ASHRAE Guideline 27P

Public Review Draft

Measurement Procedures for Gaseous Contaminants in Commercial Buildings

Fifth Public Review (March 2019)
(Draft shows proposed Independent Substantive Changes to previous Public Review Draft)

This draft has been recommended for public review by the responsible project committee. To submit a comment on this proposed standard, go to the ASHRAE website at www.ashrae.org/standards-research--technology/public-review-drafts and access the online comment database. The draft is subject to modification until it is approved for publication by the Board of Directors and ANSI. Until this time, the current edition of the standard (as modified by any published addenda on the ASHRAE website) remains in effect. The current edition of any standard may be purchased from the ASHRAE Online Store at www.ashrae.org/bookstore or by calling 404-636-8400 or 1-800-727-4723 (for orders in the U.S. or Canada).

The appearance of any technical data or editorial material in this public review document does not constitute endorsement, warranty, or guaranty by ASHRAE of any product, service, process, procedure, or design, and ASHRAE expressly disclaims such.

ASHRAE, 1791 Tullie Circle, NE, Atlanta GA 30329-2305

This is a review of Independent Substantive Changes that were made since the last (Fourth) Public Review. Areas where substantive changes have been made are highlighted in gray. In these areas, text that was removed from the previous Public Review is provided for reference but is shown in ~~strikeout~~ and text that has been added is shown with underlines.

Only the changes highlighted in gray are open to comment at this time. All other material is provided for context only and is not open for Public Review comment except as it relates to the proposed changes.

The **Independent Substantive Changes** included addition of some references near the start of the document. The new reference details and necessary reference number changes are shown in full under section 11.1 **References**. However, consequent reference number changes in the body of the text are not shown as they are not considered to be substantive changes.

FOREWORD

The intent of this guideline is to assist engineers and other professionals to plan and implement ~~testing~~measurement and sampling of gaseous contaminants in commercial buildings. Properties of gaseous contaminants are discussed in detail in the ASHRAE Fundamentals Handbook, Chapter 11 (1).

Note that ~~I~~it is assumed that users of this guideline have either been specifically requested to obtain data on gaseous contaminants, or have established through preliminary investigation that measurement or sampling of~~testing for~~ gaseous contaminants is warranted.

For the purposes of this guideline, commercial buildings include all building types covered by ASHRAE Standard 62.1. These buildings typically utilize commercial HVAC equipment. The guideline may also be used for naturally ventilated commercial buildings, though interpretation of the data may be somewhat different.

Commercial buildings are often complex structures containing a variety of functional spaces and occupant activities. HVAC systems also vary widely from building to building. The intent of the investigation will usually determine which gaseous contaminants to test. Other factors, such as likely concentration, will contribute to the choice of the most appropriate gaseous contaminant measurement or sampling~~test~~ method(s) to use, and building characteristics will play a part in selection of test locations and timing. These factors are important if meaningful data are to be obtained which can be reliably interpreted to draw conclusions about conditions in the building and to guide any recommendations for change.

This guideline is ~~only~~intended for making ~~and interpreting~~ gas measurements or sampling. ~~In most cases, other factors in addition to gas measurements need to be considered before any actual corrective recommendations can be made.~~

This guideline is not intended for use in industrial environments. Gaseous contaminant concentrations may be much higher in industrial environments, and different test methods are normally appropriate.

This guideline is also not intended for use in residential buildings. Residential buildings have different ventilation equipment, usage, and indoor air quality (IAQ) challenges from commercial buildings.

It should be noted that a variety of problems (such as odor, other IAQ complaints, and some building system issues) can often be effectively resolved without resort to measurement or sampling. Resolution is typically achieved using information gathered from inspections, interviews, and sometimes questionnaire data. Procedures for such investigations are not included here. The IAQ Investigator's Guide (2) can supply useful guidance on conducting such investigations. Other references are also provided in the text.

In the event that inspections and interviews do not resolve an issue unambiguously, test data is likely to be needed to confirm or reject a problem diagnosis. Note that the decision to acquire data needs to be made before utilizing this guideline because the guideline does not address non-equipment-based problem-solving.

Sometimes measurement or sampling~~this~~ can be completed using simple, inexpensive equipment (screening), but sometimes a further stage utilizing more complex, sensitive, or accurate equipment is needed, particularly if unacceptable levels of contaminant are indicated at the screening stage. This guideline addresses both needs.

Instrument calibration is not covered here because manufacturers normally either factory-calibrate suitable instruments or provide detailed instructions for instrument owners to enable them to carry out the task. Note that it is assumed that any instrumentation employed relative to this guideline will be calibrated, at minimum, within the manufacturers' recommended timelines and following their suggested procedures.

The GPC 27 Committee accepts that fine and ultra-fine particulates are important components of both outdoor and indoor air pollution. However, the scope of this guideline covers only gaseous contaminant test methodsmeasurement and sampling procedures. While particulate matter is not discussed here, measurement of particles should be considered when planning as part of any IAQ survey. Some tTest methods are discussed in the ASHRAE Fundamentals Handbook, Chapter 11 (1).

