccupied periods to prevent mold growth or other problems.</li> </ul>

### Compare the Original Design to the Current HVAC System

Consider the original HVAC design and compare it to the current equipment, layout, and controls. A variety of HVAC system designs have been used in public and commercial buildings. The type of system used in your building affects the control of ventilation air quantities and distribution, as well as thermal comfort. See *Appendix B* for a discussion of HVAC system types.

## Use HVAC Data to Evaluate Mitigation Measures

As you use the HVAC data to evaluate potential mitigation measures, review the suggestions made in both the box on the facing page for all HVAC systems and in the box on this page for the type of HVAC system in your building.

SYSTEM TYPES	SUGGESTIONS
No mechanical ventilation or exhaust only	<ul style="list-style-type: none"> <li>n Identify the source(s) of ventilation air (e.g., operable windows, doors propped open).</li> <li>n Check whether the location of open windows, doors, or other openings promotes the introduction of odors or contaminants.</li> </ul>
Room units (e.g., unit ventilators)	<ul style="list-style-type: none"> <li>n Check whether outdoor air intakes are obstructed. Does their location promote the introduction of odors or contaminants?</li> <li>n Note design airflows in the complaint area (outdoor air, supply, return, and exhaust) and surrounding spaces; compare to ASHRAE 62-1989 and to actual measured airflows.</li> </ul>
Constant volume	<ul style="list-style-type: none"> <li>n Note design airflows in the complaint area (outdoor air, supply, return, and exhaust) and surrounding spaces; compare to applicable building codes, ASHRAE 62-1989, and to actual measured airflows.</li> <li>n Check whether outdoor air intakes are obstructed. Does their location promote the introduction of odors or contaminants? Check for unsanitary conditions.</li> <li>n Check outdoor air damper controls.</li> </ul>
Variable air volume (VAV)	<p>In addition to all suggestions made for constant volume systems:</p> <ul style="list-style-type: none"> <li>n Confirm whether the system design allows regulation of outdoor air quantities. Do VAV boxes have stops to ensure that minimum amounts of outdoor air are delivered at all times during occupied periods? Are the system controls providing a constant ventilation rate per person regardless of total system airflows?</li> <li>n Observe changes (if any) in airflow patterns within and around the complaint area as the VAV system throttles from maximum to minimum flow.</li> </ul>

ROOM USE CHANGES	SUGGESTIONS
Increased occupant density	<ul style="list-style-type: none"> <li>n Compare temperature and humidity to comfort zone in ASHRAE 55-1981 guidelines.</li> <li>n Compare minimum outdoor air quantities to the original design, applicable building codes, and ASHRAE 62-1989 guidelines.</li> </ul>
Change in type of occupant population	<p>For example introduction of a more physically active group of occupants can change thermal comfort requirements.</p> <ul style="list-style-type: none"> <li>n Compare temperature and humidity to comfort zone in ASHRAE 55-1981 guidelines.</li> <li>n Compare minimum outdoor air quantities to the original design, applicable building codes, and ASHRAE 62-1989 guidelines.</li> <li>n Check for low-level contaminant sources.</li> </ul>
Additional non-HVAC equipment	<ul style="list-style-type: none"> <li>n Compare temperature and humidity to comfort zone in ASHRAE 55-1981 guidelines.</li> <li>n Consider the need for local exhaust at point sources of contaminants.</li> </ul>
Conversion to or addition of special uses	<p>Example: Modifications that convert or add such special uses as smoking lounges, print shops, or kitchen facilities may also require changes in the operation of the HVAC system.</p> <ul style="list-style-type: none"> <li>n Check pressure relationships between special use areas and surrounding spaces.</li> <li>n Consider the need for local exhaust at point sources of contaminants.</li> </ul>
Rearrangement of work stations (e.g., relocation of partitions)	<ul style="list-style-type: none"> <li>n Check that thermostats are properly located. Compare temperature and humidity to comfort zone in ASHRAE 55-1981 guidelines.</li> <li>n Check layout of supplies, returns, and exhausts.</li> <li>n Check to make sure that partitions do not block proper air circulation.</li> </ul>

## Compare the Original Uses of Space to Current Uses

Compare the original uses of the complaint area and surrounding rooms to current uses of those areas. Indoor air quality problems often arise when the usage of rooms changes without corresponding adjustments to the HVAC system. For example, if ventilation appears to be a problem despite a properly-functioning HVAC system, the existing system may be inadequate to meet current needs.

## Consider the Condition of the HVAC System

Consider whether the HVAC system is reasonably clean and functioning properly. Review the results of the onsite inspection. If you identified sanitary or operating problems in the HVAC system serving the complaint area, you may want to correct those problems and see whether the complaints are resolved before continuing with the investigation.

