Investigating VOCs in High-Rise Residential Buildings

A Source-Attribution Guide for Understanding VOC Behavior, Airflow Dynamics, Building Pressurization, Exposure Pathways, and Competing Explanations

Prepared for residents, indoor-air investigators, industrial hygienists, building engineers, physicians, attorneys, housing officials, regulators, journalists, and neutral third-party reviewers

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Disclaimer

This document is for educational and investigative-reference purposes only. It is not medical advice, legal advice, engineering advice, or a substitute for evaluation by qualified professionals. Readers should consult licensed physicians, certified industrial hygienists, professional engineers, or attorneys for guidance specific to their circumstances.

Executive Summary

Indoor air quality investigations in high-rise residential buildings are among the most complex environmental assessments a professional can undertake. Unlike single-family homes, high-rise buildings contain dozens or hundreds of interconnected pressure zones, shared ventilation systems, vertical shafts that act as contaminant highways, and construction materials that can emit volatile organic compounds for months or years after installation.

Volatile organic compounds (VOCs) are a large family of carbon-based chemicals that evaporate easily at room temperature. They are released by paints, adhesives, sealants, flooring products, furniture, cleaning supplies, pesticides, and many other materials found in modern buildings. The U.S. Environmental Protection Agency has documented that indoor concentrations of many VOCs are consistently two to five times higher than outdoor levels, and occasionally more than ten times higher, even in locations near significant outdoor pollution sources (EPA, "Volatile Organic Compounds' Impact on Indoor Air Quality," 2024).

A competent VOC investigation does not begin with a conclusion. It begins with observations, generates hypotheses, and then systematically evaluates those hypotheses against environmental evidence, building science, temporal and spatial patterns, measurements, records, and competing explanations. Symptoms reported by occupants are important starting points, but symptoms alone cannot identify a specific chemical source because many different chemicals and conditions can produce similar effects. Measurements alone are also insufficient because air sampling captures only a snapshot of conditions that may be episodic, and a single clean sample does not prove that a space is always clean.

Source attribution — determining where a contaminant originates, how it reaches an occupant, and what evidence supports or weakens that determination — depends on the integration of multiple evidence types. This handbook explains how that integration works, what evidence to gather, how buildings move air, how portable air conditioners and building penetrations create pathways, and how investigators distinguish between competing explanations using weight-of-evidence reasoning.

The central principle is straightforward: a competent investigation rules explanations in or out by examining sources, pathways, timing, airflow, pressure relationships, material data, environmental measurements, medical correlation, and competing explanations. It does not assume a conclusion from symptoms alone, and it does not dismiss symptoms without investigating plausible environmental pathways.

PART I — FOUNDATIONS

Chapter 1: What Is a VOC Investigation?

Volatile Organic Compounds in Plain English

Volatile organic compounds are chemicals that transition from a liquid or solid state into a gas at normal room temperatures. The word "volatile" means they evaporate easily. The word "organic" refers to their carbon-based chemical structure, not to any notion of naturalness. VOCs include thousands of individual chemicals, some harmless at typical indoor concentrations and others capable of causing irritation, illness, or long-term health effects depending on concentration, duration, and individual sensitivity.

Common VOC sources in residential buildings include paints, varnishes, adhesives, caulks, sealants, flooring materials, pressed-wood products, furniture, fabrics, cleaning products, air fresheners, personal care products, office equipment, and pesticides (EPA, "Technical Overview of Volatile Organic Compounds," 2024).

Key Concepts

Exposure refers to contact between a person and a contaminant. Exposure requires a source, a pathway through which the contaminant travels, and a receptor (the person).

Source is the material, product, or activity releasing the contaminant.

Pathway is the route through which the contaminant moves from source to receptor. In buildings, pathways include direct air movement, pressure-driven infiltration through cracks and penetrations, ventilation ductwork, vertical shafts, and wall cavities.

Receptor is the person who encounters the contaminant at the exposure point.

Attribution is the process of determining which source, through which pathway, is responsible for an observed exposure or set of symptoms.

Why Source Attribution Differs from Symptom Identification

Identifying that a person has headaches, throat irritation, or fatigue is an observation. Determining that those symptoms are caused by formaldehyde off-gassing from recently installed flooring, transported through a wall cavity under negative pressure created by a portable air conditioner, is attribution. The distance between observation and attribution is where investigation happens.

A competent investigation does not begin with a conclusion. It generates multiple hypotheses, evaluates each against available evidence, and identifies which explanations are supported, which are weakened, and which require additional data.

Chapter 2: The Logic of Source Attribution

Hypothesis Generation

Every VOC investigation should begin by generating multiple plausible explanations for the observed symptoms, odors, or complaints. A hypothesis is a testable explanation. Good investigations generate at least three to five hypotheses and then systematically evaluate each one.

Ruling Explanations In and Out

Evidence either supports or weakens a hypothesis. No single piece of evidence is typically sufficient to confirm or rule out an explanation. Instead, investigators look for convergence — multiple independent lines of evidence pointing toward the same conclusion.

Evaluation Criteria

Temporal correlation asks whether symptoms correspond in time with a potential source event. Did symptoms begin after new flooring was installed? Do they worsen when the HVAC system operates?

Spatial correlation asks whether symptoms correspond in location with a potential source or pathway. Are complaints concentrated in units above a garage? Along a particular vertical stack?