3.1 Definitions

semi-volatile organic compound (SVOC): chemical belonging to the low-volatility subset of the organic compounds that can be present in indoor air under normal indoor atmospheric conditions of temperature and pressure; specifically, an organic compound with a saturation vapor pressure between 10^{-2} and 10^{-8} kPa at 25°.

Total Volatile Organic Compounds (TVOC): the approximate sum of the concentrations of the measured VOCs ~~the total concentration of VOC~~ in a space. The TVOC value depends on the sampling and analytical methods used and therefore should be interpreted cautiously, taking into account the full description of the method used to determine the concentration.

volatile organic compound (VOC): chemical belonging to the medium-volatility subset of the organic ~~any organic chemical~~ compounds that can be present in indoor air under normal indoor atmospheric conditions of temperature and pressure; specifically, an organic compound with a saturation vapor pressure greater than 10^{-2} kPa at 25°.

3.2 Acronyms

ACGIH	American Conference of Governmental Industrial Hygienists
AHU	Air handling unit
AIHA	American Industrial Hygiene Association
ASTM	American Society for Testing and Materials
BRI	Building Related Illness
CFC	Chlorofluorocarbon
CFR	Code of Federal Regulation
CIH	Certified Industrial Hygienist
CREL	Chronic Reference Exposure Level
ECD	Electron Capture Detector
EPA	Environmental Protection Agency (USA)
ETS	Environmental Tobacco Smoke
FID	Flame Ionization Detector
GC/MS	Gas Chromatography/Mass Spectrometry
HCFC	Hydrochlorofluorocarbon
HFC	Hydrofluorocarbon
HPLC	High Performance Liquid Chromatography
HVAC	Heating, Ventilating and Air-Conditioning
IAQ	Indoor Air Quality
ISO	International Organization for Standardization~~International Standards Organization~~
IWBI	International WELL Building Institute
LEED	Leadership in Energy and Environmental Design
MDL	Method Detection Limit
MQL	Method Quantitation Limit
MSDS	Material Safety Data Sheet. Now known as Safety Data Sheet (SDS)
MVOC	Microbial Volatile Organic Compound
NAAQS	National Ambient Air Quality Standards (USA)

NARA	National Archives and Records Administration
NIOSH	National Institute of Occupational Safety and Health
NOAA	National Oceanic and Atmospheric Administration (USA)
O&M	Operations and Maintenance
OSHA	Occupational Safety and Health Administration
PCB	Polychlorinated Biphenyl
PID	Photo-ionization Detector
ppbv	parts per billion by volume (usually shortened to ppb)
ppmv	parts per million by volume (usually shortened to ppm)
RH	Relative Humidity
SDS	Safety Data Sheet. Formerly known as Material Safety Data Sheet (MSDS)
SVOC	Semi-volatile Organic Compound
TVOC	Total Volatile Organic Compound
TWA	Time-weighted Average
USGBC	United States Green Building Council
VAV	Variable Air Volume
VOC	Volatile Organic Compound
VRF	Variable Refrigerant Flow HVAC System
VVOC	Very Volatile Organic Compound
WHO	World Health Organization

4.1 The Role of Gaseous Contaminant Measurement and Sampling

It has been pointed out in the Foreword, and is fully accepted, that some IAQ problems in buildings can be effectively resolved without using measurement or sampling. Procedures are available for using this approach (2, 3). However, the mandate of this guideline does not include such procedures. This guideline exists only to provide guidance on measurement and sampling methods. This means that, throughout the rest of this document, the reader needs to understand that the decision has been made that measurement and/or sampling is required.

While the thrust of the testing~~project~~ is to determine contaminant concentrations, it is ~~usually also~~ necessary for several reasons to ~~spend some time on information-gathering~~ obtain background information on the building, including its size, function and occupancy, its systems, operation, and maintenance. Obviously, it is important to be completely clear in advance of testing about the intent of the measurements and the issues to be addressed. In addition, it should be noted that contaminant concentrations are subject to wide variability over time and by location within a building. Investigators need to identify factors that impact contaminant concentrations and to develop at least a general understanding of the range of conditions which may occur in that building (ventilation, temperature, operations and maintenance [O&M] activities, etc.). Therefore, obtaining background information on the building~~,~~ and its systems~~, operation, and maintenance~~ is necessary. This information will facilitate selection of contaminants of interest (if this is part of the project), test method selection, preparation of budget/proposal for testing (if not completed already), and interpretation of the collected air contaminant data. It should also be included in the report prepared on the data collection in order to place these data in proper context.

4.1.1 ~~Evaluation~~Tools for Obtaining~~Gathering~~ Information on the Building, its Systems, Contaminant Sources, and Perceived Problems~~Relevant to the Testing~~

~~Evaluation t~~Tools useful for gathering relevant information in buildings fall into two categories: obtaining answers from people in the building through informal interviews or more formal questionnaire surveys; and inspections carried out by the investigating team.

