Designation: D7297 – 21

Standard Practice for Evaluating Residential Indoor Air Quality Concerns[1]

This standard is issued under the fixed designation D7297; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This standard practice describes procedures for evaluating indoor air quality (IAQ) concerns in residential buildings.

1.2 The practice primarily addresses IAQ concerns encountered in single-family detached and attached (for example, townhouse or duplex design) residential buildings. Limited guidance is also provided for low- and high-rise multifamily dwellings, such as condominiums and apartments.

1.3 The IAQ evaluation procedures are comprised of interviews with the homeowner or resident(s) (including telephone interviews and face-to-face meetings) and on-site investigations (including walk-through, assessment, and measurements). For application practicality, these procedures are divided into three separate phases, which may occur over one or more site visits.

1.4 The procedures described in this standard practice are aimed at identifying potential causes contributing to an IAQ issue or concern. Such findings can be the basis for recommending corrective measures. This standard practice does not describe problem resolution or corrective measures, and the standard is not intended to evaluate the impact of corrective measures.

1.5 This practice describes a pathway for characterizing indoor air, though using this practice does not guarantee that an investigator will be able to identify or resolve an IAQ complaint for one or more of the following reasons: *(1)* the diversity of sources and contaminants in indoor air; *(2)* other factors that may affect occupant perception and acceptance of indoor air quality, such as air temperature, humidity, noise, lighting, and psychological stress; *(3)* the range of susceptibility in the population.

1.6 Implementation of procedures given in this standard requires the investigator (or investigative team) to have adequate background in several areas: general principles of IAQ; interviewing techniques; building design and construction practices; basic understanding of heating and cooling systems and appliances; use of IAQ measurement equipment; interpretation of IAQ data; and technical report writing.

1.7 Although many elements described in this standard practice may be useful in training of IAQ investigators, it should not be used as the sole basis for specifying or conducting such training.

1.8 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.* For additional safety precautionary information, see Section 6.

1.9 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D1356 Terminology Relating to Sampling and Analysis of Atmospheres

D1357 Practice for Planning the Sampling of the Ambient Atmosphere

D4861 Practice for Sampling and Selection of Analytical Techniques for Pesticides and Polychlorinated Biphenyls in Air (Withdrawn 2021)[3]

D5197 Test Method for Determination of Formaldehyde and Other Carbonyl Compounds in Air (Active Sampler Methodology)

D5438 Practice for Collection of Floor Dust for Chemical Analysis

D5466 Test Method for Determination of Volatile Organic Compounds in Atmospheres (Canister Sampling, Mass Spectrometry Analysis Methodology)

D5952 Guide for the Inspection of Water Systems for

[1] This practice is under the jurisdiction of ASTM Committee D22 on Air Quality and is the direct responsibility of Subcommittee D22.05 on Indoor Air.

Current edition approved Sept. 1, 2021. Published October 2021. Originally approved in 2006. Last previous edition approved in 2014 as D7297 – 14. DOI: 10.1520/D7297-21.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] The last approved version of this historical standard is referenced on www.astm.org.

Legionella and the Investigation of Possible Outbreaks of Legionellosis (Legionnaires' Disease or Pontiac Fever)
D5955 Test Methods for Estimating Contribution of Environmental Tobacco Smoke to Respirable Suspended Particles Based on UVPM and FPM
D6196 Practice for Choosing Sorbents, Sampling Parameters and Thermal Desorption Analytical Conditions for Monitoring Volatile Organic Chemicals in Air
D6271 Test Method for Estimating Contribution of Environmental Tobacco Smoke to Respirable Suspended Particles Based on Solanesol
D6333 Practice for Collection of Dislodgeable Pesticide Residues from Floors
E241 Guide for Limiting Water-Induced Damage to Buildings
E609 Terminology Relating to Pesticides
E620 Practice for Reporting Opinions of Scientific or Technical Experts
E741 Test Method for Determining Air Change in a Single Zone by Means of a Tracer Gas Dilution
E779 Test Method for Determining Air Leakage Rate by Fan Pressurization
E943 Terminology Relating to Biological Effects and Environmental Fate
E1186 Practices for Air Leakage Site Detection in Building Envelopes and Air Barrier Systems
E1554 Test Methods for Determining Air Leakage of Air Distribution Systems by Fan Pressurization
E1827 Test Methods for Determining Airtightness of Buildings Using an Orifice Blower Door
E2121 Practice for Installing Radon Mitigation Systems in Existing Low-Rise Residential Buildings
E2128 Guide for Evaluating Water Leakage of Building Walls

2.2 *ISO Standards:*[4]
ISO 16017-2 Indoor, ambient and workplace air — Sampling and analysis of volatile organic compounds by sorbent tube/thermal desorption/capillary gas chromatography — Part 2: Diffusive sampling
ISO 16000-4 Indoor air — Part 4: Determination of formaldehyde — Diffusive sampling method

2.3 *USEPA Documents:*[5]
USEPA 402-F-91-102 Building Air Quality: A Guide for Building Owners and Facility Managers
USEPA 402-K-01-001 Mold Remediation in Schools and Commercial Buildings
USEPA 600-R-94-173 Technical Notes on Drinking Water Methods
USEPA QA/G-5 EPA Guidance for Quality Assurance Project Plans
USEPA QA/G-9 Guidance for Data Quality Assessment: Practical Methods for Data Analysis
USEPA TO-11A Determination of Formaldehyde in Ambient Air Using Adsorbent Cartridge Followed by High Performance Liquid Chromatography (HPLC)
USEPA TO-15 Toxic Organics – 15 (TO-15): Determination of Volatile Organic Compounds (VOCs) in Air Collected in Specially-Prepared Canisters and Analyzed by Gas Chromatography/Mass Spectrometry (GC/MS)
USEPA TO-17 Determination of Volatile Organic Compounds in Ambient Air Using Active Sampling onto Sorbent Tubes

2.4 *Other Documents:*
ANSI/AARST SGM-SF 2017 Soil Gas Mitigation Standards for Existing Homes[6]
ANSI/AARST RMS-MF 2018 Radon Mitigation Standards for Multifamily Buildings[6]
ANSI/AARST MAH 2019 Protocol for Conducting Measurements of Radon and Radon Decay Products in Homes[6]
ANSI/AARST MAMF 2017 Protocol for Conducting Measurements of Radon and Radon Decay Products in Multifamily Buildings[6]
ANSI/AARST MS-QA 2019 Radon Measurement Systems Quality Assurance[6]
ANSI/AARST MW-RN 2020 Protocol for the Collection, Transfer and Measurement of Radon in Water[6]
ANSI/ACCA 4 QM – 2019 Quality Maintenance of Residential HVAC Systems[7]
ANSI/ASHRAE 62.2-2019 Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings[8]

3. Terminology

3.1 *Definitions*—For definitions of terms used in this practice, refer to Terminologies D1356, E609, and E943.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *hypothesis, n*—a provisional theory set forth to explain certain indoor air quality problems or phenomena.

