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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 ~~included~~provided for low- and high-rise multifamily ~~dwellings.~~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 ~~practicality in application,~~ 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 ~~the~~an IAQ issue or concern. Such findings ~~should become a~~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 ~~adherence to~~ 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.

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[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.

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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 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
~~D6345 Guide for Selection of Methods for Active, Integrative Sampling of Volatile Organic Compounds in Air (Withdrawn 2018)[3]~~
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
~~E1998~~E2121 ~~Guide for Assessing Depressurization-Induced Backdrafting and Spillage from Vented Combustion Appliances~~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)

[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.
[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.

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]
~~ASHRAE 62.2-2010~~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*—~~buoyancy associated with indoor-outdoor temperature differences.~~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 ~~unacceptable~~adverse indoor environmental conditions such as mold or bacterial growth or ~~lingering~~persistent odors.

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 ~~cognizant~~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, ~~develop~~ development of hypotheses on potential causes of complaints, ~~determine~~determining measurement parameters and instrumentation, ~~determine~~determining the need and feasibility of monitoring, if appropriate, ~~conduct~~conducting monitoring, ~~analyze~~analyzing data and ~~evaluate~~evaluating hypotheses, and ~~develop~~ preparing a report on findings. Critical ~~purposes~~criteria underlying these steps and the procedures involved are described. The relationships among the steps are illustrated ~~through~~using a flow diagram.

4.5 The success of an IAQ investigation often depends on whether ~~or not~~ the investigator has taken the time to ~~step back to~~ assess

[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.

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 process.~~investigation.

5. Significance and Use

5.1 IAQ-based complaints and problems ~~including discomfort/health~~include discomfort/medical symptoms and unacceptable indoor environmental conditions such as odors that exist in residential ~~buildings, but the~~ buildings. The frequency of the occurrence of IAQ complaints and problems ~~is not known.~~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 ~~deemed essential to be obtained from the owner and, where applicable, from other tenants. An investigator should seek legal advice in these matters.~~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, ~~etc.,~~

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

6.1.3 Microbiological contamination, and

6.1.4 General safety (for example, weakened ~~staircases, etc.).~~staircases).

6.2 ~~Most~~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 ~~planned to be~~ conducted by the investigator (for example, use of smoke tracers) ~~influences~~ 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 ~~masks),~~respirators), and ~~safe~~safety procedures ~~(that is,~~(for example, avoid direct inhalation of strong vapors) to reduce hazards that cannot be otherwise ~~moderated.~~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 ~~problems~~issues and their potential causes. This section ~~provides an illustrative~~ 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 and problems can be grouped into two categories: those that adversely affect the residents' health, and those that create annoying circumstances. The first category is perceived symptom-based response (related to residents' health status or~~

~~perception of well-being), and may or may not be detectable by the senses. The second category relates to acceptability of indoor environmental conditions, which relate to sensory phenomena, but may or may not be related to health concerns.~~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 that are based on symptom complaints include building-related illnesses whose symptoms can be identified and whose cause can be directly attributed to airborne building pollutants, as well as illnesses without known etiological origins.~~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.~~ dust, etc.

7.3 *Contaminants and Indoor Sources:*

7.3.1 Two ~~major~~common types of contaminants are biological and chemical contaminants. ~~Bioaerosols~~ Biological contaminants represent a broad class of viable particles (viruses, bacteria, ~~protista,~~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 ~~are conveniently~~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 ~~would~~ include the use of pressurized consumer products as well as volatilization of chemicals from the water supply. Activity sources also include tobacco ~~smoke,~~ 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 ~~also~~ can also be a conveyor ~~of~~ or ~~a~~ source of indoor air pollution. The improper maintenance or moisture accumulation in HVAC system can lead to ~~colonization of organisms.~~ 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 ~~the~~a yard to indoors ~~can be~~ is a common source of contamination ~~of~~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**).