Informal interviews should include the Facilities Manager and/or Property Manager to confirm the intent of the investigation and acquire information on the building. It should also include maintenance personnel who can report on operation and maintenance of the heating, ventilating and air-conditioning (HVAC) and other building systems and type and location of any nearby outdoor gaseous contaminant sources. Table 4.1 gives an example of a checklist of building information to obtain.

Table 4.1: Information to Obtain from Building ~~Managers~~Staff

General Description of the Building
Name and street address
Building function (offices, school, etc.)
Number of wings/towers
Number of floors in each wing/tower
Number of HVAC systems
Type and amount of refrigerant in the building
Location of mechanical room(s) and air intake(s)
HVAC operating schedule
Information Relevant to the Testing
Type and location of any nearby outdoor gaseous contaminant sources
Type and location of any known indoor gaseous contaminant sources
Subset of zones/floors where testing is to be carried out
Types of air handling unit (AHU) relevant to the test zone(s)
Test zone space types/functions
Date and details of last Testing and Balancing work

Informal interviews with occupants may be conducted before or during an indoor air quality (IAQ) investigation. Occupants can provide perceptions about IAQ, in addition to information on activities, events, and conditions that might have contributed to problems.

Questionnaire surveys can reveal potential causes of poor IAQ through information obtained on timing, location, and nature of symptoms and on occupant activities.

Inspections of occupied spaces and other functional areas such as storage rooms, parking garages, janitor closets, mechanical rooms, the HVAC system, air intakes, etc., provide information that can identify or help to identify point sources of air contaminants and causes of problems related to the building and its systems.

If further information on conducting IAQ investigations is needed, *The IAQ Investigator's Guide* (2) provides an occupant questionnaire, a detailed HVAC inspection checklist, and a comprehensive list of references. ASHRAE's Performance Measurement Protocols for Commercial Buildings (3) covers non-instrument-based data acquisition, and the Indoor Air Quality Guide (4) discusses contaminant generation

and when measurement is/is not appropriate. The US Environmental Protection Agency (EPA) publication, *A Standardized EPA Protocol for Characterizing Indoor Air Quality in Large Office Buildings* (~~3~~5), presents detailed building inspection checklists in Appendices A and D and an occupant questionnaire in Appendix F~~(3)~~. The US EPA document *Indoor Air Quality Tools for Schools Coordinators Guide* (~~4~~6) also contains some useful checklists.

Reviewing Safety Data Sheets (SDSs) (Material Safety Data Sheets [MSDSs]), discussion with maintenance personnel or more detailed inspection can allow assessment of the strength of point sources. The information obtained can be used to identify contaminants to test and facilitate selection of the appropriate measurement or sampling technique. Technique selection often requires knowledge of the approximate contaminant concentration present.

Note that manipulating HVAC operation and source emissions to achieve worst-case contaminant scenarios for facilitating problem characterization or assessment of remediation effectiveness is outside the scope of this guideline (though it is acknowledged that useful information may often be obtained through such manipulations).

4.1.2 Presence and Concentration of Gaseous Contaminants

There are normally many hundreds of gaseous contaminants in the air in commercial buildings, typically ranging in concentration from ~~trace~~levels less than 1 part per billion by volume (ppb) to one part per million by volume (ppm) or more (4, ~~5~~7). Some originate outdoors and enter buildings through the HVAC system or by infiltration, while others have indoor sources.

Carbon dioxide is a special case, as it is a metabolic gas rather than a contaminant of health concern in indoor air. The global average outdoor concentration (2018) is about 405 ppm, and this is currently increasing by roughly 2 ppm per year (8). It has many outdoor sources, and local ambient levels may deviate significantly from the global average, with urban areas or locations near emission sources typically higher. For this reason, site-specific outdoor measurements should always be made for reference purposes during a survey. In no case should outdoor concentrations be inferred or reported from published data. The main indoor source in commercial buildings is the respiration of building occupants, and concentrations in properly ventilated buildings typically range from ambient to 700ppm above ambient. Higher indoor levels may be found, occasionally even >2000ppm above ambient, in locations that have high/variable occupancy but inadequate ventilation (e.g., conference rooms).~~. It is typically present at levels of about 405 ppm outdoors (currently increasing by roughly 2 ppm per year) (6), often at higher ambient levels in urban areas. It ranges from ambient to >700ppm above ambient indoors. It is not uncommon to find 3000 ppm indoors. The higher levels are normally contributed from respiration of the building occupants.~~ Carbon dioxide can be used as a tracer gas for estimating ventilation rates under some conditions (~~7~~9).

Not all air contaminants are equally important. During testing, usually only a small number need to be quantified (often only around 2-8, though testing for LEED (10) or ASHRAE Standard 189.1 (11) may include more than 30).~~During an investigation, usually only a small number actually need to be quantified.~~ Sometimes the party requesting the testing will dictate which contaminants to test. Otherwise, the choice will depend both on the nature of the contaminant (toxicity, corrosion potential, irritancy, odor threshold, type and volume of the contaminant present, etc.), and on the likelihood, based on source information, of

the contaminant being present in a quantity likely to have an impact on people, equipment, or materials. ASHRAE's Performance Measurements Protocol (3) and IAQ Guide (4) can provide useful guidance here.