Plausibility asks whether building science supports the proposed pathway. Is there a credible mechanism for the contaminant to travel from the proposed source to the reported location?

Measurement support asks whether environmental measurements are consistent with the hypothesis. Do VOC levels increase when the proposed pathway is active?

Alternative explanations asks what other sources or conditions could produce the same observations.

Source-Attribution Model

A complete attribution analysis addresses each element in sequence:

1. **Source** — What material, product, or activity is proposed as the origin?
2. **Release mechanism** — How does the contaminant enter the air (off-gassing, evaporation, combustion, mechanical disturbance)?
3. **Transport pathway** — How does the contaminant travel from source to exposure point (direct emission, pressure-driven infiltration, duct leakage, stack effect)?
4. **Exposure point** — Where does the occupant encounter the contaminant (bed, desk, AC unit area, bathroom)?
5. **Symptom or observation pattern** — What does the occupant report, and does it correlate with the pathway's expected behavior?
6. **Supporting evidence** — What records, measurements, or observations support this explanation?
7. **Competing explanations** — What other explanations fit the same observations?

Chapter 3: Evidence Standards

Types of Evidence

Occupant reports are firsthand accounts of symptoms, odors, and observations. They are valuable because occupants experience the environment continuously, but they are subjective and may be influenced by awareness, stress, or expectations.

Odor logs are dated records of when odors were detected, their character (chemical, sweet, musty, exhaust-like), intensity, duration, and location. Repeated patterns in odor logs can support or weaken specific hypotheses.

Maintenance records document work performed in the building, including materials used, dates, locations, and contractors involved. They can establish temporal links between material installation and symptom onset.

Construction records document the building's original design, materials, HVAC specifications, and subsequent renovations.

Product Safety Data Sheets (SDS) identify the chemical composition, hazards, and handling requirements of specific products. They can confirm whether a material contains chemicals capable of producing reported symptoms.

Photographs document conditions, penetrations, material labels, installation quality, and ventilation configurations at specific points in time.

Pressure measurements quantify the direction and magnitude of air movement between spaces, identifying whether contaminants can be drawn from one area into another.

Air sampling measures concentrations of specific chemicals at specific locations and times. Sampling is powerful but limited by timing, location, and the episodic nature of many exposures.

Material sampling identifies the chemical composition of specific materials and can link a material to measured airborne chemicals.

HVAC data documents ventilation rates, filter conditions, duct configurations, and air distribution patterns.

Medical documentation records symptoms, diagnoses, treatment, and temporal relationships between building occupancy and health effects.

Strengths and Limitations

Each evidence type has characteristic strengths and limitations. Occupant reports capture temporal patterns that instruments may miss but cannot quantify exposure. Air sampling quantifies concentration at the moment of collection but may miss episodic events. Pressure measurements reveal transport pathways but do not identify specific chemicals. SDS sheets identify potential emissions but do not prove that emissions actually occurred at significant levels. No single evidence type is sufficient; competent investigations integrate multiple types.

PART II — HIGH-RISE BUILDING SCIENCE

Chapter 4: How Air Moves in Buildings

Air moves through buildings in response to pressure differences. Pressure differences arise from three primary forces: wind, temperature differences (buoyancy), and mechanical systems (fans, HVAC equipment, exhaust systems).

Wind creates positive pressure on the windward side of a building and negative pressure on the leeward side. Air flows from high pressure to low pressure, so wind can push outdoor air into a building on one side while pulling indoor air out on the other.

Temperature differences cause warm air to rise because warm air is less dense than cool air. This creates buoyancy-driven pressure differences known as stack effect, discussed in detail in Chapter 5.

Mechanical systems deliberately move air through buildings using fans, blowers, and ductwork. HVAC systems, exhaust fans, dryer vents, kitchen hoods, and bathroom exhaust fans all create pressure differences. When mechanical systems remove more air from a space than they supply, the space becomes negatively pressurized, and air is drawn in through any available opening.

Leakage paths are unintentional openings in the building envelope — cracks around doors and windows, gaps at pipe and conduit penetrations, unsealed wall cavities, electrical outlets, and construction joints. Air moves through these paths in response to the pressure differences created by wind, temperature, and mechanical systems.

Air balancing refers to the deliberate adjustment of supply and exhaust airflows to maintain desired pressure relationships between spaces. Poor air balancing can inadvertently create pathways for contaminant transport.

Think of a building as a collection of interconnected boxes, each with its own pressure relative to its neighbors. Air constantly flows from higher-pressure boxes to lower-pressure boxes through every available crack, gap, and opening. Understanding this flow is fundamental to understanding how contaminants travel.

Chapter 5: Stack Effect in High-Rise Buildings

Stack effect is one of the most important airflow phenomena in tall buildings. It occurs because warm air is less dense than cool air and therefore rises, creating pressure differences between the top and bottom of a building.

Winter Stack Effect

During cold weather, heated indoor air rises through vertical pathways — elevator shafts, stairwells, utility chases, pipe penetrations, electrical conduits, trash chutes, wall cavities, and mechanical shafts. As this warm air rises and exits through openings at upper levels, cold outdoor air is drawn into the building through openings at lower levels. The result is upward airflow through the building's core.

For a 30-story building with a 25°C (45°F) indoor-outdoor temperature difference, the pressure difference due to stack effect can reach approximately 40 pascals — sufficient to cause noticeable drafts, difficulty opening doors, and significant air infiltration (CTBUH, "Stack Effect in High-Rise Buildings: A Review," 2017).