3.2.2 *pause point, n*—an interim step within a procedural sequence designed to allow subsequent actions to be based on the analysis and evaluation of recently collected data.

3.2.3 *stack effect, n*—air movement resulting from air buoyancy as influenced by differences in air temperature, density or pressure.

4. Summary of Practice

4.1 IAQ-based complaints and problems in residential buildings include discomfort and health symptoms arising from exposure to indoor air pollutants, as well as adverse indoor environmental conditions such as mold or bacterial growth or persistent odors.

[4] Available from International Organization for Standardization (ISO), ISO Central Secretariat, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, https://www.iso.org.

[5] Available from United States Environmental Protection Agency (EPA), William Jefferson Clinton Bldg., 1200 Pennsylvania Ave., NW, Washington, DC 20460, http://www.epa.gov.

[6] Available from American Association of Radon Scientists and Technologists (AARST), Hendersonville, NC, https://standards.aarst.org/.

[7] Available from Air Conditioning Contractors of America (ACCA), 1330 Braddock Place, Suite 350, Alexandria, VA 22314, https://www.acca.org/home.

[8] Available from American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. (ASHRAE), 1791 Tullie Circle, NE, Atlanta, GA 30329, http://www.ashrae.org.

4.2 This practice describes procedures for the systematic investigation of IAQ concerns using an iterative process that involves problem definition, information gathering, formulation of hypotheses, measurements (if necessary), and problem source identification. It may include testing hypotheses by taking corrective actions and evaluating their impact on the IAQ concern.

4.3 To enhance the effectiveness and management of an IAQ investigation, it is often conducted in three separate phases: *(1)* initial meeting(s) with the building owner or occupant, or both, and a walk-through, *(2)* detailed assessment of the building and its systems, and *(3)* pollutant measurements, if necessary. Such phased investigations also allow informing the building owner or the reporting/impacted party of the progress and seeking approval for ensuing work. However, circumstances may require all three phases to occur during a single site visit.

4.4 Major steps recommended for IAQ investigations include an initial interview with the building owner or occupant, on-site meeting and walk-through, development of hypotheses on potential causes of complaints, determining measurement parameters and instrumentation, determining the need and feasibility of monitoring, if appropriate, conducting monitoring, analyzing data and evaluating hypotheses, and preparing a report on findings. Critical criteria underlying these steps and the procedures involved are described. The relationships among the steps are illustrated using a flow diagram.

4.5 The success of an IAQ investigation often depends on whether the investigator has taken the time to assess all field observations and data that have been collected at any given point in time to determine or postulate potential causes. These interim evaluation points are called pause points and several such pause points are recommended during the investigation.

5. Significance and Use

5.1 IAQ-based complaints and problems include discomfort/medical symptoms and unacceptable indoor environmental conditions such as odors that exist in residential buildings. The frequency of the occurrence of IAQ complaints and problems may be unknown.

5.2 Characterization of IAQ concerns and identification of their underlying causes require systematic observations and measurements of the indoor air and environment, its occupants and potential contaminant sources. This practice provides background and procedures for the investigation of IAQ concerns.

5.3 Where the dwelling is not owner-occupied, formal permission to access certain areas of the property and to collect information essential to the IAQ investigation is often required.

5.4 The stepwise and phased approach described in this practice allows for an investigation that is commensurate with the nature of the problem and the level of resources available for the investigation.

6. Hazards and Precautions

6.1 In the course of conducting on-site investigations, a variety of situations may arise that could pose a hazard to the investigator and residents. Examples include but are not limited to the following:

6.1.1 Improperly stored or uncharacterized household chemicals, and pesticides,

6.1.2 Fire hazards (for example, inappropriate storage of combustible material),

6.1.3 Microbiological contamination, and

6.1.4 General safety (for example, weakened staircases).

6.2 Many potential hazards are recognized visually, and can be accommodated by asking the homeowner or occupants, as appropriate, to remove the hazards.

6.3 If any testing or assessment conducted by the investigator (for example, use of smoke tracers) may impact the occupants or indoor environment, or both, risks related to such procedures must be reviewed with the resident and explicit written permission of the resident should be obtained prior to initiating such testing.

6.4 Where applicable, use protective equipment (for example, eye protection, gloves, and respirators), and safety procedures (for example, avoid direct inhalation of strong vapors) to reduce hazards that cannot be otherwise addressed.

7. Background on the Nature of Residential IAQ Problems, Contaminants and Sources

7.1 For successful diagnosis of IAQ problems, investigators need to have a thorough understanding of types of issues and their potential causes. This section presents background on common types of IAQ problems, contaminants, and indoor sources. This list is not all inclusive. For detailed discussion, refer to the documents listed in the bibliography (Annex A7). The next section (Section 8) gives background on building and system related IAQ problems.

7.2 *IAQ Concerns and Problems:*

7.2.1 IAQ concerns, issues, and problems may create a nuisance, discomfort, or health effect. Distinguishing between these categories can be difficult, especially during the initial phase of an evaluation. Although some building-related health effects are clinically diagnosable, many are not. This can blur the distinction between a health effect, nuisance, and discomfort. The investigator's role is to identify the conditions that might lead to IAQ concerns and problems; not diagnose health effects.

7.2.2 IAQ concerns, issues, and problems may be perceivable or imperceivable. A perceivable concern is one where the human senses can identify the problem. Examples include disagreeable odors, mold growth, and visible deposits of smoke residues. Imperceivable concerns are not manifested with an odor or visual indicator. For example, carbon monoxide and radon are colorless and odorless gases that cannot be perceived by smell or sight. Imperceivable concerns may also arise from odorant chemicals that are below their odor thresholds, or from too small a visual signal (e.g. mold colony too small to be observed by the unaided eye). Further, concerns may be imperceivable because they are located in inaccessible areas of the building, such as inside wall cavities or air ducts.

7.2.3 IAQ concerns that are based on perceived acceptability of environmental conditions include disagreeable odors,

visible deposits of soot-like residues, or mold growth on various surfaces, and excessive dust, etc.

7.3 *Contaminants and Indoor Sources:*

7.3.1 Two common types of contaminants are biological and chemical contaminants. Biological contaminants represent a broad class of viable particles (viruses, bacteria, protists, and fungal spores), and nonviable particles (that is, fragments of dead organisms and particulate waste products). Chemical contaminants can exist as gases, vapors, and aerosols that are or may become airborne. There are also chemical contaminants that originate from living organisms.