4.2.1 Baseline Measurements

It can be useful for interpretation of data taken later to carry out contaminant monitoring at the start of a building's lifecycle. In some cases, it is required; for example, to obtain credit(s) for green building certification, or as part of the commissioning process for buildings designed using the ASHRAE Standard 62.1 IAQ Procedure (~~8~~12). The contaminants of interest may be specified by an agency (as is done for Leadership in Energy and Environmental Design [LEED] certification) or be selected during the building design phase based on source information. Monitoring may be carried out pre-occupancy, post-occupancy, or both before and after the occupants move in. Data collected at a later time can then be compared to the baseline data to assess complaints, need for maintenance or HVAC system modification, etc.

If baseline data is being used for a building, it is good practice for new baseline data to be ~~taken~~ collected after functional changes have been made to a space, after remodeling (new floorings, painting, furniture, etc.), or after remediation has been carried out ~~to~~ in the building or its systems (including changes made following testing as described in this guideline).

4.2.2 Addressing IAQ Issues

Monitoring for gaseous contaminants may be done as part of an IAQ survey. Surveys can be quite varied in their intent, and examples of reasons for monitoring include:

- the need to provide data to indicate that IAQ in the building is acceptable;
- the need to comply with a building's O&M program;
- inability to resolve reported IAQ problems on the basis of interviews, inspections, and questionnaire use alone;
- the need to locate and characterize a suspected contaminant source and to evaluate the impact of exposure on building occupants.

Monitoring undertaken as part of an~~for~~ O&M ~~purposes~~ requirement may be carried out ~~every 1–2 years~~ periodically. Periodic monitoring should make note of, and be considerate of, climate variations between seasons, occupancy load variations, and seasonal ventilation system settings.~~In places with large climate variations between seasons, it may be appropriate to carry out testing in each season.~~

When the IAQ survey is used to investigat~~ing~~e complaints or potential contaminant sources, a specific contaminant or set of contaminants may be targeted. Otherwise, a small set of contaminants ~~is usually~~can be monitored along with temperature and relative humidity (RH). More details can be found in Section 5.1.

In addition to the EPA protocol (~~3~~5), publications such as Nagda and ~~Rector's~~ Harper's *Design and Protocol for Monitoring Indoor Air Quality* (~~9~~13) may be of value in project planning.

4.4.1 Determining which Contaminants to Test

In some cases, there is no decision to make because the contaminants have been preselected by the party requesting the testing or are dictated by an agency as occurs for testing done to achieve credits for green building certifications such as LEED, IWBI or Green Globes.

In ~~other~~ cases where a decision needs to be made, the choice ~~is down to professional judgement:~~ of contaminants to test ~~testing should only be carried out for contaminants likely to be present in the building at measurable concentrations and likely to be the~~ is based on information obtained about sources of contaminants that might cause ~~of~~ material damage, health impacts, or complaints, as well as on building operating conditions that will affect concentrations.

Most IAQ testing utilizes a small set of parameters, which are discussed in Section 5.1.1. However, a contaminant with a (suspected) strong source near or in the building may be added to the set, or it may be the sole focus of the testing.

4.4.3 Deciding on use of Instantaneous Measurement or Integrated Sampling

Important technical considerations that play a part in method selection include ~~sensitivity~~detection limit, selectivity, accuracy, and precision. These are defined in Section 3 and discussed in Section 5.4. Other criteria for selection are discussed in Sections 5.5, 5.6, and 5.7, and the selection process is summarized in Section 5.8. Section 5.9 offers practical advice on using the equipment described earlier. The later parts of Section 5 also cover budgeting and planning the on-site testing.

5. PREPARATION FOR TESTING

This section is mainly concerned with techniques and equipment for measuring and sampling gaseous contaminants in indoor air and heating, ventilating and air-conditioning (HVAC) systems. Note that the decision whether or not to measure or sample contaminants as part of an IAQ investigation should have been made before starting to use this guideline.

5.1 Common Gaseous Contaminants

Usually only a small number of gaseous contaminants need to be measured as part of an investigation. Which gases to test depends both on the nature of the contaminant (toxicity, corrosion potential, irritancy, odor threshold, volume of contaminant present, etc.), and on the likelihood, based on source information, of the contaminant being present, indoors or outdoors, in a quantity likely to have an impact on people, equipment, or materials (2, 3, 4).

The gases which are important vary depending on the aim of the testing as identified in the previous section. Typical aims include:

- Indoor air quality (IAQ) baseline testing, problem resolution, and repeat testing;
- Sensitive materials baseline testing, problem resolution, and repeat testing;
- Leadership in Energy and Environmental Design (LEED) baseline testing in new construction or renovation (10);
- Pre-occupancy testing under ASHRAE Standard 189.1 (11);
- To ensure leak free operation of systems that utilize potential building contaminants, such as VRF systems; and

- Preparation for HVAC design and commissioning using the Standard 62.1 IAQ Procedure (12).