SYSTEM CONDITIONS	SUGGESTIONS
Unsanitary conditions n Moisture or standing water n Debris n Dust and/or mold growth	n Correct sanitary problems and adopt necessary measures to prevent recurrence of problems.
HVAC malfunctions n Equipment breakdown n Obstructed diffusers or grilles n Air distribution or mixing problems: (e.g., equipment is out of balance, requires calibration, or needs other adjustment) n Air bypasses filters (due to loose filter tracks, incorrect filter size, or filter overloaded with dirt) n Air distribution system leaks (e.g., leaky ductwork; unin-tended openings in pressurized ceilings or in return air plenums)	n Evaluate whether the HVAC defect could have caused the IAQ complaint. n Correct the malfunction(s), and see whether complaints are resolved. n Review maintenance program and revise as needed to prevent future problems.
HVAC functions properly. However, there is evidence of underventilation.	n Consider what adjustments could be made to increase the supply of outdoor air (or decrease the ventilation demand) in the complaint area.

### WHAT DO YOU KNOW SO FAR?

- n Use the **Hypothesis Form** on page 223 to make brief notes.
- n Decide whether you have a hypothesis that might explain the complaints. If so, test it. (See page 78 for a discussion of hypothesis testing.)
- n Decide what else you need to know. Consider whether in-house expertise is sufficient or outside assistance is needed (See *Section 8* for guidance on hiring outside assistance.)

## COLLECTING INFORMATION ABOUT POLLUTANT PATHWAYS AND DRIVING FORCES

Unless the IAQ problem is caused by an obvious contaminant located in the complainant's immediate workspace, you will need to understand the patterns of airflow into and within the complaint area. Correction of IAQ problems often involves controlling pollutant movement through sealing of pollutant pathways or manipulation of the pressure relationships.

If the complaints being investigated are limited to a few areas of the building, pollutant pathways can be evaluated so that the complaint area is properly defined before conducting the source inventory. If complaints are spread throughout the building,

evaluation of pathways could be a very time-consuming process, and it may be more practical to look for major contaminant sources before trying to discover how the contaminants move within the building.

### Identify Pollutant Pathways

Architectural and mechanical pathways allow pollutants to enter the complaint area from surrounding spaces, including the outdoors. An examination of architectural and mechanical plans can help in developing a list of connections to surrounding areas. These include:

- n doors
- n operable windows
- n stairways
- n elevator shafts
- n utility chases
- n ductwork and plenums
- n areas served by common HVAC controls (e.g., shared thermostats)

Onsite inspection is needed to confirm the existence of these connections and to identify other openings (e.g., accidental openings such as cracks and holes). Fire codes usually require that chases and hidden openings be firestopped. Check for the existence and condition of firestops in chases, especially those that connect both vertically and horizontally.

### COLLECTING PATHWAY INFORMATION

Strategies	Tools
Identify pollutant pathways	<ul style="list-style-type: none"> <li>n Architectural and mechanical drawings</li> <li>n Pollutant Pathway Form for Investigations</li> <li>n Sketch plan of complaint area</li> </ul>
Observe direction of air movement	<ul style="list-style-type: none"> <li>n Testing and balancing reports</li> <li>n Chemical smoke tests</li> <li>n Micromanometer or equivalent</li> </ul>

*Chemical smoke is being used to detect the direction and amount of airflow through this closed doorway. A building investigator must know how the ventilation in the building is designed to operate in order to decide whether the observed flow of smoke is appropriate.*



The **Pollutant Pathway Form for Investigations** shown to the right can be used along with a sketch plan of the complaint area (similar to the example on page 70) to record pathways and directions of pollutant movement. A blank copy of the form is included in Tab V.

### Observe Air Movement Direction

The airflow quantities shown in mechanical plans or in testing and balancing reports can be used to determine the direction of air movement intended by the designer. Onsite examination is necessary to determine the actual direction of airflow at each available pathway.

Chemical smoke tubes can be used to determine airflow directions between the complaint area and surrounding spaces (including the outdoors), and to reveal air circulation patterns within the complaint area. A micromanometer (or equivalent) can measure the magnitude of pressure differences between these areas. The sketch plan and the **Pollutant Pathway Form for Investigations** can be used to record the results.

It may be necessary to make observations under different conditions, as airflow direction can change depending upon weather conditions, windspeed and direction, equipment operation within the building, traffic through doors, and other factors (e.g., as VAV systems throttle back). Switching air handlers or exhaust fans on and off, opening and closing doors, and simulating the range of operating conditions in other ways can help to show the different ways that airborne contaminants move within the building. Dust tracking patterns around door frames can reveal the dominant direction of air and pollutant movement.