7.3.2 Indoor levels of biologically-derived pollutants may arise from biological contamination of the indoor environment (for example, mold colonization), or from the transport of biologically-derived contaminants from other indoor airspaces, the outdoors, or from soil gas entry (**1**, **2**).[9]

7.3.3 Sources of chemical contaminants in indoor air can be grouped as *(1)* activity-related, *(2)* material-related sources, *(3)* transport-related sources, *(4)* tracked-in dirt, and *(5)* bioeffluents.

7.3.3.1 Activity-related sources are characterized by process rates. The emission rate for aerosols and gases from combustion sources, for example, is often expressed in terms of fuel consumption rate. Malfunctioning of such sources such as spillage from combustion sources relates to process rate and other factors such as depressurization. Other direct-discharge sources include the use of pressurized consumer products as well as volatilization of chemicals from the water supply. Activity sources also include tobacco or cannabis smoke, electronic cigarette and vaping devices, cleaning and bathing products, sweeping and vacuuming, cooking, use of home office equipment, hobbies, painting and varnishing and pest control efforts.

7.3.3.2 Material-related sources include volatilization of chemicals from liquid films (for example, drying paint, cleaners) and from solid media (for example, carpet backing, building materials, glues and paints). Air "fresheners" also generate volatilization of chemicals from solid or liquid media.

7.3.3.3 Transport-related sources of indoor air pollution bring contaminated air from other areas into the indoor airspace of concern. Examples include infiltration of outdoor gases and aerosols, migration of combustion products (aerosols and gases) from attached garages, and soil gas entry. Heating, ventilating, and air-conditioning (HVAC) distribution system or ductwork can also be a conveyor or source of indoor air pollution. The improper maintenance or moisture accumulation in HVAC system can lead to fungal and bacterial growth. Use of woodstoves and fireplaces can leave residues of polycyclic aromatic hydrocarbons (PAHs) and soot indoors.

7.3.3.4 Tracked-in dirt by individuals, especially children, or pets coming from outside or a yard to indoors is a common source of contamination from lawn and garden chemicals such as herbicides, insecticides, fungicides, or fertilizers. Similarly PAHs and other semivolatile organics can come from nearby roadways, restaurants, industrial sites, and landfills (**3**).

7.3.3.5 Bioeffluents consist of CO2 produced by respiration, and a large number of volatile organic compounds (VOCs), including compounds such as ethanol produced by metabolism. Individual compounds in lowconcentrations may have a modest sensory impact, but together may become an unpleasant odor or even impact health (**4**). VOC emissions from mold contamination can also be considered under this category of sources. Microbial VOCs (MVOCs) may be present at levels above odor thresholds.

7.3.3.6 In addition to above groups of sources, chemical interaction between chemicals within the same or different groups may need to be considered. Examples include interaction between chlorine compounds in bleach and other chemicals or interaction between nitrogen oxides or ozone and furnishings.

8. Background on Building and Building Systems-Related IAQ Problems

8.1 IAQ problems may result from elements of the building itself, the mechanical equipment used to condition and ventilate it and interactions between occupants, the building envelope and outdoor conditions. Concerns may arise from flaws in design, construction, operations, or maintenance. This section provides a brief background on building and system related factors. The discussion below is not comprehensive but illustrative.

8.2 *Building Airtightness and Infiltration:*

8.2.1 In residences, outdoor air infiltration and mechanical ventilation are the principal dilution mechanism for pollutants released from indoor sources. The air infiltration amount or air leakage into a building depends on complex interactions among variables including but not limited to: indoor-outdoor pressure differences (which in turn depend on indoor-outdoor temperature differences and wind conditions) and the operation of exhaust appliances such as kitchen or bathroom fans, clothes dryers, and fireplaces (**5**). Window and door openings can add to building air change rate. Imbalances in the air distribution of a forced-air heating/cooling system caused by barriers between supply and return or duct leakage contribute further to building depressurization and pressurization. Also, the physical layout of the building (for example, a flat one-story building "ranch style" versus a taller and narrower structure) influences the stack effect caused by temperature differences and the impact of wind conditions. Such stack effects are increased with building features such as open stairwells in a multi-floor building.

8.2.2 ANSI/ASHRAE 62.2-2019 specifies minimum ventilation requirements for providing acceptable air quality in residential buildings. Leakage communication between the building and the outdoors can be qualitatively established using visual tracers and controlled pressurization and depressurization (Practices E1186).

8.3 *Water Leakage and Moisture Damage:*

8.3.1 Unwanted water penetration into exterior walls, interior walls, and floors causes direct water damage to such components and areas as well as secondary damage including that resulting from mold growth. (An exterior wall system includes exterior and interior finishes, fenestration, structural

[9] The boldface numbers in parentheses refer to the list of references at the end of this standard.

components and structural components and perimeter units associated with heating, cooling, and ventilation.) Water penetration or leakage is considered problematic if it exceeds the planned resistance, or temporary retention and drainage capacity is causing premature deterioration of a building or its contents or is adversely affecting the performance of other components (Guide E2128). Plumbing leaks and condensation can result in extensive fungal growth.

8.4 *Heating/Cooling Systems:*

8.4.1 Central forced-air residential heating and cooling systems installed in dwellings are designed to recirculate air. The number of dwellings that are served by central HVAC systems designed to bring in outdoor air are limited, in the U.S.A. but are becoming more common. However, such systems when present may be equipped with air-to-air heat exchangers for energy conservation.

8.4.2 *Humidification*—Humidification systems may be integral to the central forced-air heating system, or may appear in the form of portable (room-sized) units. Humidification systems are designed to inject water vapor into indoor air and, depending on details of design and maintenance, can become reservoirs for mold and bacteria.

8.5 *Intake and Exhaust Fans:*

8.5.1 Local exhaust fans remove unwanted odors and other contaminates from specific areas such as kitchens and bathrooms and, in some cases, areas set-aside for specific hobbies (for example, woodworking, ceramics). Note that many kitchen range hoods do not exhaust air directly to the outdoors. Rather, cooking emissions are recirculated through a grease trap/filter housed in the range hood.

8.5.2 Vent stacks associated with local exhaust fan(s) should be located to avoid re-entrainment of vented material, and the extraction efficiency of the exhaust fan(s) should be optimized by selecting proper flow capacity so that these fans do not depressurize the building. Building depressurization can interfere with venting of combustion appliances and allow combustion products to spill into the interior space.

8.5.3 Whole-house fans, operating via thermostat or user control, can significantly depressurize the building during operation.