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

7.3.3.5 Bioeffluents consist of ~~CO~~CO_2, produced by respiration, and a large number of volatile organic compounds (VOCs), including compounds such as ethanol produced by metabolism. ~~Each such VOC occurs in small concentrations with~~Individual compounds in lowconcentrations may have a modest sensory impact, but together ~~provide the characteristic human body odor~~ may become an unpleasant odor or even impact health (**4**). ~~Also~~ VOC emissions from mold contamination ~~could~~ 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 ~~the~~ occupants, the ~~equipment, the~~ building envelope and outdoor conditions. ~~Problems~~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 only.~~illustrative.

8.2 *Building Airtightness and Infiltration:*

8.2.1 In residences, ~~infiltration of~~ outdoor air ~~is~~ infiltration and mechanical ventilation are the principal dilution mechanism for pollutants released from indoor sources. The ~~amount of~~ air infiltration amount or air leakage into a building depends on complex interactions among ~~many variables including,~~ 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, for example,~~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 ~~the~~ 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 ~~ASHRAE 62.2-2010~~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 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.~~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 ~~the~~ indoor air and, depending on details of design and maintenance, can become reservoirs for ~~mold.~~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 ~~the kitchen~~ kitchens and bathrooms and, in some cases, ~~area~~areas set-aside for specific hobbies (for example, woodworking, ceramics). ~~It should be noted~~ Note that many kitchen range hoods do not ~~remove~~ 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 ~~such~~these fans do not depressurize the building. ~~Depressurization of building could~~ 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 ~~the~~ 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 ~~inadvertent~~ 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 ~~Malfunctioning vented sub-floor and sub-slab depressurization systems~~The radon subslab depressurization system used in high soil gas areas ~~may add to~~ 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 ~~carry~~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,~~ 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 ~~normal operations~~ water disinfection processes (**11**). ~~Contamination of domestic~~ Domestic well water contamination may be caused by industrial activities (for example, hazardous ~~waste)~~ 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 ~~source of water,~~ 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 ~~information gathering,~~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 ~~as box with dotted lines~~ in a dotted line box in Fig. 1~~, though~~; 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 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.