Some investigators study air movement by releasing a small amount of peppermint oil at the opening to a suspected pathway and asking an assistant to sniff for the

Sample Form  
Pollutant Pathway for Investigations Form

Building Name \_\_\_\_\_ File Number \_\_\_\_\_

Address: \_\_\_\_\_

Completed By (name): \_\_\_\_\_

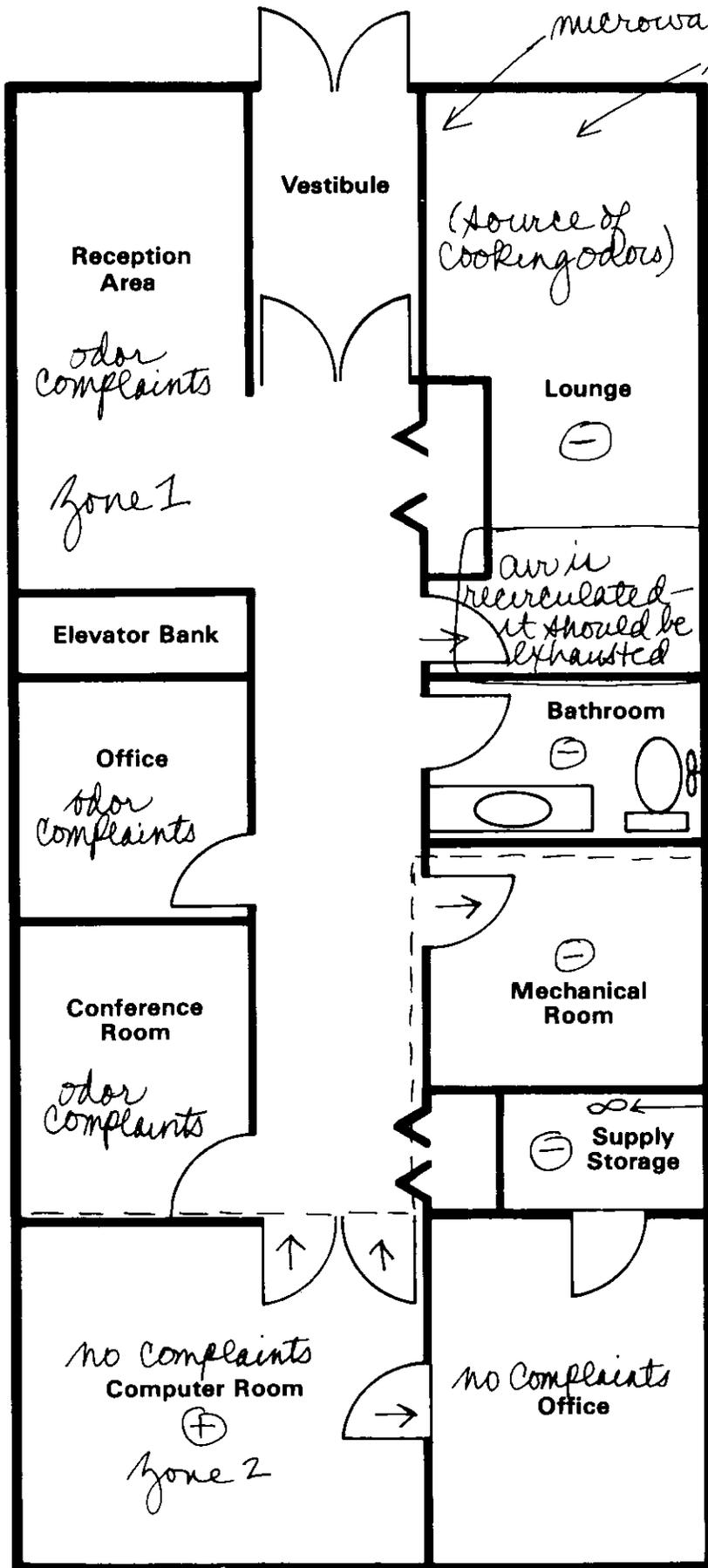
Rooms or Zones Connected to the Complaint Area by Pathways	Use	Pressure Relative to Complaint Area		Comments (e.g., potential pollutant sources)
		+/-	date/time	

“toothpaste” smell. If this technique is used, it is important that the assistant have an acute sense of smell. If the building is in use during the investigation, occupants may also notice the odor and could find it distracting. Some investigators prefer to use methods that release an odor during unoccupied periods. Investigators should note two common causes of false negative results (falsely concluding that no pathway exists):

- n The nose quickly becomes tolerant of strong odors, so that the assistant may need to take a long rest (breathing fresh air) between tests.
- n If there is substantial airflow through the pathway, the peppermint oil odor could be diluted so that it is imperceptible.

Tracer gases such as sulfur hexafluoride (SF<sub>6</sub>) can provide qualitative and quantitative information on pollutant pathways and ventilation rates. Use of tracer gases to obtain quantitative results requires considerable technical expertise. If it appears that a sophisticated study of pathways (or ventilation rates) is required, you need to use trained investigators.

SEE COMPLETE FORM PAGE 211



## USING POLLUTANT PATHWAY DATA

Pollutant pathway information helps the investigator to understand airflow patterns in and around the complaint area. The pollutant pathway data may indicate a need to enlarge the complaint area, or may direct attention toward contaminant sources that deserve close study.