5.1.1 Contaminants for Different Test Scenarios

Temperature and relative humidity (RH) are also normally included because some occupant IAQ complaints ("no oxygen," "no air," "stuffy," etc.), are likely to be due to thermal comfort problems rather than to presence of contaminants. Note that, under normal circumstances, oxygen deficiency never actually occurs in occupied spaces in commercial buildings.

~~While an inclusive, operational definition for VOC has been adopted in this document, t~~The World Health Organization (WHO) categorizes indoor organic pollutants as very volatile, volatile, and semi-volatile, with the rationale that higher volatility (lower boiling point) compounds and mixtures are more emitted from a product or surface into the air. Very volatile organic compounds (VVOCs) are almost entirely gases in ambient air. The least volatile compounds (semi-volatile organic compounds or SVOCs) are present indoors and mainly adsorbed on surfaces including dust, furnishings, and building materials. The medium-volatility VOC group includes microbial VOCs (MVOCs) which are emitted during mold or bacterial growth. MVOCs belong to a variety of chemical classes including alcohols, ketones, organic acids, and heterocyclic compounds. Many have extremely low odor thresholds and may be quite objectionable and irritating.

TVOC is different from the other contaminants listed previously. The concentration of TVOC is a composite number intended to represent the approximate sum of the concentrations of ~~all of~~ the measured VOCs in a space. Being a composite concentration has two consequences: the unit of measurement must always be mg/m^3 because the molecular weight is not defined (see Section 5.1.2); and the concentrations obtained using different methods vary widely because of the varied responses of VOCs to different measurement or sampling methods. It should be noted that no technique will capture all of the individual VOCs present. TVOC measurements of similar VOC mixtures, taken with the same instrument in the same building, may be meaningfully compared. However, comparisons between buildings should not be attempted. It is also impossible to deduce from TVOC data which contaminants are responsible for the quantity found. Thus, TVOC data cannot be related to health impacts. Measuring TVOC is useful for screening purposes only.

5.2.1 IAQ Standards and Guidelines

Table 5.3: Selected IAQ Guidelines for Specific Gases

	World Health Organization [1]	**Illinois Department of Public Health [2]**	**French IAQ Guidelines [3]**	**Hong Kong [4] (8-hour average) Good Class**
Benzene	No safe level of exposure can be recommended		10 µg/m3 (>1 year)	16.1 µg/m3 (5 ppb)
Carbon monoxide	• 8 hours – 10 mg/m3•	9 ppm	10 mg/m3 (8 hours)	< 10 mg/m3 (8.7 ppm)

Formaldehyde	0.1 mg/m3 – 30-minute average	0.1 ppm (Office) 0.03 ppm (Home)	10 µg/m3 (>1 year)	< 100 µg/m3 (81 ppb)
Nitrogen dioxide	• 200 µg/m3 – 1 hour average • 40 µg/m3 – annual average	0.05 ppm – 24 hr	20 µg/m3 (>1 year)	< 150 µg/m3 (80 ppb)
Radon	100 Bq/m3*	4.0 pCi/L (148 Bq/m3)		200 Bq/m3
Tetrachloroethylene	250 µg/m3 – annual average		250 µg/m3 (>1 year)	250 µg/m3 (37 ppb)
Carbon Dioxide		1,000 ppm (<800 ppm preferred)		< 1,000 ppm
Hydrogen sulfide		0.01 ppm		
Ozone		0.08 ppm		< 61 ppb
Total Volatile Organic Compounds (TVOC)				600 µg/m3 ~~(261 ppb)~~
1,4-dichlorobenzene				200 µg/m3 (33 ppb)
Toluene				1,092 µg/m3 (143 ppb)

*** Reference level proposed by WHO**

[1] WHO 2010 (~~19~~22)
[2] Illinois Department of Public Health 2011 (~~20~~23)
[3] ANSES 2014 (~~21~~24)
[4] Hong Kong IAQ Objectives for Offices and Public Places 2003 (~~22~~25)

While the guidelines for individual gases usually bear some relationship to health impact, the same is not true, and never can be true, for TVOC. This is because TVOC is likely to contain a different mix of airborne chemicals in each building tested because measurement does not include all VOCs present, because individual chemicals are not identified, and because the health impacts of individual VOCs vary widely both in type and severity. The utility of the TVOC guideline is that exceeding the limit may signify a problem of high emission or low ventilation rate.

5.2.2 Sensitive Materials Standards and Guidelines

For direct measurement of single gas or vapor concentrations, concentration values can be compared to predetermined acceptability limits for those gases or vapors. Table 5.7 provides selected guidelines from various sources. It should be noted that the requirements for nitrogen oxides, ozone, and sulfur dioxide are lower than the concentration limits for outdoor air (the US National Ambient Air Quality Standards

[NAAQS] are shown in the first column for comparison) and also that the National Archives and Records Administration (NARA) limits are only in force in US federal archival facilities (though they are used voluntarily in a number of state and private institutions). For reference (21), it should be noted that later editions of the ASHRAE HVAC Applications Handbook do not include these criteria.