Summer Reverse Stack Effect

During hot weather, the pattern reverses. Air-conditioned indoor air is cooler and denser than outdoor air. Warm outdoor air enters through upper openings and cooler indoor air leaks out through lower openings, creating downward airflow through the building's core. The effect is generally weaker in summer because indoor-outdoor temperature differences are typically smaller than in winter.

Neutral Pressure Plane

The neutral pressure plane (NPL) is the height in the building where indoor and outdoor pressures are equal. Below the NPL, air flows inward; above the NPL, air flows outward during winter stack effect. The NPL location depends on the distribution of openings in the building envelope and can shift with wind conditions, HVAC operation, and door/window positions. Research indicates the NPL typically sits between 30% and 70% of total building height (NIST, "Effects of Air Infiltration and Ventilation," Building and Fire Research Laboratory).

Vertical Pathways

Stack effect is amplified by vertical pathways that connect multiple floors:

- **Elevator shafts** are large, continuous vertical openings that act as primary chimneys
- **Stairwells** provide multi-story vertical connections, especially when doors are propped open

- **Utility chases** carry pipes, wires, and ducts vertically through the building, often with unsealed penetrations at each floor
- **Pipe penetrations** where plumbing, gas, and sprinkler pipes pass through floor slabs
- **Electrical conduits** that run vertically between floors
- **Trash chutes** that connect every floor to the building's base
- **Wall cavities** in certain construction types where air can move vertically within wall assemblies
- **Mechanical rooms** that may connect to multiple floors via ductwork and shafts

These pathways mean that a contaminant released in a garage, loading dock, or mechanical room at the building's base can potentially reach upper-floor apartments during winter stack effect conditions.

Chapter 6: Seasonal and Weather Effects

Environmental conditions outside a building directly affect how air moves inside it.

Outdoor temperature drives stack effect intensity. Greater indoor-outdoor temperature differences produce stronger stack-driven airflows. Cold winters produce the strongest upward stack effect; hot summers produce the strongest downward (reverse) stack effect.

Indoor temperature is the other half of the stack effect equation. Buildings maintained at higher indoor temperatures during winter experience stronger stack effect.

Wind direction and speed create pressure differences across the building envelope. Strong winds can overpower stack effect on windward and leeward faces, changing infiltration and exfiltration patterns. Wind direction determines which face of the building experiences positive or negative pressure.

Humidity affects occupant comfort and can influence perception of air quality. High humidity can increase off-gassing rates from some materials and promote mold growth, which may complicate VOC investigations with overlapping biological contaminant issues.

Rain can seal some building openings temporarily while activating others (e.g., water entering through compromised envelope components can carry dissolved contaminants or activate mold growth).

Sun exposure heats building surfaces, increasing off-gassing from exterior materials and sun-exposed interior surfaces. South-facing and west-facing units may experience higher VOC levels during sunny periods.

Building orientation determines which faces are exposed to prevailing winds and solar heating, affecting pressure patterns and temperature distributions.

Chapter 7: Pressure Zones in Multi-Unit Residential Buildings

A high-rise residential building contains many interacting pressure zones, each of which can be at a different pressure relative to its neighbors at any given time.

Individual apartments are semi-enclosed spaces whose pressure depends on window positions, exhaust fan operation, HVAC supply and return balance, portable AC operation, and connections to adjacent spaces.

Hallways are common spaces that often operate at a different pressure than apartments. Pressurized hallway designs (where hallways are deliberately maintained at slightly higher pressure than apartments) are intended to prevent odor and contaminant transfer between units, but this design is not universal and may not function correctly in all conditions.

Vertical shafts (elevator, stairwell, utility, trash) are the primary conduits for stack-effect-driven airflow, connecting every floor.

Garages are typically below-grade or ground-level spaces containing vehicle exhaust, fuel vapors, and maintenance chemicals. Code-compliant garage ventilation is designed to maintain the garage at negative pressure relative to occupied spaces, but system failures or imbalances can reverse this relationship.

Trash rooms may contain decomposing waste and cleaning chemicals. They are typically exhausted but may share air pathways with adjacent spaces.

Loading docks are open or semi-enclosed spaces exposed to vehicle exhaust, deliveries, and outdoor conditions. They can be sources of VOCs and combustion products that enter the building through poorly sealed connections.

Mechanical rooms contain HVAC equipment, boilers, pumps, and sometimes chemical storage. They may be pressure sources or sinks depending on equipment operation.

Exterior walls are the primary boundary between indoor and outdoor environments. Their airtightness determines how much infiltration occurs in response to pressure differences.

Each of these zones interacts with the others through the building's leakage paths, creating a dynamic pressure network that shifts with weather, HVAC operation, occupant activity, and time of day.

PART III — PORTABLE AIR CONDITIONERS AND PRESSURE EFFECTS

Chapter 8: Single-Hose Portable AC Units

Single-hose (also called single-duct) portable air conditioners are commonly used in apartments that lack central air conditioning or window units. These units draw room air across the condenser coil to reject heat, then exhaust that heated air outdoors through a single hose, typically routed through a window panel or wall opening.

The Negative Pressure Problem

Because a single-hose unit exhausts indoor air to the outside, it creates a net removal of air from the room. The air that is exhausted must be replaced. Since the unit does not have a separate intake hose to draw replacement air from outdoors, the replacement air enters the room through any available opening — the path of least resistance.