### Strategies for Using Pathway Information

- Evaluate airflow patterns
- Confirm or revise boundaries of the complaint area

The receptionist and office occupants in Zone 1 have complained of food odors. The investigator is using a fire escape plan to record air movement, sources, and complaint information. The investigator has noted one hypothesis about the cause of the complaints in the room marked "Lounge."

## Evaluate Airflow Patterns

Evaluate airflow patterns into and within the complaint area. Because of the complexity and variability of airflow patterns, investigators cannot be expected to understand how air moves within the building under all potential operating conditions. However, data on pathways and driving forces can help to locate potential pollutant sources and to understand how contaminants are transported to building occupants.

## Confirm or Revise Boundaries of the Complaint Area

The discovery of unexpected pollutant pathways can show a need to study areas of the building that may be distant from the original complaint area.

AIRFLOW PATTERNS	SUGGESTIONS
<ul style="list-style-type: none"> <li>n Onsite observations</li> </ul>	<ul style="list-style-type: none"> <li>n Look for temporal patterns linking changes in airflow direction to incidents of complaints.</li> <li>n Look for spatial patterns linking potential sources to the locations of complaints.</li> </ul>

COMPLAINT AREA	SUGGESTIONS
<ul style="list-style-type: none"> <li>n Complaint area connected by architectural features to other areas</li> <li>n Complaint area connected by mechanical system to other areas</li> <li>n Unintentional pathways (e.g., cracks, holes)</li> </ul>	<ul style="list-style-type: none"> <li>n Check whether pressure relationships between complaint area and surrounding locations follows intent of ventilation design.</li> <li>n Check whether air from other locations flows into the complaint area under some conditions. If so, consider expanding the investigation to inventory pollutant sources (and perhaps collect HVAC or occupant data) in those locations.</li> </ul>

### WHAT DO YOU KNOW SO FAR?

- n Use the **Hypothesis Form** on page 223 to make brief notes after reviewing the pollutant pathway data.
- n Decide whether you have a hypothesis that might explain the complaints. If so, test it. (See page 78 for a discussion of hypothesis testing.)
- n Decide what else you need to know. Consider whether in-house expertise is sufficient or outside assistance is needed. (See *Section 8* for guidance on hiring outside assistance.)

## COLLECTING SOURCE INFORMATION

### Strategies

### Tools

Conduct onsite inspection

- n Pollutant and Source Inventory
- n Chemical Inventory

Talk with building occupants, facilities staff, and contractors

- n Pollutant and Source Inventory
- n Chemical Inventory

### Sample Form Pollutant and Source Inventory Form

Using the list of potential source categories below, record any indications of contamination or suspected pollutants that may require further investigation or treatment.

Source Category	Checked	Needs Attention	Location	Comments
<b>SOURCES OUTSIDE THE BUILDING</b>				
Contaminated Ambient Air				
Pollen, dust				
Industrial contaminants				
General vehicular contaminants				

### Sample Form Chemical Inventory

The inventory should include chemicals stored or used in the building for cleaning, maintenance, operations, and pest control.

Date	Chemical/ Brand Name	Use	Storage Location(s)	MSDS on File?

SEE  
COMPLETE  
FORMS  
PAGES 213  
AND 221

## COLLECTING INFORMATION ON POLLUTANT SOURCES

Throughout the investigation, the building investigator will try to identify pollutant sources that may be causing the occupant complaints. Any public or commercial building is likely to contain a number of sources that produce odors, contaminants, or both. The investigator's task is to identify the source(s) that may be responsible for the complaint(s).

The area included in the pollutant source inventory should be defined by the investigator's understanding of the building's architectural and mechanical layout and pollutant pathways. Common sense will help to differentiate unusual sources (e.g., spills, strong odors from new furnishings or equipment) from those that are normally found within or near the building.

Remember that very few sources of indoor air contaminants are both continuous and constant in volume over time. Pollutant concentrations often vary in strength over time, and may not be evident at the time of the site visit. Some sources are subtle and might only be noticed by a trained investigator. As the investigation progresses, the inventory of pollutant sources may need to be revised by expanding the definition of the complaint area or examining specific locations more closely (e.g., under various operating conditions).

### Onsite Inspection

Depending upon the nature of the complaint, the investigator may find some of the following activities to be useful. This list is not intended to be complete.

#### *Inventory outdoor sources*

- n Examine the area around the outdoor air intake for unsanitary conditions, standing water, or nearby pollutant sources such as exhaust vents or motor vehicles.
- n Observe patterns of traffic, construction activity, and other potential sources in the neighborhood of the building.

- n Inquire about outdoor ambient air problems in the area. (This information may be available from your local Health Department.)
- n Observe soil gas entry points.

#### ***Inventory equipment sources***

- n Review non-HVAC equipment, particularly large office equipment such as engineering drawing reproduction machines and wet-process copiers. Learn about usage patterns and identify items that are not equipped with local exhaust.
- n Review biocides, water treatment used on HVAC equipment.