8.6 *Soil Gas Transport:*

8.6.1 The pressure imbalances that drive infiltration/exfiltration also control contaminant entry via soil-gas transport through building surfaces in contact with soil (**6, 7, 8**).

8.6.2 Most scientific studies of soil-gas entry are associated with indoor radon (**6, 8**). Even in areas judged to be of low radon potential, however, significant IAQ problems can prevail from VOCs and other gas phase contaminants present in the surrounding soil (**7**).

8.6.3 While basements are designed to provide some resistance to soil-gas entry, numerous pathways exist in the form designed joints as well as cracks that form in concrete. Soil-gas can also diffuse through intact concrete, though at a much slower rate than with pressure-driven flow (**6, 8, 9**).

8.6.4 The radon subslab depressurization system used in high soil gas areas should be tested to ensure to ensure its proper performance, as malfunctioning may result in unabated intrusion of soil gas into indoor spaces.

8.7 *Potable Water Supply:*

8.7.1 Residential water supplies may contain chemicals to which occupants can be exposed through ingestion, dermal contact, or inhalation (**10**).

8.7.2 Chemicals and gases conveyed to the indoor environment by the water supply include contaminants subject to volatilization during water use (for example, trichloroethylene) or aeration of water (for example, radon). Water delivered by municipal systems may contain disinfection by-products such as chloroform that are produced in the course of water disinfection processes (**11**). Domestic well water contamination may be caused by industrial activities (for example, hazardous waste disposal) as well as naturally occurring processes (for example, arsenic) (**11**).

8.7.3 Among indoor water uses, showering, bathing and hand washing of dishes or clothes provide the primary opportunities for dermal exposure (**10, 11**).

8.7.4 The inhalation exposure potential for a given water use scenario depends on the water source, the types and extents of water uses, and the extent of volatilization of specific chemicals. Such inhalation exposure can occur during various types of residential water use including showering, bathing, toilet use, clothes washing, dishwashing, and faucet use (**11, 12**).

8.8 *Sanitary Drains:*

8.8.1 Sewer gases have been of concern for the indoor environment since the inception of indoor plumbing (**13**). In modern buildings, sanitary drains can become conduits for sewer gas if water in the drain trap evaporates due to infrequent use. If the building interior is under negative pressure, sewer gas can be drawn indoors through the dry drain trap or in the event of sewer line leaks outside the building may be drawn in as part of the soil gas.

9. Overall Strategy and Steps in IAQ Investigations

9.1 Conceptually, the investigation of IAQ concerns is an iterative process that involves gathering information, formulation and testing of hypotheses, problem identification, and problem resolution (Fig. 1). (As stated in section 1.4, problem resolution is not within the scope of this document and thus is shown in a dotted line box in Fig. 1; although the IAQ investigator can provide recommendations for possible solutions and, if necessary, interim measures for temporary relief.)

9.2 The IAQ investigation is the principal means of gathering information on IAQ concerns (symptoms and complaints elicited through interviews and observation) and information relating to potential causes (as observed or based on measurements conducted by the IAQ Investigator).

9.2.1 Information on IAQ problems and potential sources can be obtained in various ways: *(1)* from the occupant through interviews, *(2)* on-site observations by the IAQ Investigator(s), *(3)* discussion with management and maintenance personnel (for tenant-occupied premises) and *(4)* on-site testing/monitoring. The concept of testing and monitoring includes medical evaluation as well as environmental monitoring. To

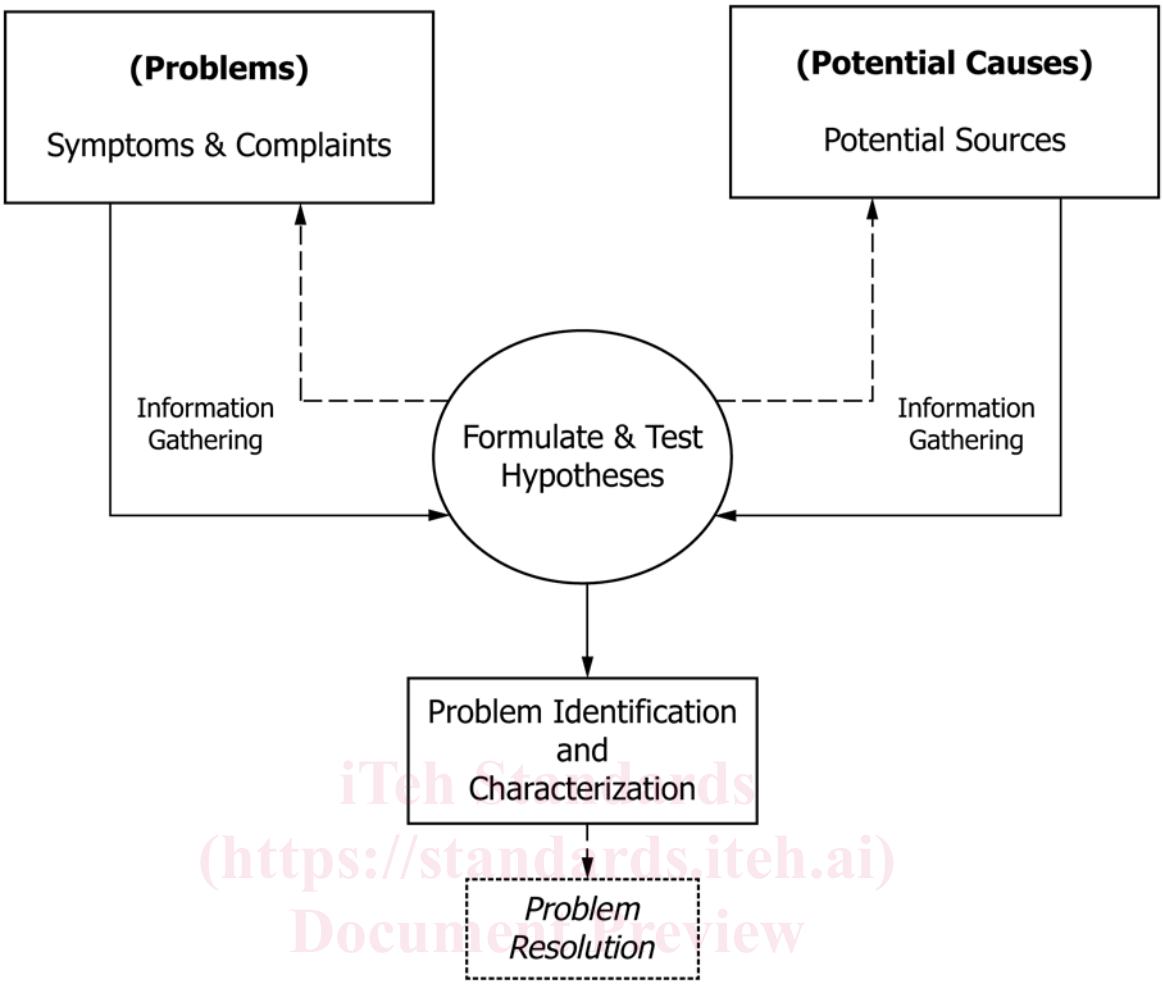

FIG. 1 Iterative Approach to Solving IAQ Problems

diagnose a health problem, medical evaluations are conducted by physicians or other health professionals to assess the residents' symptoms, observations by the health professional, and results of the clinical tests. Environmental monitoring is conducted by the IAQ Investigator to measure air concentrations of selected contaminants.