The U.S. Department of Energy acknowledged this phenomenon in federal rulemaking, noting that "infiltration from outside the conditioned space occurs due to the negative pressure induced as condenser air is exhausted to the outdoor space" and that "this effect is most pronounced for single-duct units, which draw all of their condenser air from within the conditioned space" (Federal Register, Vol. 80, No. 228, November 27, 2015).

Where Replacement Air Comes From

Replacement air may be drawn from any space connected to the depressurized room through leakage paths:

- **Hallways** through door gaps and frame leakage
- **Neighboring units** through shared wall penetrations, electrical outlets, and pipe chases
- **Wall cavities** through gaps around electrical boxes, pipe penetrations, and construction joints
- **Utility chases** through unsealed openings where pipes and wires enter the unit
- **Trash rooms** through plumbing or utility connections

- **Garages** through floor penetrations, elevator lobbies, and stairwell connections
- **Loading docks** through similar pathways as garages
- **Stairwells** through door gaps
- **Elevator shafts** through lobby connections
- **Outdoor cracks or windows** through envelope leakage

This means that operating a single-hose portable AC in an apartment can draw contaminated air from garages, maintenance areas, neighboring units, or other building spaces into the occupied unit.

Chapter 9: Dual-Hose and Window AC Units

Dual-hose portable AC units use two hoses — one to draw outdoor air across the condenser coil and one to exhaust that heated air back outdoors. Because the condenser air circuit is separate from the room air, dual-hose units do not create significant negative pressure in the room. The room air is cooled by passing across the evaporator coil and returned to the room.

Window AC units are mounted in a window opening with the condenser section exposed to outdoor air. Like dual-hose portable units, window ACs do not exhaust room air outdoors. The condenser rejects heat directly to outdoor air without removing air from the room.

Both dual-hose and window units generally reduce negative-pressure problems compared with single-hose systems because they do not create a net removal of room air. However, installation quality matters — poorly sealed window panels, gaps around units, and compromised window seals can still allow uncontrolled air infiltration.

Chapter 10: Installation Defects

The quality of portable AC installation significantly affects whether the unit creates air quality problems beyond the inherent pressure effects of single-hose designs.

Gaps around window panels — Most portable ACs come with adjustable window panels that are intended to seal the window opening around the exhaust hose. These panels frequently do not seal tightly, allowing outdoor air, insects, and moisture to enter.

Hose leaks — Exhaust hoses can develop leaks at joints, connections, or through wear. A leaking hose releases hot, moist air into the room, reducing efficiency and potentially introducing condensation and associated biological growth.

Poorly sealed wall penetrations — When tenants or maintenance staff cut holes in walls for AC hoses rather than using windows, the resulting penetrations may not be properly sealed, creating permanent pathways between the unit and wall cavities or adjacent spaces.

Tape-sealed penetrations — Duct tape and similar adhesive tapes degrade over time, lose adhesion, and can themselves emit VOCs. They are not reliable long-term seals for building penetrations.

Improvised hose extensions — Extending exhaust hoses beyond manufacturer specifications increases backpressure on the unit, reduces efficiency, and increases the volume of room air exhausted per cooling cycle.

PART IV — BUILDING ENVELOPE PENETRATIONS

Chapter 11: Why Penetrations Matter

Every hole in a wall, floor, or ceiling is a potential pathway for air movement and contaminant transport. Modern buildings contain hundreds of penetrations for:

- **AC hoses** — Openings cut or drilled for portable AC exhaust and intake hoses
- **Cables** — Television, internet, telephone, and electrical cabling
- **Pipes** — Plumbing supply, drain, waste, vent, gas, and fire sprinkler piping
- **Conduits** — Electrical conduit carrying wiring between floors and units
- **Ducts** — HVAC supply, return, and exhaust ductwork
- **Maintenance work** — Openings created during repairs, renovations, or equipment installation
- **Utility chases** — Vertical spaces carrying multiple utilities between floors
- **Temporary repairs** — Holes patched with non-permanent materials

Each unsealed or poorly sealed penetration creates a transport pathway. When pressure differences exist across a penetration — due to stack effect, wind, HVAC operation, or exhaust fan use — air moves through the opening, potentially carrying contaminants from one space to another.

Chapter 12: Tapes, Sealants, Foams, and Adhesives

Materials used to seal penetrations can themselves become VOC sources.

Tapes — Duct tape, foil tape, and adhesive-backed tapes contain solvents and adhesive compounds that can off-gas, particularly when new or when heated. Duct tape is not rated for permanent sealing applications and degrades over time.

Sealants — Silicone, polyurethane, and acrylic sealants emit VOCs during curing and may continue low-level emissions afterward. Research has documented that moisture-dominated cure adhesives such as silicone sealant are significant sources of VOC emissions indoors, particularly in newly sealed

areas (Wang et al., "A one-dimensional VOC emission model of moisture-dominated cure adhesives," Building and Environment, 2019).

Spray foams — Expanding polyurethane foams used to fill gaps around pipes and conduits contain isocyanates and other chemicals during application and curing. Proper ventilation during and after application is important.

Adhesives — Construction adhesives used for flooring, countertops, wall panels, and trim can emit a variety of VOCs including toluene, xylene, and mineral spirits. Studies have shown that adhesive emissions can continue for weeks or months after installation (Katsoyiannis et al., "Comparison of VOC Emissions Produced by Different Types of Adhesives," Materials, 2021).