#### ***Review building components and furnishings***

- n Check drain traps to make sure they are not dry.
- n Identify areas of excessive dust and/or deteriorated furnishings.
- n Identify areas of soil or water damage.
- n Identify locations of new furnishings.

#### ***Inventory other potential sources***

- n Identify special use areas such as smoking lounges, laboratories, print shops.
- n Identify areas where remodeling, repair, or redecorating activities are in progress or recently completed. Check procedures being used to isolate demolition dust, paint fumes, and other contaminants related to the process.
- n Inventory cleaning materials used in the building.

(See *Section 4* for another discussion of problem indicators and common problems that may become obvious during a walkthrough of the building.)

The **Pollutant and Source Inventory** can be used to record your observations. The **Chemical Inventory** form is intended to serve as a record of materials such as solvents, biocides, pesticides, and cleaning compounds that may require special care in storage and handling. Material Safety Data Sheets (MSDSs) should be collected

on these materials whenever possible. (See *Section 4* for further discussion of MSDSs.) Portions of both forms are shown on the poopsite page; the complete form is included in Tab V.

#### **Talk With Building Occupants and Facility Staff**

Building occupants and facility staff can provide valuable information about the location and timing of activities that produce odors or contaminants (e.g., smoking, cooking, housekeeping, maintenance). They may also suggest explanations for the IAQ problem that can help in the development of hypotheses. Facility staff and outside contractors (e.g., persons involved in housekeeping, pest control, or remodeling) should be interviewed or asked to provide a current list of materials, procedures, and schedules used for cleaning and pest control.

It may be useful to discuss the following items with building occupants:

#### ***Inventory activities***

- n Review smoking policy (and actual practice; cleaning staff may know where smoking occurs in violation of policy, especially in private offices).
- n Identify areas of overcrowding.
- n Review products used for housekeeping, maintenance, and pest control and the schedules of their use.
- n Inquire about housekeeping schedules and procedures.
- n Identify supply storage areas and check for well-sealed containers and proper ventilation.

#### ***Discuss incidents that could be sources***

- n Inquire about prior and neighboring uses of land (e.g., landfills, underground fuel tanks).
- n Inquire about events such as spills, fires, or leaks.
- n If such events have occurred, learn what remedial actions were taken to clean up after the incidents and to prevent their recurrence.

PATTERNS	SUGGESTIONS
Location(s) of sources	<ul style="list-style-type: none"> <li>n Compare locations of sources to locations of complaint(s).</li> <li>n Identify pathways linking potential sources to the complaint area.</li> <li>n Revise definition of complaint area if necessary.</li> </ul>
Timing of emissions	<ul style="list-style-type: none"> <li>n Note whether the sources emit on a continuous or intermittent basis.</li> <li>n Compare the timing of emissions to the timing of complaints.</li> <li>n Identify occasions when the source is likely to be strongest.</li> <li>n Determine whether pathways between the source(s) and the complaint location could account for the occasions of complaints.</li> </ul>

identify potential contaminant sources that are unrelated to the present IAQ complaint (i.e., either the location of the source, the timing of emissions, or both fit poorly with the pattern of complaints). These should be prioritized for remedial work according to their potential for causing health problems or complaints in the future.

A detailed study of pollutants and sources may involve an engineering evaluation of equipment that is releasing IAQ contaminants, diagnostic sampling to assess sources in operation, or other measurements. These may require skills or instruments that are not available in-house.

#### WHAT DO YOU KNOW SO FAR?

- n Use the **Hypothesis Form** on page 223 to make brief notes after reviewing the pollutant source data.
- n Decide whether you have a hypothesis that might explain the complaints. If so, test it. (See page 78 for a discussion of hypothesis testing.)
- n Decide what else you need to know. Consider whether in-house expertise is sufficient or outside assistance is needed. (See *Section 8* for guidance on hiring outside assistance.)

#### USING POLLUTANT SOURCE DATA

If a strong pollutant source is identified in the immediate vicinity of the complaint, a simple test (e.g., sealing, covering, or removing the source) can sometimes reveal whether or not it is the cause of the IAQ problem. If a number of potential sources have been found in and around the complaint area, other data (e.g., the pattern of symptoms, the HVAC system design and operation, and pollutant pathways) may be needed in order to determine which source(s), if any, may be related to the complaint.

##### Strategies for Using Source Information

- n Identify patterns linking emissions to complaints
- n Evaluate unrelated sources

##### Identify Patterns Linking Emissions to Complaints

Look for patterns linking emissions from potential sources to the IAQ complaints.