9.2.2 Reports of allegations of building-related illness may require a physician's diagnosis and assessment of potential exposures. Such medical evaluations may involve health professionals interviewing concerned individuals, compiling detailed medical histories and conducting physical examinations and tests.

9.2.3 Adequate information from both areas—IAQ concerns and potential sources—is necessary for the formulation of a hypotheses on potential causes for complaints and for subsequent testing of each hypothesis to accept or reject each provisional theory of causes for complaints. While hypothesis testing leads to problem identification, more than one iteration of hypothesis development and testing may be required, and more than one problem may be identified.

9.3 Development and testing of hypotheses is probably the most challenging part of the IAQ investigation. It requires extensive understanding of factors affecting indoor air quality and understanding of the practical realities of building systems.

9.3.1 Hypothesis testing is a useful design tool for data interpretation, such as comparing and assessing the magnitude of measured values compared to criteria. Traditional hypothesis testing is a procedure for deciding whether to accept or reject a statement. The full statement of the statistical hypothesis has three major parts: the hypothesis being tested, a null hypothesis (that is, the statement to be accepted or rejected), and an occasional alternative hypothesis (that is, the statement to be accepted if the null hypothesis is rejected). In all parts, a population parameter is compared to either a fixed value or another population parameter. The population parameter is a quantitative characteristic of the population that the investigator wants to estimate using the data, such as the mean value. Considering that IAQ investigations are not research projects, it is not possible to recommend that the project adhere to statistical hypothesis testing. However, the concepts underlying the development of hypothesis and testing provides a good platform for refining the investigative thought process on an on-going investigation.

9.3.2 For residential IAQ complaints and issues, developing and evaluating hypotheses involves review and analysis of information from various sources, steps, or phases of the investigation. In particular, it involves control experiments such that the impact of suspected sources and contributing factors could be identified.

9.4 The IAQ investigation is conducted in discrete phases to enhance the effectiveness and management of the investigation. Such phased investigations provide for informing the building owner or the impacted party of progress and provides for obtaining additional approvals, including that of budget approvals, for continuing work. IAQ investigations are often conducted according to the following phases:

9.4.1 *Phase I*—Conduct an on-site interview followed by a walk-through of the building and its surrounding. The purpose of this phase is to understand the problem and identify, to the extent feasible, potential causes. Developing plans for the next phase (Phase II), estimating required resources, and obtaining approval for performing Phase II are part of this effort.

9.4.2 *Phase II*—The purpose of this phase is to conduct a detailed assessment of various possible problem sources such as water leakage and systems such as heating/cooling appliances and forced-air distribution. Some of the aspects surveyed in Phase I may need to be repeated to obtain detailed understanding of the building and its systems. Also, certain on-site evaluations such as pressure mapping are conducted to provide insights into potential problems. IAQ problems are often identified in this phase. If they are not identified, plans are developed to either continue further Phase II evaluations or, as necessary, develop hypothesis and plans for contaminant measurements (Phase III). The resources required for Phase III are estimated for obtaining necessary approvals.

9.4.3 *Phase III*—Contaminant measurements may aid in identification or confirmation of IAQ problem. Systematic development of measurement and data quality objectives is very important part before performing Phase III measurements. The results sometimes indicate the need for repeating Phase III or even Phase II.

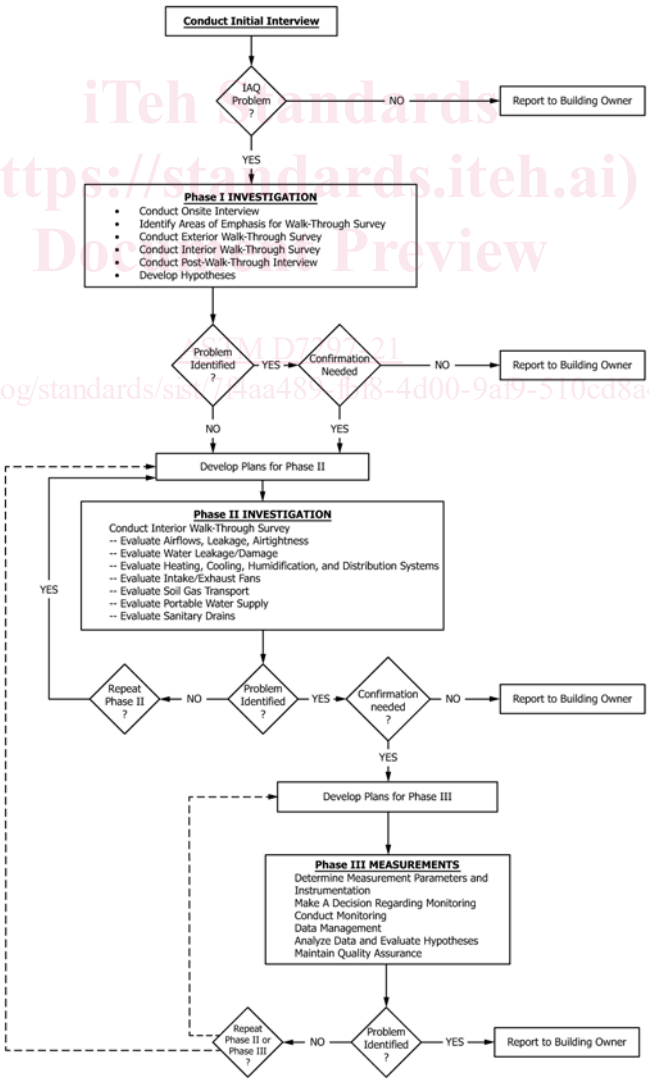

FIG. 2 An Illustrative Flow Diagram for IAQ Investigations

9.4.4 Fig. 2 provides a flow diagram for the three investigative phases and emphasizes the iterative process involved in an IAQ investigation. The following steps that are applicable to one or more phases are shown in the figure:

9.4.4.1 Conduct initial interview,
9.4.4.2 Conduct on-site meeting,
9.4.4.3 Identify walk-through areas of emphasis,
9.4.4.4 Conduct walk-through exterior survey,
9.4.4.5 Conduct walk-through interior survey,
9.4.4.6 Conduct post-walk-through interview,
9.4.4.7 Develop hypotheses,
9.4.4.8 Determine measurement parameters and instrumentation,
9.4.4.9 Make decision regarding monitoring,
9.4.4.10 Conduct monitoring,
9.4.4.11 Analyze data and evaluate hypotheses,
9.4.4.12 Quality assurance, and
9.4.4.13 Report findings.