Caulks and mastics — HVAC duct mastics and general-purpose caulks contain solvents and plasticizers that emit VOCs during and after application.

Investigators should obtain product names, SDS sheets, installation dates, batch numbers if available, and manufacturer technical sheets for any sealing materials used in the area under investigation.

Chapter 13: Off-Gassing

Off-gassing is the release of gases from a solid or liquid material into the surrounding air. In plain English, it is the process by which chemicals trapped in a material escape into the air you breathe.

Factors Affecting Off-Gassing

Heat — Higher temperatures increase evaporation rates and accelerate off-gassing. A material near a heating source, in direct sunlight, or in a poorly ventilated enclosed space may emit chemicals more rapidly than the same material in a cool, well-ventilated area.

Age of material — Most materials emit the highest concentrations of VOCs when new. Emission rates generally decline over time, but some materials can continue off-gassing at lower levels for months or years. The ATSDR notes that formaldehyde emissions from pressed-wood products can persist for extended periods (ATSDR, "Toxicological Profile for Formaldehyde," 2010).

Ventilation — Good ventilation dilutes and removes emitted chemicals, reducing indoor concentrations. Poor ventilation allows chemicals to accumulate.

Surface area — Larger exposed surfaces emit more total VOCs than smaller surfaces of the same material.

Curing chemistry — Some materials (sealants, adhesives, coatings) undergo chemical reactions during curing that release byproducts. Off-gassing during curing can be quite different from off-gassing after curing is complete.

Humidity — Some materials emit more VOCs under high-humidity conditions. Moisture can interact with material chemistry to release chemicals that would otherwise remain bound.

Air movement — Air flowing across a material's surface carries away emitted chemicals, which can increase the emission rate by maintaining a concentration gradient at the material surface.

PART V — VOC SOURCES AND PATHWAYS

Chapter 14: Source Categories

An investigator should consider all plausible source categories. The following list is not exhaustive but covers the most common sources encountered in high-rise residential buildings.

In-room sources — Products, materials, and activities within the occupied space: new furniture, flooring, paint, cleaning products, personal care products, cooking, hobby materials, stored chemicals, and air fresheners.

Wall-cavity sources — Materials within the wall assembly that may not be visible from the room: insulation, vapor barriers, adhesives, sealants, fire-stopping materials, and construction residues.

Neighboring-unit sources — Activities or materials in adjacent apartments: cooking, smoking, cleaning, renovations, hobbies involving solvents, and personal care products.

Hallway sources — Cleaning products used in common areas, carpet and flooring in hallways, and materials stored in hallway utility closets.

HVAC sources — Contamination within ductwork, filters, drain pans, coils, and mechanical rooms. Also includes cross-contamination when return air from one area is supplied to another.

Garage sources — Vehicle exhaust (including carbon monoxide, benzene, toluene, and other VOCs), fuel evaporation, stored chemicals, and maintenance activities.

Loading dock sources — Diesel exhaust from delivery vehicles, spilled products, waste handling, and outdoor pollution drawn in through dock openings.

Trash room sources — Decomposing waste, cleaning chemicals, pest-control products, and biological contaminants.

Restaurant exhaust sources — Cooking fumes, grease, cleaning chemicals, and combustion byproducts from commercial kitchen operations in mixed-use buildings.

Outdoor pollution sources — Vehicle traffic, industrial emissions, construction dust, and seasonal pollen or agricultural chemicals.

Maintenance-material sources — Products used by building staff for cleaning, painting, pest control, sealing, and repair work.

Pesticide sources — Insecticides, rodenticides, and fumigants applied in or near occupied spaces.

Cleaning-product sources — Disinfectants, floor cleaners, degreasers, glass cleaners, and other products used in common areas or individual units.

Chapter 15: Transport Pathways

Direct emission — Contaminant is released within the occupied space and the occupant is exposed without an intermediate transport mechanism.

Pressure-driven transport — Contaminant moves from a higher-pressure space to a lower-pressure space through openings in the separating structure.

Ventilation transport — Contaminant enters the HVAC system and is distributed through supply ductwork to occupied spaces.

Stack-effect transport — Contaminant is carried vertically through the building by buoyancy-driven airflow through shafts and leakage paths.

Cavity transport — Contaminant moves through wall cavities, floor cavities, or ceiling plenums that connect separate spaces.

Shaft transport — Contaminant travels through elevator shafts, stairwells, trash chutes, or utility chases.

Duct leakage — Supply or return ducts that pass through contaminated spaces (e.g., mechanical rooms, garages) leak air into or out of the duct, mixing contaminated air with supply air.

Return-air pathways — Contaminants enter the HVAC system through return-air grilles, transfer grilles, or undercut doors and are recirculated.

Exhaust-driven replacement air — When exhaust systems (including portable ACs) remove air from a space, replacement air is drawn in from surrounding spaces through the path of least resistance.

Chapter 16: Exposure Points

Exposure may occur at specific locations within a unit. Identifying where symptoms or odors are strongest can provide clues about the transport pathway.

Bed — Occupants spend extended periods sleeping, increasing cumulative exposure. Proximity to exterior walls, utility chases, or AC units may be relevant.

Desk area — Extended occupancy during waking hours. Computer equipment and electronics may also emit low levels of VOCs.