##### Evaluate Unrelated Sources

Evaluate sources that appear unrelated to the complaints. It is not unusual to

#### SAMPLING AIR FOR CONTAMINANTS AND INDICATORS

Although air sampling might seem to be the logical response to an air quality problem, such an approach may not be required to solve the problem and can even be misleading. Air sampling should not be undertaken until some or all of the other investigative activities mentioned previously have been used to collect considerable information. Before beginning to take air samples, investigators should develop a sampling strategy that is based on a comprehensive understanding of how the building operates, the nature of the complaints, and a plan for interpreting the results.

It may be desirable to take certain routine air quality measurements during an investigation to obtain a “snapshot” of current conditions. These tests should be limited to those that are indicative of very common IAQ concerns such as temperature, relative humidity, air movement, or carbon dioxide (CO<sub>2</sub>). Unusual readings may or may not indicate a problem, and should always be interpreted in perspective, based upon site-specific conditions.

Measurement of specific chemical or biological contaminants can be very expensive. Before expending time and

money to obtain measurements of indoor air pollutants, you must decide:

- n how the results will be used (e.g., comparison to standards or guidelines, comparison to levels in complaint-free areas)
- n what substances(s) should be measured
- n where to take samples
- n when to take samples
- n what sampling and analysis method to use so that the results provide useful information

It is often worthwhile for building staff to develop skills in making temperature, humidity, airflow, and CO<sub>2</sub> measurements and assessing patterns of air movement (e.g., using chemical smoke). *Appendix A* provides a brief introduction to ventilation and thermal measurement strategies and to methods of sampling for specific air contaminants.

#### How Will the Results Be Used?

Although air sampling will generate numbers, it will not necessarily help resolve the IAQ problem. Many IAQ complaints are resolved without sampling or with inconclusive sampling results.

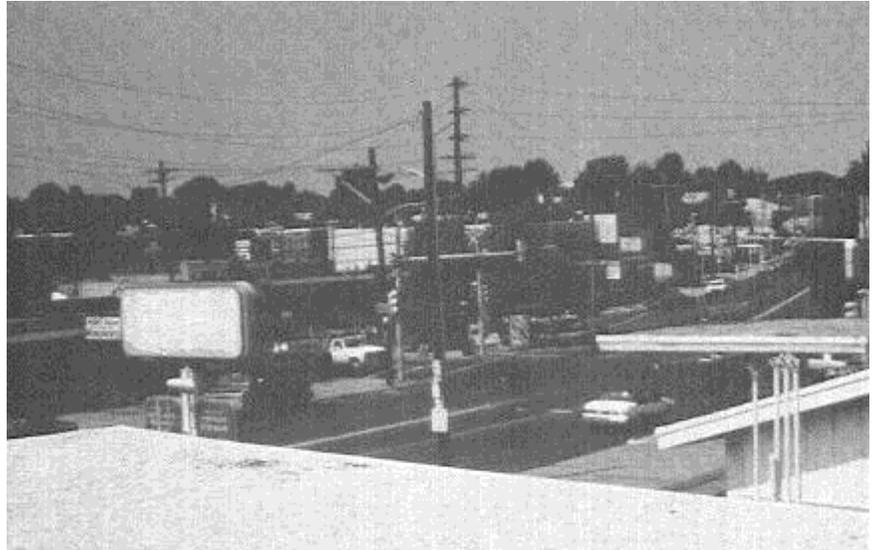
The design of an air sampling strategy should fit the intended use of the measurements. Potential uses of indoor air measurements include:

1. Comparing different areas of the building or comparing indoor to outdoor conditions in order to:

***Confirm that a control approach has the desired effect of reducing pollutant concentrations or improving ventilation***

***Establish baseline conditions so that they can be compared to concentrations at other times or locations, such as***

- n concentrations in outdoor air
- n concentrations in areas where no symptoms are reported



- n expected “background” range for typical buildings without perceived IAQ problems

***Test a hypothesis about the source of the problem, such as***

- n checking emissions from a piece of equipment
2. Testing for “indicator” compounds associated with particular types of building conditions:

***Peak carbon dioxide (CO<sub>2</sub>) concentrations over 1000 ppm (parts per million) are an indicator of underventilation***

***Carbon monoxide (CO) over several ppm indicates inappropriate presence of combustion by-products (which may also account for high CO<sub>2</sub> readings)***

3. Comparing measured concentrations to guidelines or standards

***Occupational exposure standards and guidelines, such as***

- n OSHA PELs (Occupational Safety and Health Administration’s Permissible Exposure Limits)
- n NIOSH RELs (National Institute for Occupational Safety and Health’s Recommended Exposure Limits)
- n ACGIH TLVs (American Conference of Governmental Industrial Hygienists’ Threshold Limit Values)

*Occupants in this one-story office building were complaining of intermittent gasoline odors. Exhausts from underground gasoline storage tank vent pipes (visible in the lower right portion of this photograph) were being drawn into the office building through outdoor air intakes on this roof. The gasoline storage tanks belonged to an adjacent service station.*

### ***Public health guidelines for specific pollutants***

- n EPA National Ambient Air Quality Standards
- n World Health Organization Air Quality Guidelines
- n Canadian Exposure Guidelines for Residential Air Quality

It is prudent to begin a program of chemical sampling only if symptoms or observations strongly suggest that a specific pollutant or a specific source may be the cause of the complaint and if sampling results are important in determining an appropriate corrective action.