5.3.1 Instantaneous Measurements

Instruments based on photo-ionization, flame ionization, and electron capture detection each respond to large numbers of gaseous contaminants. Thus, they can effectively measure single chemicals only if one is predominant in a space. Otherwise, they will measure all of the gases that they can detect. These techniques can thus be used to measure TVOC. However, TVOC levels measured with one of these techniques should never be compared to levels measured with a different technique because detector responses vary widely between techniques. For this reason, TVOC concentrations measured with direct-reading equipment ~~are inherently inaccurate and~~ should primarily be used for screening and source tracking purposes.

5.3.3.1 Active Sampling Methods

Active methods are more complex than other techniques.~~,~~ If such methods are found to be the most useful for the task in hand,~~and~~ investigators may wish to consider contracting out testing to a qualified and trained person with appropriate experience such as a Certified Industrial Hygienist (CIH) ~~if such methods are found to be the most useful for the task in hand~~.

5.9.3 Active Integrated Sampling Systems

Active integrating sampling systems are more complex than passive ones. The sampling system consists of a pump for drawing air, the sampling medium in a flow-through container, and often a device for holding the container securely in place during sampling. The sampling medium may be contained in a filter cassette, glass tube, or glass vessel with liquid in it (an impinger) or other container.

Because of this complexity, an ~~inexperienced~~ investigator who is unsure of any part of the procedure should consider asking for advice ~~if unsure of any part of the procedure~~ from the laboratory that will carry out the sample analysis or from a Certified Industrial Hygienist (CIH).

6.5 Reference Locations

Reference locations are places for obtaining reference data to compare with data taken as part of the project testing. The key criteria are that a reference location should be free from contaminant sources, and free from air pathways to sources, so that it will show concentrations at background levels only.

Outdoor air is ~~widely used as~~ a very important reference, and it is recommended that all sampling plans include site-specific outdoor air testing. ~~t~~The best measurement or sample location is directly outside the air intake of the AHU serving the area being investigated (location corresponds to B’ in Figure 6.1.). When collecting data, verify that outdoor air is actually entering the intake. If air from nearby exhausts, relief vents, loading docks, etc., appears to be re-entrained, this needs to be noted and measurements should be made to establish the extent of the entrainment.

11. REFERENCES AND BIBLIOGRAPHY

11.1 References

(1) ASHRAE. ~~2013~~2017. Fundamentals Handbook, Chapter 11, *Air contaminants*. American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta, GA.

(2) AIHA. 2016. *The IAQ Investigator's Guide* (3rd edition). American Industrial Hygiene Association, Falls Church, VA.

(3) ASHRAE. 2012. *Performance Measurement Protocols for Commercial Buildings – Best Practices Guide*. American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta, GA.

(4) ASHRAE. 2009. *Indoor Air Quality Guide: Best Practices for Design, Construction, and Commissioning*. American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta, GA.

(~~3~~5) EPA. 2003. *A standardized EPA protocol for characterizing indoor air quality in large office buildings*. US Environmental Protection Agency, Research Triangle Park, NC 27711.

(~~4~~6) EPA. 2009. *Indoor Air Quality Tools for Schools Coordinators Guide*. US Environmental Protection Agency, Research Triangle Park, NC 27711.

(~~5~~7) LBL. 2016. Lawrence Berkeley National Laboratory, Indoor Air Quality Scientific Findings Resource Bank: *Indoor Volatile Organic Compounds (VOCs) and Health*. Available at https://iaqscience.lbl.gov/voc-intro.

(~~6~~8) NOAA. 2016. https://www.esrl.noaa.gov/gmd/ccgg/trends/

(~~7~~9) ASTM. 2011. *Standard test method for determining air change in a single zone by means of a tracer gas dilution*. ASTM E741, Philadelphia, PA.

(10) US Green Building Council (USGBC). 2015. *LEED for Building Design + Construction, version 4 (v4).*

(11) ASHRAE. 2017. ANSI/ASHRAE Standard 189-.1-2017, *Standard for the Design of High-performance Green Buildings*. American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta, GA.

(~~8~~12) ASHRAE. ~~2013~~2016. ANSI/ASHRAE Standard 62.1-2013, *Ventilation for Acceptable Indoor Air Quality*. ~~Atlanta, GA:~~ American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., ~~2013~~ Atlanta, GA.

(~~9~~13) Nagda, N.L., and J.P. Harper. 1989. *Design and protocol for monitoring indoor air quality*. ASTM STP 1002, Philadelphia, PA.

(~~10~~14) AIHA. 2016. *Volatile Organic Compound (VOC) criteria for new construction*. White paper. American Industrial Hygiene Association, Falls Church, VA.

(~~11~~15) ASHRAE. ~~2013~~2016. ANSI/ASHRAE Standard 15-2013 (packaged w/ Standard 34-2013), *Safety Standard for Refrigeration Systems*. American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta, GA.

(~~12~~16) ASHRAE. ~~2013~~2016. ANSI/ASHRAE Standard 34-2013 (packaged w/ Standard 15-2013), *Designation and Safety Classification of Refrigerants*. American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta, GA.