AC hose opening — The area around a portable AC hose penetration is a direct connection to the wall cavity, adjacent space, or outdoors.

Window — Open windows can admit outdoor pollutants; closed windows near leaky frames may admit pressure-driven infiltration.

Bathroom exhaust — Bathroom exhaust fans create localized negative pressure that can draw air from wall cavities and adjacent spaces.

Kitchen exhaust — Range hoods and kitchen exhaust fans create significant negative pressure, drawing replacement air from surrounding spaces.

Electrical outlets — Outlets on exterior walls or shared walls are often pathways for air movement through wall cavities.

Pipe penetrations — Where plumbing enters through walls or floors, unsealed gaps allow air exchange.

Closets — Closets that share walls with utility chases or elevator shafts may be entry points for shaft-transported contaminants.

HVAC registers — Supply and return grilles are direct connections to the ventilation system.

Door gaps — The gap between an apartment door and hallway allows air exchange, particularly when hallway pressure differs from apartment pressure.

PART VI — TEMPORAL PATTERN ANALYSIS

Chapter 17: Timing Clues

The timing of symptoms, odors, or environmental changes can support or weaken specific source hypotheses. Investigators should look for correlations between symptoms and identifiable events or conditions.

Symptoms immediately after installation may indicate off-gassing from newly installed materials. This pattern is consistent with adhesive, sealant, flooring, paint, or furniture emissions.

Symptoms after maintenance work may indicate that maintenance materials (adhesives, sealants, paints, cleaning products) are the source, or that maintenance work created new penetrations or disturbed existing barriers.

Symptoms that worsen during warm weather may indicate heat-accelerated off-gassing, increased outdoor pollution infiltration, or summer reverse stack effect drawing contaminants from upper building areas.

Symptoms that worsen when HVAC operates may indicate contamination within the HVAC system, cross-contamination between zones served by the same system, or pressure changes created by HVAC operation that activate transport pathways.

Symptoms that worsen when portable AC operates may indicate that the unit is creating negative pressure that draws contaminants from adjacent spaces, wall cavities, garages, or hallways.

Symptoms that improve when windows are opened may indicate that the contaminant source is indoor and that ventilation dilutes it, or that opening windows changes pressure relationships, reducing infiltration from contaminated spaces.

Symptoms that improve when occupant leaves the building are consistent with a building-related source but do not by themselves identify which source. This pattern is a hallmark of sick building syndrome and warrants investigation.

Symptoms tied to garage activity — symptoms that coincide with vehicle arrivals, departures, or idling may indicate garage exhaust infiltration.

Symptoms tied to restaurant activity — symptoms that coincide with restaurant operating hours, cooking activity, or ventilation operation may indicate restaurant exhaust infiltration.

Symptoms tied to cleaning activity — symptoms that coincide with building cleaning schedules may indicate cleaning product exposure.

Symptoms tied to wind or weather — symptoms that change with wind direction, speed, or outdoor temperature may indicate weather-dependent infiltration pathways.

Chapter 18: Repeated Patterns vs. Isolated Incidents

A single symptom event is difficult to interpret. It could be caused by any number of transient factors. However, a pattern of symptoms that repeats under similar conditions is much more informative.

Investigators should look for:

- Symptoms that recur on the same days of the week (suggesting activity-related sources)
- Symptoms that recur at the same time of day (suggesting HVAC schedule or occupancy patterns)
- Symptoms that recur under similar weather conditions (suggesting stack effect or wind-driven infiltration)
- Symptoms that recur after specific building events (maintenance, cleaning, deliveries)
- Symptoms that recur in the same location within a unit (suggesting a nearby pathway)

Daily exposure logs (see Chapter 43) are the most effective tool for identifying repeated patterns. An occupant who records symptoms, conditions, and activities consistently over weeks can provide data that reveals patterns invisible in individual observations.

PART VII — SPATIAL PATTERN ANALYSIS

Chapter 19: Location Clues

The geographic distribution of symptoms, odors, or environmental observations within a building can indicate the source location and transport pathway.

One room — Symptoms confined to a single room may indicate an in-room source or a pathway entering that specific room (e.g., a wall penetration, AC hose opening, or HVAC register).

One unit — Symptoms throughout a unit but not in neighboring units may indicate an in-unit source, unit-specific HVAC problems, or pathways unique to that unit.

Multiple units — Symptoms in multiple units suggest a shared source or shared transport pathway, such as a common HVAC system, vertical shaft, or building-wide pressure condition.

Same vertical stack — Symptoms concentrated in units on the same vertical line strongly suggest stack-effect transport through a shared vertical pathway (utility chase, pipe penetration, wall cavity).

Same floor — Symptoms on the same floor may indicate a floor-level source (recently renovated common area, floor-specific HVAC zone) or horizontal transport through hallways and shared walls.

Above a garage — Symptoms in units directly above a parking garage are consistent with garage exhaust infiltration through floor penetrations, elevator lobbies, or stairwell connections.

Near an elevator shaft — Symptoms concentrated near elevator shafts suggest stack-effect transport through the shaft, which acts as a primary vertical chimney.

Near a trash chute — Symptoms near trash chute openings may indicate odor or contaminant migration from waste decomposition or cleaning chemicals.

Near a mechanical room — Symptoms near mechanical rooms may indicate leakage of HVAC system contaminants, refrigerants, or maintenance chemicals.