There are no widely accepted procedures to define whether IAQ test results are acceptable. Extreme caution must be used in comparing contaminant concentrations to existing occupational standards and guidelines. Although a contaminant concentration above those guidelines is a clear problem indicator, occupants may still experience health and comfort problems at concentrations well within those guidelines. **It is extremely rare for occupational standards to be exceeded — or even approached — in public and commercial buildings, including those experiencing indoor air quality problems.**

Where specific exposure problems are suspected, more detailed diagnostic testing may be needed to locate or understand major sources, confirm the exposure, and to develop appropriate remedial actions. For example, the control of microbial or pesticide contamination may involve surface or bulk sampling. (Surface sampling involves wiping a measured surface area and analyzing the swab to see what organisms are present, while bulk sampling involves analyzing a sample of suspect material.) Specialized skills, experience, and equipment may be needed to obtain, analyze, and interpret such measurements.

### ***What Substance(s) Should Be Measured?***

Measurement of “indicator” compounds such as CO<sub>2</sub> or CO can be a cost-effective strategy. Such measurements can help the investigator understand the nature of the problem and define the complaint area.

Air sampling for specific pollutants works best as an investigative tool when it is combined with other types of information-gathering. It is prudent to begin a program of chemical sampling only if symptoms or observations strongly suggest that a specific pollutant or a specific source may be the cause of the complaint and if sampling results are important in determining an appropriate corrective action.

### ***Where Should Air Samples Be Taken?***

The identified problem area is an obvious site for air sampling. Measurements taken outdoors and in a control location (e.g., a complaint-free area of the building) are helpful in interpreting results from the complaint area.

The conditions experienced by building occupants are best simulated by sampling air from the “breathing zone” away from the influence of any particular individual. However, if an individual sits at a desk all day (except for brief periods), samplers placed on the desk when the individual is elsewhere can provide a good estimate of that person’s exposure.

There are several ways to locate sampling sites for an IAQ investigation. One approach first divides the building into homogeneous areas based on key factors identified in the building inspection and interviews. Examples of how a building might be divided include:

- n control zones (e.g., individual rooms)
- n types of HVAC zones (e.g., interior vs. perimeter)
- n complaint vs. non-complaint areas
- n relationship to major sources (e.g., spaces directly, indirectly, or not impacted by smoking areas)
- n complaint types

Test sites can then be selected to represent complaints, controls, and potential sources with a reasonable number of samples.

## When Should Indoor Air Samples Be Taken?

Samples may be designed to obtain “worst-case” conditions, such as measurements during periods of maximum equipment emissions, minimum ventilation, or disturbance of contaminated surfaces. Worst-case sample results can be very helpful in characterizing maximum concentrations to which occupants are exposed and identifying sources for corrective measures.

It is also helpful to obtain samples during average or typical conditions as a basis of comparison. It may, however, be difficult to know what conditions are typical. Research shows that exposure to some pollutants may vary dramatically as building conditions change. Devices that allow continuous measurements of key variables can be helpful.

Symptoms or odors that only occur occasionally will not generally be seen during the IAQ investigation. Air samples should not be taken if an incident is not occurring, unless the purpose of the sample is to establish a baseline for future comparisons.

One approach to intermittent IAQ problems is for the IAQ investigator to ask appropriate building staff or other occupants to document changes over time using day-to-day records such as the **Occupant Diary** and **Log of Activities and System Operation**. When an odor episode does occur, the building engineer could inspect the air handler and intake area while another staff member documents the status of several potential sources.

Another strategy is to manipulate building conditions to create worst-case conditions during the building investigation (e.g., arrange for the trash truck to idle at the loading dock or close outdoor air dampers to minimum settings). Chemical smoke and tracer gases can be used to assess where emissions may travel under various building conditions. (Such strategies should be carried out in ways that minimize occupant exposure.)

## What Sampling and Analysis Method Should Be Used?

Take care to select appropriate measurement techniques and to provide interpretations so that the results provide useful information. *Appendix A* provides guidance on measurement techniques that are commonly used in IAQ investigations.

### COMPLAINTS DUE TO CONDITIONS OTHER THAN POOR AIR QUALITY

Complaints that initially seem to be linked to thermal discomfort, underventilation, or indoor air pollutants may actually be caused or complicated by factors such as:

- n environmental stressors (e.g., lighting, noise, vibration)
- n ergonomic stressors
- n job-related psychosocial (human relations) stressors

The following briefly discusses each of these three kinds of stressors. Investigators should bear in mind that complaints produced by these stressors are sometimes mistakenly blamed on contaminated air. To complicate matters, such stressors also can produce a heightened sensitivity to poor indoor air quality. Thus, even when specific stressors are obvious, the investigator should not assume that they are the only reason for the complaints.