9.4.5 Note that while data analysis and hypotheses evaluation is described in a separate section near the conclusion of this standard, in actual practice, the analysis of observations and data, evaluation of hypothesis, and their interpretation is a continuous process associated with all steps and sub steps of the investigation. It should also be noted that the phases may not always be clearly delineated and could be intermingled. For example, combining some characterization measurements with inspection and hypothesis testing with detailed inspection may be necessary to limit the number of site visits. In any case, the phasing principle is very important in conducting successful investigations and, thus, any deviation from phasing as described in this document is acceptable as long as the concept itself is not compromised.

9.4.6 Additionally, while the steps stated above and described in this practice are focused on IAQ investigations, these procedures may provide a standardized basis for conducting IAQ research.

9.5 *Understand Critical Purposes Underlying Major Steps in the Process for Evaluating Residential IAQ Concerns:*

9.5.1 Although IAQ investigations described in this practice for identifying the source(s) of the problem may give the appearance of being a set of simple or straightforward steps, this can be misleading and successful investigations can be very challenging. Thus, to carry out investigations and achieve reliable outcomes, it is essential that investigators understand the *objectives* for each major step.

9.5.2 The major steps in the evaluation process outlined above are listed in Table 1. The intent of Table 1is to emphasize objectives underlying each step in the investigation.

9.5.3 The success of an IAQ investigation often depends on whether the investigator has stepped back to assess all field observations and collected data to determine causes or postulate potential causes.

9.5.4 These evaluation points are called *pause points* and five such pause points are recommended during the investigative process. Table 2 lists these pause points and the type of information, observations, and results to be evaluated.

10. Conduct Initial Interview of Residents

10.1 The initial interview is generally conducted by telephone. The interview should include questions in the following areas: dwelling information; nature and the history of the problem; resident information; and contact and address information. Since the interview is conducted by telephone, the

TABLE 1 Critical Purposes Underlying Various Steps in the Approach for Evaluating Residential Indoor Air Quality Problems

Section	Step	Underlying Critical Purpose
10	Conduct initial interview	To obtain basic information about the complaint, the dwelling, and residents and to confirm the likely existence of an IAQ problem.
11	Conduct on-site meeting	To gain confidence of the residents, and to get their first-hand impressions of the problem, including perceived potential causes.
11.4	Develop plans for walk-through	Pause to focus attention on elements of walk-through based on a best understanding of the perceptions of the problem, its history and its impact on the residents.
11.5	Conduct exterior walk-through survey	To review immediate and nearby surroundings to examine if any exterior factors may contribute to the IAQ problem under investigation.
11.6, 11.7	Conduct interior walk-through survey	To review in a comprehensive manner the building envelope, HVAC, appliances, furnishings, drains, water supply, etc., to judge their impact on IAQ and role in the IAQ problem under investigation. Review related information.
11.8	Conduct post walk-through interview	To gain insights into the resident practices that may have an impact on IAQ and a role in the IAQ problem under investigation.
12	Develop hypotheses	Pause to assemble all information collected thus far into a systems perspective to track IAQ problems back to possible origin(s) and to develop a specific statement of the problem.
13.2	Determine measurement parameters and instrumentation	To select instrumentation for hypotheses evaluation.
13.3	Decisions Regarding Monitoring	Pause to evaluate whether to conduct measurements based a review of how measurements will help in hypothesis evaluation and the investigation in general. If affirmative, establish criteria and objectives for measurement.
13.4	Conduct monitoring	To obtain primary data and test the hypotheses.
14	Analyze data and Evaluate hypotheses	To analyze data for testing hypotheses.To accept or reject hypotheses based on the collected data. Based on the outcome either to identify causes of the IAQ problem or to construct a new hypotheses for testing and returning to Section 12 activity.
16	Maintain Quality Assurance	To ensure that defined quality standards are met; a quality assurance plan should be in force prior to conducting field operations.
17	Report Findings	To develop the report in a manner that is appropriate for court proceedings, if needed, and to share with the resident details of the investigation and results.

TABLE 2 Pause Points and Problem Assessment

No.	Pause Points	Stages in Problem Assessment: The Type of Information, Observations, and Results to be Evaluated
1	After initial on-site visit and interview	Summarize the problem(s); potential areas to be investigated; plans for walk-through.
2	After walk-through (Phase I) and before proceeding to building and systems characterization	Problem observations; identification, if any at this stage, of potential causes. Proposal for building/systems characterization.
3	After building/system characterization (Phase II)	Identification, if any at this stage, of potential complaint causes. Rationale, strategy, measurement plan including criteria, and resources for proposed monitoring under Phase III.
4	After completion of Phase III investigation and measurements and analysis	Measurement results and comparison with criteria and objectives. Conclusions drawn from measurements.
5	After an overall and final evaluation of the problem	Nature of problem(s) discovered, relationship of the problem(s) to the symptoms and complaints, qualitative degree of confidence in such relationships.

questionnaire scope must be constrained to accomplish information-gathering without unduly burdening the respondent. Note that experience has shown that fairly detailed telephone questionnaires can be administered to gather information relating to residential IAQ in time periods that consume no more than 15 to 20 minutes of respondent time (**14**).

10.2 The initial interview should collect information on the following:

10.2.1 The type of building, year of construction and remodeling if any, number of bedrooms, and type of major appliances (cooking, water heating, space heating and cooling).

10.2.2 Household characteristics, including number of persons, ages of children and adults, and particular health problems experienced by each person.

10.2.3 The nature and history of the problem as perceived by the resident(s), including any activities or environmental changes that may coincide with the IAQ concern, and any medical evaluations.

10.2.4 Possible outdoor sources suggested by the resident, such as nearby streets and street intersections, airports, and commercial/industrial facilities.

10.2.5 Other IAQ problem cases and unaffected (that is, control) residences in the neighborhood as practical. (The information on other cases and use of controls is useful if the initial iteration of on-site investigation fails to produce results.)