(~~13~~17) ASTM. 2012. *Guide for using indoor carbon dioxide concentrations to evaluate indoor air quality and ventilation*. ASTM D6245, Philadelphia, PA.

(~~14~~18) ASHRAE. 2016. *User's Manual for ANSI/ASHRAE Standard 62.1-2016*. American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta, GA.

(~~15~~19) International Organization for Standardization (ISO). 2006. Standard 16000-9:2006, *Indoor Air - Part 9: Determination of the emission of volatile organic compounds from building products and furnishing – Emission test chamber method*. ISO Central Secretariat, Geneva, Switzerland.

(~~16~~20) ASHRAE. ~~2011~~2016. ASHRAE Standard 145.2-2011, *Method of testing gaseous contaminant air cleaning devices for removal efficiency*. ASHRAE Standard 145.2-2011. American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta, GA.

(~~17~~21) ASHRAE. 2003. HVAC Applications Handbook, Chapter 21, *Museums, Libraries and Archives*. American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta, GA.

~~(18)~~

(~~19~~22) WHO. 2010. *Guidelines for Indoor Air Quality: Selected Pollutants*. World Health Organization.

(~~20~~23) Illinois Department of Public Health. 2011. *Guidelines for Indoor Air Quality*.

(~~21~~24) Agence nationale de securite sanitaire de l'alimentation, de l'environment, et du travail (ANSES). 2014. Available at https://www.anses.fr/fr/system/files/VGAIPublieesjuillet2014.pdf

(~~22~~25) Hong Kong. 2003. *IAQ Objectives for Offices and Public Places*.

(~~23~~26) EPA. 2015. *National ambient air quality standards (NAAQS)*. Environmental Protection Agency, Washington, D.C. Available at https://www.epa.gov/criteria-air-pollutants/naaqs-table.

(~~24~~27) EPA. 2006. *Building Assessment Survey and Evaluation Study (BASE)*. Washington, DC. Available at http://www.epa.gov/indoor-air-quality-iaq/building-assessment-survey-and-evaluation-study.

(~~25~~28) Sacchi, E. and C. Muller. 2005. *Air Quality Monitoring at Historic Sites: Redefining an Environmental Classification System for Gaseous Pollutio*n. ASHRAE Journal. Aug. 2005: 40-46.

(~~26~~29) Thomson, G. 1986. *The Museum Environment*. 2nd ed. Conservation and Museology. Oxford, United Kingdom: Butterworth-Heinemann. ISBN 7506-20412.

(~~27~~30) NBS. 1983. *Air Quality Criteria for Storage of Paper-Based Archival Record.* NBSIR 83-2795. National Bureau of Standards, Washington DC.

(~~28~~31) NARA. 2002. NARA 1571, *Archival Storage Standards*. National Archives and Records Administration, USA.

(~~29~~32) Manahan, S.E. 2001. *Fundamentals of Environmental Chemistry*, Boca Raton: CRC Press LLC.

(~~30~~33) Phalen, R.F. & R.N. Phalen. 2013. *Introduction to Air Pollution Science: A Public Health Perspective*, Jones & Bartlett Publishers.

(~~31~~34) Desauziers, V. 2004. *Traceability of pollutant measurements for ambient air monitoring*, Trends in Analytical Chemistry, Vol. 23, No. 3, pp.252-260.

(~~32~~35) Won, D.Y. & H. Schleibinger. 2011. *Commercial IAQ Sensors and their Performance Requirements for Demand-Controlled Ventilation*, IRC-RR-323, Institute for Research in Construction, National Research Council Canada.

(~~33~~36) ASTM. 2005. *Test Method for Carbon Monoxide in the Atmosphere (Continuous Measurement by Nondispersive Infrared Spectrometry).* ASTM D3162. ASTM, Philadelphia, PA.

(~~34~~37) ASTM. 2005. *Test Methods for Continuous Measurement of Oxides of Nitrogen in the Ambient or Workplace Atmosphere by the Chemiluminescent Method*. ASTM D3824. ASTM, Philadelphia, PA.

(~~35~~38) ASTM. 2010. *Practice for Calibration of Ozone Monitors and Certification of Ozone Transfer Standards using Ultraviolet Photometry*. ASTM D5110. ASTM, Philadelphia, PA.

(~~36~~39) ASTM. 2016. *Test Methods for Continuous Measurement of Ozone in Ambient, Workplace, and Indoor Atmospheres (Ultraviolet Absorption).* ASTM D5156. ASTM, Philadelphia, PA.

(~~37~~40) ASTM. 2016. *Test Method for Ozone in the Atmosphere: Continuous Measurement by Ethylene Chemiluminescence*. ASTM D5149. ASTM, Philadelphia, PA.

(~~38~~41) NIOSH. 2003. *NIOSH Manual of Analytical Methods*, 4th edition 94-113 (1994) with First Supplement 96-135 (1996), Second Supplement 98-119 (1998), and Third Supplement 2003-154 (2003). More information at www.cdc.gov/niosh/docs.