#### Lighting

Stresses from inadequate or poorly designed lighting (e.g., glare, flicker, poor illumination of work surfaces) can produce symptoms such as eyestrain and headaches. Lack of natural sunlight can also be a source of stress. These complaints are sometimes mistakenly interpreted as signs of poor indoor air quality. Lighting problems may be evident in large areas or localized in particular workspaces.

Investigators should bear in mind that complaints produced by these stressors are sometimes mistakenly blamed on contaminated air. To complicate matters, such stressors also can produce a heightened sensitivity to poor indoor air quality.



*The glare from the windows was causing a variety of occupant complaints in this building and was disrupting the workers' ability to use the video display terminals. Complaints such as headaches are sometimes incorrectly blamed on poor indoor air quality.*

## Noise

Noisy surroundings can reduce the ability to concentrate and produce stress-related symptoms such as headaches. Noise can also contribute to job dissatisfaction, particularly if the problem is caused by overcrowding or other factors likely to produce a sense of substandard work conditions.

The ear gets used to sounds quickly, so it is possible for a complainant to be unaware of a constant or regular sound. Investigators should recognize that noise can be a source of stress, even if it is not reported as a problem and is within current industrial exposure criteria (which are designed primarily to prevent hearing loss).

## Vibration

Low-frequency vibration is another source of stress that may go unreported by building occupants or become confused with pollutant problems. Vibration can be caused by nearby machinery or movement of the building as a whole; motion sickness has been reported in some high rise buildings that sway in the wind.

## Ergonomic Stressors

Fatigue, circulatory problems, and other physical problems can be produced by furniture that is mismatched to the task, such as chairs that are the wrong height for computer terminals. If IAQ investigators inquire about whether new furniture has recently been installed in the problem area (to determine if the furniture could be contributing to increased contaminant levels), they should also ask about whether the occupant finds the furniture comfortable.

## Job-related Psychosocial Stressors

It is well documented that various job-related psychosocial conditions can produce symptoms in workers. Excessive workload and work pressure are easily recognized job stressors. Lack of clarity about what is expected of the worker (role ambiguity) and the presence of conflicting expectations (role conflict) are also commonly encountered stressors in modern organizations. Poor interpersonal relations, management styles that allow little participation in decision-making, and factors related to career development are also thought to be potentially stressful.

## FORMING AND TESTING HYPOTHESES

As the building investigation progresses, you should be developing one or more hypotheses that could explain the occupant complaints. The investigation can then be shaped to collect information that will either support or refute your hypotheses.

The **Hypothesis Form** on the opposite page is designed to pull together the separate pieces of information that have been collected by summarizing the results of the investigation. More pages can be added if desired, but the form is designed for brief notes that can be scanned easily. As you review the information, write down

any explanation(s) for the IAQ problem that make sense, and think about how the pieces of the puzzle fit together when building conditions are compared to occupant complaints.

Is all (or most) of your information consistent with your hypothesis? If not, is there a reasonable explanation for the inconsistencies? A different hypothesis might provide a better fit with your information.

You may find that there are several IAQ problems (e.g., underventilation in one zone, a strong contaminant source in another room). If you have discovered potential IAQ problems that do not appear related to the original complaint, they can be prioritized and corrected as time and funding permit.

Think of ways to test your hypotheses. You may want to change ventilation rates, change the pressure relationship between spaces, cover or remove suspected sources, seal pathways, or temporarily relocate affected individuals. If your manipulations can reduce occupant complaints, you have found a reasonable hypothesis. Sometimes it is not possible (or not practical) to manipulate important factors. You can also test your hypothesis by seeing how accurately you can predict changes in building conditions (e.g., as outdoor temperature changes).

If you are having difficulty developing hypotheses, review the information you have collected and the suggestions about how to use that information. For suggestions on using occupant complaint data, see pages 53-57; on using HVAC system information, see pages 62-67; on using pollutant pathway information, see pages 70-71; on using pollutant/source inventory data, see page 74; on using air sampling information, see pages 75-76.

The changes that are made during hypothesis testing may offer a practical solution to the IAQ problem, or may be only temporary measures. The mitigation chapter presents a variety of approaches that have been used in correcting some selected categories of IAQ problems and discusses how to evaluate those strategies.

SEE  
COMPLETE  
FORM  
PAGE 223

Sample Form  
Hypothesis Form

Complaint Area (may be revised as the investigation progresses):

---

---

Complaints (e.g., summarize patterns of timing, location, people affected):

---

---

HVAC: Does the ventilation system appear to provide adequate air, efficiently distributed to meet occupant needs in the complaint area? If not, what problems do you see?

---

---

Pathways: What pathways and driving forces connect the complaint area to locations of potential sources?

---

---