10.3 The initial telephone interview should request or confirm address and contact information to facilitate subsequent on-site activities.

10.4 The scope of work, including permission to perform a walk-through, should be discussed and agreed upon prior to arriving on site. The investigator should ask if there are any areas to be avoided or excluded during the walkthrough. If there are such areas, the resident/owner shall be informed that this may impact the IAQ investigation, and limit the identification of sources or causes of IAQ problems.

10.5 An example questionnaire suitable for use in an initial telephone interview is given in Annex A1. Note, this Annex and other Annexes provide *example* questionnaires. Before initiating an investigation, these examples should be reviewed for suitability and modified by the investigator to make them more relevant for the situation. It is also important to recognize that factors other than those related to IAQ can cause effects or symptoms perceived by residents as IAQ related. Consequently, it is important to recognize that while prepared questionnaires enable data collection in an organized format, any question and answer sessions with residents should be open-ended so that all information relevant to an investigation is collected.

11. Conduct On-Site Investigation

11.1 The on-site investigation should be composed of the following: *(1)* initial on-site meeting, *(2)* walk-through, and *(3)* detailed interview(s). This sequence is important because the IAQ investigator needs to engage the resident(s) in the definition and resolution of the problem and maintain that interest throughout the on-site investigation. This sequence also assists in gaining the confidence of the household members. This is necessary for acquiring answers to potentially sensitive follow up questions relating to factors such as personal habits, hygiene, and possible culpability during the detailed resident interview.

11.2 Support equipment and field supplies necessary to conduct the On-Site Investigation include field data collection forms, a camera, a flashlight, small hand tools like screwdrivers, and a stepladder. Also as detailed later, a few IAQ investigation tools such as a smoke bottle, moisture meter, and temperature gauge can provide useful information during the walk-through without consuming substantial time or resources.

11.3 *Conduct Initial On-Site Meeting:*

11.3.1 The initial meeting sets the overall tone for cooperation and inquisitiveness for the on-site investigation. This gains the confidence of the resident and facilitates acquisition of the best available information by the IAQ Investigator. The initial meeting also allows the IAQ Investigator to probe into the nature and the history of the problem beyond the initial interview of the resident.

11.3.2 Gather the following information during the initial meeting: when the problem was first noted, continuous or intermittent nature of the problem, frequency of occurrence, suspected causes, details on any prior investigations and their results, and any remediation steps undertaken. While collecting such information, it should be kept in mind that the central purpose of the meeting is to collect the reasons and clues that lead the occupants to believe that there is a building problem, for example, odors, stains, or physiological symptoms, or combination thereof, that occur when in the building. Toward the conclusion of the initial meeting, confirm that the resident

gives permission to conduct a walk-through, and ask that they identify areas, if any, that should be avoided or excluded during the walk-through. An example of a data collection form that could be used for the initial on-site meeting is given in Annex A2.

11.3.3 If the IAQ concern is symptom-based, the residents should be asked if they have seen a physician and, if so, ask them to provide written permission to speak with the doctor.

11.3.4 If the interviewee has health concerns or asks for medical advice, then they should be encouraged to consult a physician or health-care provider of their choice. (The IAQ investigator should indicate to the interviewee that findings of this IAQ investigation when completed might be appropriate to be shared with the health-care provider, as needed.)

11.3.5 This initial onsite visit is a very important opportunity to get an understanding of the nature of the IAQ problem and to gain further insights. Questions on variation in the intensity of the problem over time, season, or a particular situation or condition should be explored with the residents. Similarly, efforts should be made to clarify the problem to the extent possible. For example, if the problem is an offensive odor, but otherwise there are no symptoms (headaches, sinus problems, skin rash), it should be noted that no symptoms accompany the odor.

11.4 *Identify Areas of Emphasis for Walk-Through:*

11.4.1 As indicated in Section 9 (Overall Strategy), the walk-through is an integral part of Phase I and, as necessary, for Phase II. The Phase I walk-through involves noting visual qualitative characteristics observations of each area of the building relevant to the IAQ problem, and the Phase II walk-through includes further detailed and semi-quantitative investigation with appropriate tests. For example, in Phase I, the investigator observes if there are obvious leakage pathways between an integral garage and the remainder of the house, but in Phase II, the investigator can run qualitative tests (for example, visual tracers) to test for air migration. As the line between Phase I and II is not rigid, it is up to the investigator to decide the scope of the walk-through for each phase.

11.4.2 Briefly analyze the information collected through the initial interview and initial on-site meeting to identify areas of emphasis for walk-through. This should be done on-site after the initial on-site meeting to develop investigative strategies that are appropriate to the residence.

11.4.3 The analysis should identify times, places and people as they relate to the residents' appreciation of the problem:

11.4.3.1 Affected areas within the home that can be compared to non-affected areas,

11.4.3.2 Nature of contributing factors (seasonality, timing and location of triggering events), and

11.4.3.3 Characteristics of affected residents (and possibly visitors) that could relate to heightened sensitivity.

11.4.4 As necessary, seek clarification from the resident on previous answers.

11.4.5 Make brief notes relating to investigative plans on the Investigation Questionnaire (see Annex A3). Such planning helps the IAQ Investigator to identify dwelling areas to focus the investigation upon.

11.5 *Conduct Exterior Walk-Through Survey:*

11.5.1 The exterior walk-through portion of the IAQ investigation is a *qualitative* evaluation of the building and its surroundings. Except for necessary activities associated with ascertaining dimensions of building elements and defining distances between building features, taking measurements is avoided during the exterior walk-through stage. The exterior walk-through should focus on identifying or characterizing biological and chemical sources of indoor air pollutants.

11.5.2 An example of a data collection form that could be used for the exterior walk-through is given in Annex A3.

11.5.3 In conducting the exterior walk-through, observe general conditions in the outdoor environment in the near-vicinity of the home.

11.5.3.1 Evaluate the neighborhood for possible air pollutant sources that could be drawn into the home. Determine the proximity of the home site to possible outdoor sources air pollution that are beyond the property lines, including vehicular traffic, industrial activity, significant expanses of exposed soil, and agricultural activity.

NOTE 1—Substantive analysis of possible commercial/industrial sources beyond the fence-line may require information and insights from the appropriate local air quality authorities.

11.5.3.2 Examine the immediate vicinity of the building (the yard, sidewalks, and street) for the presence of possible sources of air pollutants. Note the presence of outdoor cooking facilities, outdoor wood-fired hydronic heaters, vehicular parking (especially carports, attached garage), and areas of inadequate grading, etc. Information on use of pesticides and other lawn and garden chemicals should be solicited from the resident.