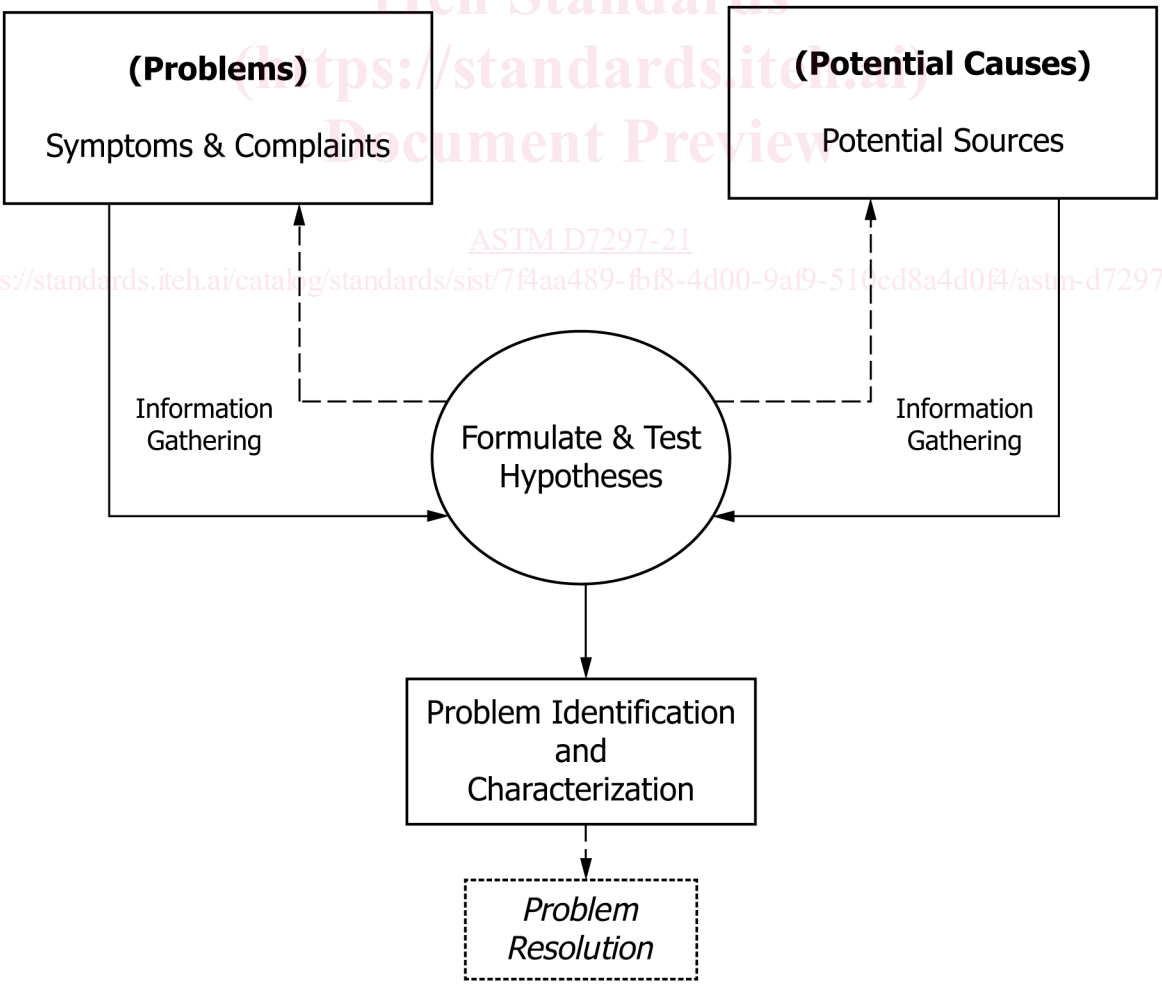

FIG. 1 Iterative Approach to Solving IAQ Problems

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,~~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 ~~judging~~ 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 ~~both~~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 ~~sharpening~~refining the ~~thinking process for the~~ investigative thought process on an on-going investigation.

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

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

9.4.1 *Phase I*—~~An~~ Conduct an on-site interview followed by a walk-through of the building and its ~~surrounding is conducted.~~ 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 ~~resources required,~~required resources, and obtaining approval for ~~the~~performing Phase II are ~~also~~ part of this effort.

9.4.2 *Phase II*—The purpose of this phase is to conduct a detailed assessment of various possible problem ~~areas~~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, ~~then~~ plans are ~~to be~~ developed ~~either~~ 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 ~~to be~~ estimated for obtaining necessary approvals.

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

9.4.4 Fig. 2 provides a flow diagram for the three investigative phases ~~of investigations~~ 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 for walk-through,~~emphasis,