(~~39~~42) ASTM. 2010. *Standard Guide for Selection of Methods for Active, Integrative Sampling of Volatile Organic Compounds in Air*. ASTM D6345. ASTM, Philadelphia, PA.

(~~40~~43) Drolet, D. & G. Beauchamp. 2013. *Sampling Guide for Air Contaminants in the Workplace*, 8th edition, Technical Guide T-15, Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST), Montréal, Québec, Canada.

(~~41~~44) EPA. 1990. *Compendium of Methods for the Determination of Air Pollutants in Indoor Air*, EPA/600/4-90/010. US Environmental Protection Agency, Research Triangle Park, NC.

(~~42~~45) EPA. 1999. *Compendium of Methods for Determination of Toxic Organic Pollutants in Ambient Air*, 2nd edition, EPA/625/R-96/010b, United States Environmental Protection Agency, Cincinnati, Ohio.

(~~43~~46) ASTM. 2009. *Test Method for Determination of Formaldehyde and Other Carbonyl Compounds in Air (Active Sampler Methodology).* ASTM D5197. ASTM, Philadelphia, PA.

(~~44~~47) ISO. 2011. *Determination of Formaldehyde and Other Carbonyl Compounds in Indoor Air and Test Chamber Air – Active Sampling Method*. ISO 16000-3. ISO, Geneva, Switzerland.

(~~45~~48) ASTM. 2012. *Test Method for Nicotine and 3-ethynylpyridine in Indoor Air.* ASTM D5075. ASTM, Philadelphia, PA.

(~~46~~49) ASTM. 2005. *Practice for Sampling and Selection of Analytical Techniques for Pesticides and Polychlorinated Biphenyls in Air*. ASTM D4861. ASTM, Philadelphia, PA.

(~~47~~50) ASTM. 2016. *Test Method for Determination of Radon Decay Product Concentration and Working Level in Indoor Atmospheres by Active Sampling on a Filter.* ASTM ~~D4861~~D6327. ASTM, Philadelphia, PA.

(~~48~~51) EPA. 1992. *Indoor Radon and Radon Decay Product Measurement Device Protocols.* US Environmental Protection Agency document 520-402-R-92-004.

(~~49~~52) ASTM. 2015. *Test Method for Determination of Volatile Organic Chemicals in Atmospheres (Canister Sampling Methodology).* ASTM D5466. ASTM, Philadelphia, PA.

(~~50~~53) ASTM. 2015. *Practice for Selection of Sorbents, Sampling, and Thermal Desorption Analysis Procedures for Volatile Organic Compounds in Air.* ASTM D6196. ASTM, Philadelphia, PA.

(~~51~~54) ISO. 2011. *Determination of Volatile Organic Compounds in Indoor and Test Chamber Air by Active Sampling on Tenax TA Sorbent, Thermal Desorption and Gas Chromatography using MS or MS-FID.* ISO 16000-6. ISO, Geneva, Switzerland.

(~~52~~55) ASTM. 2010. *Guide for Placement and Use of Diffusion Controlled Passive Monitors for Gaseous Pollutants in Indoor Air*. ASTM D6306. ASTM, Philadelphia, PA.

(~~53~~56) US Statute. 2015. Definition and Procedure for the Determination of the Method Detection Limit. 40 CFR Part 136 Appendix B.

(~~54~~57) ASHRAE. ~~2013~~2017. Fundamentals Handbook, Chapter 14, *Measurement and Instruments*. American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta, GA.

(~~55~~58) ASHRAE. 2010. Guideline 2-2010, *Engineering Analysis of Experimental Data.* American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta, GA.

(~~56~~59) Nagda, N.L., H.E. Rector, Z. Li, and E.H. Hunt. 1999. ASHRAE Research Project 959-RP: *Determine aircraft supply air contaminants in the engine bleed air supply system on commercial aircraft.*

(~~57~~60) ASTM. 2005. Special Technical Publication 957:2005/Cor 1:2006, *Sampling and calibration for atmospheric measurements*. ASTM International, West Conshohocken, PA 19428-2959, USA.

(~~58~~61) International Organization for Standardization (ISO). 2005. Standard ISO/IEC 17025:2005, *General requirements for the competence of testing and calibration laboratories*. ISO Central Secretariat, Geneva, Switzerland.

(~~59~~62) ASHRAE. 2013. ANSI/ASHRAE Standard 41.1-2013, *Standard Methods for Temperature Measurement*. American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta, GA.

(~~60~~63) ASHRAE. 1987. ANSI/ASHRAE Standard 41.2-1987, *Standard Methods for Air Velocity and Airflow Measurement*. American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta, GA.

(~~61~~64) ASHRAE. 2014. ANSI/ASHRAE *Standard* 41.3-2014, *Standard Methods for Pressure Measurement*. American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta, GA.

(~~62~~65) ASHRAE. 2013-4. Standard 55-2013, *Thermal environmental conditions for human occupancy.* American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta, GA.

(~~63~~66) ASHRAE. ~~2011~~2016. Guideline 10-~~2011~~2016, *Interactions affecting the achievement of acceptable indoor environments.* American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta, GA.