11.5.3.3 Characterize the structure in terms of type of foundation, type of wall construction, sheathing, type of roof, etc.

11.5.3.4 Examine the building's foundations for evidence of structural/maintenance flaws related to possible entry of outdoor pollutants and accumulations of water. Note blocked gutters, condition of splash-blocks, presence of low spots, and standing water. Note all mechanical equipment intakes and outlets such as plumbing vents and dryer vents, chimneys, exhaust vents for bath and kitchen fans. Resolve any discrepancies between known indoor exhaust appliance and outlets found on the outside of the building, that is, each combustion device, exhaust fan, drier should have an outlet, each outlet should have an indoor device).

11.5.3.5 Examine the condition of building exterior. Note the presence and condition of designed apertures, adventitious openings, and structural flaws. Note flaws in cladding, windows, doors, and trim, especially as they relate to possible entry of outdoor pollutants, and water penetration. Note any signatures of current or past adverse conditions (for example, wood rot, mold/algae, blocked gutters, surface staining, etc.).

11.6 *Conduct Interior Walk-Through Survey—Phase I:*

11.6.1 The purpose of the Phase I walk-through survey is to note qualitative characteristics of each area of the building, building systems, appliances, and other features relevant to IAQ problems.

11.6.2 Observe and record general features of the home interior, layout, and contents, including number and placement

of specific-use rooms (kitchen, baths, bedrooms, etc.), heating/cooling systems, water supply, air cleaners and other appliances, furnishings, sanitary drains, and other potential sources.

11.6.3 In each room (including closets), observe and record the presence of odors, excessive dust accumulation, excess moisture, evidence of water penetration, visible wall staining , carpets, and other surfaces (be especially careful to note patterning of such stains as it relates to structural, thermal, and flow considerations) and other potential sources of airborne pollutants. Note any additional factors that may be associated with the underlying problem (for example, insect or rodent infestation, household pets).

11.6.4 For residences equipped with an integral garage, note any obvious flow paths that could connect garage air with the rest of the home (including condition and fit of connecting doorway, presence of supply/return ducts). Observe and record the presence of potential sources stored in the building or the garage (for example, gasoline, paints, garden chemicals, etc.).

11.6.5 In the basement, observe and record the general condition of the foundation, wall finishes and floor coverings, noting possible areas of soil gas entry, airflow/pressure patterns, floor drain, whether air is moving into a floor drain, and doormat or track-off systems at entries.

11.6.6 Observe and record the location and general operating condition of the HVAC system(s) and other major appliances, including the following:

11.6.6.1 Central forced-air system(s) for heating and cooling (note control sequences, condition of filter(s) and drain pans, note whether cooling coil and drain pan have access to allow inspection and cleaning), any direct mechanical ventilation or outdoor air intakes, and location (mechanical closet, garage, crawlspace, or attic);

11.6.6.2 Humidification systems (integral to central HVAC system or portable); note evidence of inadequate maintenance general condition and, for integral systems, observe whether there is evidence of moisture carryover into the HVAC system;

11.6.6.3 Through-the-wall, or window-mounted air conditioner(s), or both (note condition of filter(s) and damper position for each appliance); and

11.6.6.4 Auxiliary space heaters (woodstoves, kerosene heaters, freestanding gas or electric, or both).

11.6.7 Observe and record general operating condition of all fans (exhaust as well as recirculating). Note the color and apparent texture of any visible accumulations on fan housing, fan blades, or lint traps, or combination thereof.

11.6.8 In the kitchen, observe operation of range hood (or ceiling exhaust, or both), note condition of associated ductwork, note whether the design is of the recirculating type or exhausts to the outdoors.

11.6.9 In each bathroom, observe operation of exhaust fan for flow adequacy. Note any evidence of surface mold or moisture accumulation.

11.6.10 In the laundry area, observe operation of automatic clothes dryer, note condition of associated vent (including exterior outlet). Note any stored chemicals, evidence of surface mold, or moisture accumulation in the laundry area.

11.6.11 Observe and record general operating condition of powered whole house fan (if present).

11.6.12 In the main residential area, observe and record the type and condition of doormats and other track-off systems at each entry, furnishings, decorations and wall/floor coverings. Note any odors that could be correlated with residents' complaints. Note evidence of repairs, new furnishings, wall coverings, or carpet, or combination thereof.

11.6.13 Sewer gas entry can be evaluated by direct inspection for odors and visual evidence of leaking waste pipes. Observe and record the condition of drain traps and that there is standing water in the traps.

11.6.14 Observe and record the type of water supply.

11.6.15 Observe and record the location of radon subslab depressurization system, if any, and conduct a test to ensure it performs properly (ANSI/AARST MS-QA 2019). A significant body of practical diagnostic information has emerged from various studies of indoor radon. This information has been organized into reliable protocols to evaluate the potential for soil-gas entry in specific buildings (ANSI/AARST MAH 2019, USEPA 402-F-91-102). These references describe specific procedures to characterize conditions within buildings that may contribute to soil-gas entry. These procedures include visual inspection to identify critical building characteristics that relate to soil-gas entry (for example, large cracks in slabs, exposed earth in crawlspaces, open stairways to basements, continuously running HVAC fans and exhaust fans), as well as instrumented pressure communication testing to provide quantitative information on soil-gas transport.

11.6.16 Observe and record general stove, refrigerator(s) and freezer(s)operating condition.

11.6.17 Observe and record the general condition of special-use areas or equipment such as crawlspaces, attics, pools, enclosed hot tubs, pool equipment rooms, sump pumps, coal storage areas, condition of the vapor barrier (if present) in crawlspaces, or presence of crawlspaces with bare earth floor, etc.

11.6.18 Observe the presence of carbon monoxide alarms and confirm the number of units and their location are in accordance with local building codes.

11.7 *Conduct Interior Walk-Through Survey—Phase II:*

11.7.1 Analyze and review the information collected during the initial onsite meeting, exterior walk-through survey, and Phase I interior walk-through survey to develop plans for Phase II. The analysis focuses on identifying events in terms of times, places, people, activities and mechanisms that could be responsible for problems noted by the residents or visitors.

11.7.2 Phase II is an opportunity to obtain additional, specific information for areas identified in Phase I as important or relevant to the IAQ problem. Phase II includes collecting additional observations as well as selected characterization measurements. Note that characterization measurements do not necessarily imply pollutant concentration measurements, but qualitative or quantitative measurements that provide insights into the problems or possible sources of the problem. These are briefly described below for different areas. Brennan (**15**) presents useful insights into characterization measurements, including tools and test equipment for measurements.