Near a restaurant exhaust route — In mixed-use buildings, symptoms near the path of restaurant exhaust ductwork may indicate exhaust leakage or re-entrainment.

Chapter 20: Multi-Unit Patterns

When multiple tenants report similar complaints, the pattern across units can significantly strengthen or weaken specific source theories.

If complaints follow a vertical line, the investigation should focus on shared vertical pathways — utility chases, pipe runs, elevator shafts, stairwells, and wall cavities connecting those units.

If complaints are concentrated on one floor, the investigation should focus on floor-level sources and horizontal transport pathways.

If complaints are scattered without a clear spatial pattern, the investigation should consider building-wide sources such as HVAC system contamination, outdoor pollution, or common-area cleaning products.

If only one unit is affected despite shared construction and similar conditions in neighboring units, the investigation should focus on unit-specific factors: recent renovations, personal products, unique penetrations, portable AC operation, or unit-specific HVAC problems.

Multi-unit surveys — simple questionnaires distributed to all tenants in a building or section — can reveal patterns that are not apparent from individual complaints.

PART VIII — BUILDING INVESTIGATION METHODOLOGY

Chapter 21: Occupant Interviews

Structured occupant interviews are essential early steps in any investigation. Sample questions include:

1. When did you first notice symptoms or odors?
2. Can you describe the symptoms? (headache, throat irritation, eye irritation, fatigue, nausea, dizziness, etc.)
3. Can you describe the odor? (chemical, sweet, musty, exhaust-like, solvent-like, new-material smell)
4. Where in your unit are symptoms or odors strongest?
5. What time of day are symptoms worst?
6. Do symptoms change with weather or season?
7. Do symptoms change when you operate your air conditioner, exhaust fans, or open windows?
8. Do symptoms improve when you leave the building?
9. How quickly do symptoms resolve after leaving?
10. Are you aware of any recent maintenance, renovation, or construction in your unit, neighboring units, or common areas?
11. Have you installed any new furniture, flooring, or materials recently?
12. What cleaning products do you use?
13. Do you have a portable air conditioner? What type? How is it installed?
14. Have you noticed any new holes, gaps, or penetrations in walls, floors, or ceilings?
15. Have other residents in the building reported similar problems?

Chapter 22: Maintenance and Construction Records

Investigators should request the following records from building management:

- **Work orders** — All maintenance requests and completed work, particularly in the affected unit and adjacent areas
- **Contractor invoices** — Identifying specific contractors, services, and dates
- **Material lists** — Products and materials used in maintenance and renovation
- **Product labels** — Photos or copies of labels from materials used
- **SDS sheets** — Safety Data Sheets for all products used in the building
- **Photos** — Before, during, and after photos of maintenance work
- **Installation dates** — When specific materials were installed
- **HVAC service records** — Filter changes, coil cleaning, duct cleaning, refrigerant charges, air balancing reports
- **Pest-control logs** — Dates, chemicals used, application methods, and locations
- **Cleaning logs** — Products, schedules, and areas cleaned
- **Complaint logs** — Records of tenant complaints about air quality, odors, or health symptoms
- **Incident reports** — Any documented incidents involving chemical spills, system failures, or environmental complaints

Chapter 23: Product Safety Data Sheets

Safety Data Sheets (SDS, formerly MSDS) are standardized documents that describe the properties, hazards, and safe handling procedures for chemical products. They are required for all chemical products sold or used in workplaces under OSHA's Hazard Communication Standard.

What SDS Can Show

SDS sheets identify chemical ingredients, concentration ranges, known health hazards, physical properties, and recommended exposure controls. They can confirm that a specific product contains chemicals capable of producing reported symptoms.

What SDS Cannot Show

SDS sheets do not predict actual indoor air concentrations. They describe the product's properties, not the resulting exposure. A product listed as containing formaldehyde does not prove that formaldehyde from that product reached a specific occupant at a harmful concentration.

Key Sections to Review

- **Section 2: Hazard identification** — GHS classifications, signal words, hazard statements
- **Section 3: Composition/information on ingredients** — Chemical names, CAS numbers, concentration ranges
- **Section 4: First-aid measures** — Symptom descriptions and treatment for overexposure
- **Section 7: Handling and storage** — Ventilation requirements, temperature sensitivity
- **Section 8: Exposure controls/personal protection** — Occupational exposure limits (OELs), recommended ventilation
- **Section 9: Physical and chemical properties** — Vapor pressure, boiling point, evaporation rate (indicators of volatility)
- **Section 10: Stability and reactivity** — Conditions that may trigger decomposition or additional emissions
- **Section 11: Toxicological information** — Health effects data, routes of exposure, target organs

Chapter 24: Pressure Measurements

Differential pressure measurements quantify the pressure difference between two spaces, indicating the direction and magnitude of air movement between them.

Differential Pressure in Plain English

Imagine two rooms connected by a crack under a door. If Room A is at higher pressure than Room B, air flows from Room A into Room B through that crack. A manometer (pressure measuring device) placed with one port in each room shows the difference. If the reading is positive, air flows from the reference side to the measurement side; if negative, the reverse.