9.4.4.4 Conduct walk-through exterior survey,

9.4.4.5 Conduct walk-through interior survey,

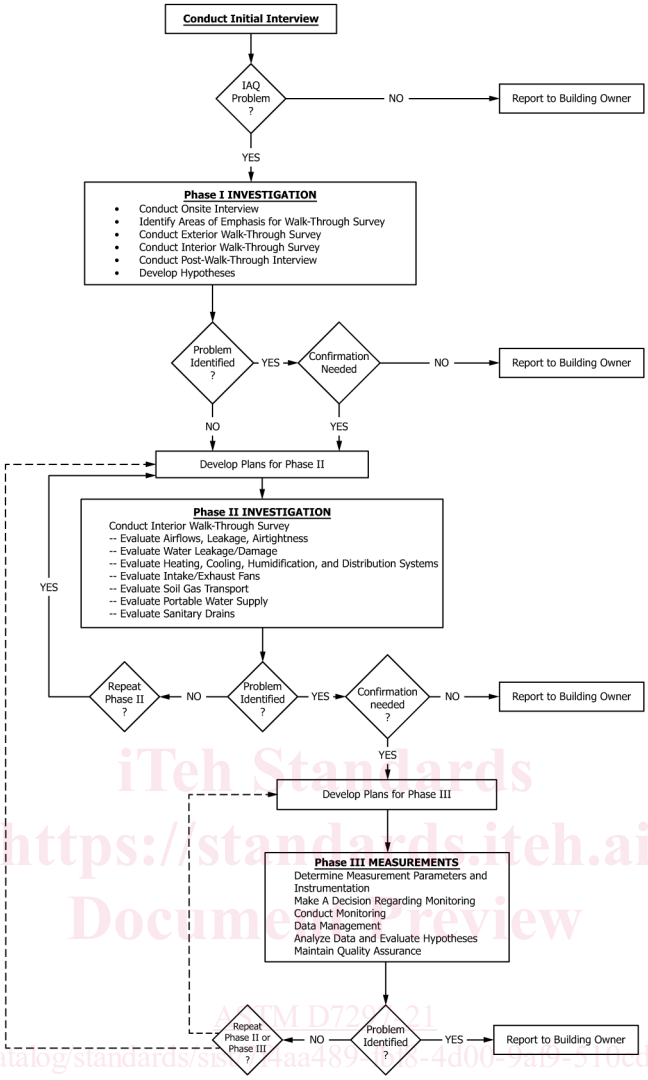

FIG. 2 An Illustrative Flow Diagram for IAQ Investigations

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 ~~analysis of~~ data analysis and hypotheses evaluation ~~of hypotheses~~ is described in a separate section near the conclusion of ~~the investigation,~~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 ~~substeps~~ sub steps of the investigation. It should also be noted that the phases may not always be ~~divided cleanly~~clearly delineated and could be ~~somewhat enmeshed.~~ 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 ~~of phasing~~ is very important in conducting successful investigations and, thus, any deviation from phasing ~~should be recognized by the investigator in order that~~ as described in this document is acceptable as long as the concept itself is not compromised.

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

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

9.5.1 Although IAQ investigations ~~to identify a source of the problem described in this practice may give an~~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 ~~to~~and achieve reliable outcomes, it is essential that investigators understand the ~~*critical purpose*~~*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 ~~critical purposes~~ objectives underlying each step in the investigation.

9.5.3 The success of an IAQ investigation often depends on whether ~~or not~~ the investigator has ~~taken the time to step~~ stepped back to assess all field observations and ~~data that have been collected at any given point~~ 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 ~~investigation~~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 questionnaire scope must be constrained to accomplish information-gathering without unduly burdening the respondent. Note that ~~practical~~ 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,~~ 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 ~~The possible~~ Possible outdoor sources ~~known to~~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 ~~far as~~ practical. (The information on other cases and use of controls ~~would be~~ 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

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 for elements of walk-through based on a best understanding of the perceptions of the problem, its history and its impact on the residents.~~
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 of the exterior factors may contribute to the IAQ problem under investigation.~~
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 a role in the IAQ problem under investigation. Review related information.~~
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 it possible origin(s) and to develop a specific statement of the problem.~~
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 evaluation of hypotheses.~~
13.2	Determine measurement parameters and instrumentation	To select instrumentation for hypotheses evaluation.
~~13.3~~	~~Decisions Regarding Monitoring~~	~~Pause to evaluate whether or not to conduct measurements based a review of how measurements will help in the evaluation of hypothesis and the investigation in general. If affirmative, establish criteria for measurement parameters.~~
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 to test the hypotheses.~~
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 new hypotheses for testing and returning to section 12 above.~~
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 standards of quality are met; a quality assurance plan should be in force prior to any field operations.~~
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 would be appropriate for a court proceeding, if needed, and to share with the resident known details of the investigation and results.~~
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.

on site. The investigator should ask if there are any areas to be avoided or excluded during the walkthrough. If there are ~~areas~~ 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 ~~suited to~~suitable for use in ~~the~~an initial telephone interview is given in Annex A1. ~~It should be recognized that~~ Note, this Annex and other Annexes provide *example* questionnaires. Before initiating an investigation, these examples should be ~~carefully~~ 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 ~~be causing~~ cause effects or symptoms perceived by residents as IAQ related. Consequently, it is important to recognize that while pre-prepared questionnaires enable data collection in an organized format, any question and answer sessions with residents should be ~~in an~~ open-ended ~~forum~~ so that all information relevant to an investigation is collected.