Using Manometers

Digital micromanometers can detect pressure differences as small as 0.1 pascal. Investigators typically measure pressure differences across:

- **Apartment to hallway** — Determines whether apartment is positive (air flows out to hallway) or negative (air is drawn in from hallway)
- **Apartment to outdoors** — Determines overall building envelope pressure at that location
- **Apartment to wall cavity** — Determines whether air moves from wall cavity into the room (possible contaminant pathway)
- **Apartment to garage-adjacent spaces** — Determines whether garage air can be drawn into occupied spaces
- **Bathroom to apartment** — When exhaust fan operates, bathroom becomes negative, pulling air from apartment. When fan is off, check for reverse flow
- **AC hose area to room** — During portable AC operation, determines the magnitude of negative pressure created

Measurements should be taken under multiple conditions: HVAC on/off, portable AC on/off, exhaust fans on/off, windows open/closed, and different weather conditions.

Chapter 25: Ventilation Assessment

A ventilation assessment evaluates how fresh air enters, moves through, and exits a building or space.

Air supply — Fresh outdoor air delivered to occupied spaces through the HVAC system. ASHRAE Standard 62.2 establishes minimum ventilation rates for residential buildings, including high-rise multifamily buildings (ASHRAE, "Standards 62.1 & 62.2," current edition).

Return air — Air drawn back to the HVAC system from occupied spaces for reconditioning or exhaust.

Exhaust air — Air deliberately removed from the building, typically from bathrooms, kitchens, and laundry areas.

Fresh air — Outdoor air introduced into the HVAC system to dilute indoor contaminants and maintain air quality.

Filtration — The type and condition of air filters in the HVAC system. Higher-efficiency filters (MERV 13 or above) can remove more particulate matter but do not remove gaseous VOCs.

Air balancing — The measured airflow at each supply and return register, ensuring that supply and return are matched to maintain desired pressure relationships.

Make-up air — Air provided to replace air removed by exhaust systems. Without adequate make-up air, exhaust systems depressurize occupied spaces, creating uncontrolled infiltration pathways.

Air changes per hour (ACH) — The number of times the entire volume of air in a space is replaced per hour. Higher ACH reduces indoor pollutant concentrations but requires more energy.

Chapter 26: Air Sampling

Air sampling measures the concentration of specific airborne chemicals at a specific location and time.

Common Measurements

VOC sampling — Total VOC (TVOC) measurements provide a general screening value. Speciated VOC analysis identifies and quantifies individual compounds. Sampling methods include sorbent tubes, canisters, photoionization detectors (PIDs), and passive badges.

Formaldehyde sampling — Dedicated formaldehyde sampling methods (e.g., DNPH cartridges analyzed by HPLC) provide specific formaldehyde concentrations.

Carbon monoxide — Continuous CO monitors can identify combustion product infiltration from garages, loading docks, or malfunctioning combustion equipment.

Carbon dioxide — CO2 levels indicate ventilation adequacy. Levels consistently above 1000 ppm suggest insufficient outdoor air supply.

Particulate matter — Particle counters measure suspended particulate, which may accompany VOC sources or indicate biological contamination.

Temperature and humidity — Continuous monitoring provides context for off-gassing rates and occupant comfort.

Limitations

Short sampling windows — A 4-hour or 8-hour sample captures average conditions during that period. It may miss peak exposures that last minutes or hours.

Episodic exposures — If the source is intermittent (e.g., garage exhaust during rush hour, cleaning on Tuesdays), sampling at other times will not capture the exposure.

Dilution — Ventilation dilutes indoor concentrations. A well-ventilated room may show low VOC levels even when a significant source is present.

Wrong location — Sampling at the center of a room may miss elevated concentrations near a specific pathway (e.g., a wall penetration or AC hose opening).

Wrong timing — Sampling when the proposed pathway is not active (e.g., when the portable AC is off, when weather conditions do not create the suspected pressure differential) may produce misleadingly low results.

Background levels — Some VOCs are present in all indoor environments at background levels. Distinguishing between background and source-specific contributions requires comparison with appropriate reference data and conditions.

Chapter 27: Material Sampling

Material sampling involves collecting physical samples of building materials, products, or residues for laboratory analysis to determine their chemical composition.

Material sampling may be appropriate when:

- A specific material is suspected of emitting a contaminant detected in air sampling
- The identity of an installed material is unknown or disputed
- SDS information is unavailable or insufficient
- A material has visibly deteriorated, and decomposition products are suspected

Chain of custody documentation ensures that samples can be traced from collection through analysis, maintaining their value as evidence.

Samples intended for use in formal disputes, legal proceedings, or regulatory actions should be collected by qualified professionals (certified industrial hygienists, environmental consultants, or forensic analysts) using established protocols.

PART IX — MEDICAL SYMPTOM CORRELATION

Chapter 28: Common Indoor-Air Symptoms

The following symptoms are commonly reported in indoor air quality complaints and have been documented in association with various indoor pollutants by the EPA, ATSDR, and the medical literature:

- **Headache** — One of the most frequently reported symptoms, associated with numerous VOCs, carbon monoxide, and poor ventilation
- **Dizziness** — May indicate significant exposure to solvents, carbon monoxide, or other central nervous system depressants
- **Fatigue** — Persistent unexplained fatigue, especially when it resolves away from the building, is consistent with chronic low-level exposure
- **Sore throat** — Irritation of the pharynx, consistent with exposure to formaldehyde, particulate matter, or other respiratory irritants
- **Chest tightness** — May indicate lower respiratory tract irritation or bronchospasm
- **Nausea** — Associated with various VOC exposures and carbon monoxide
- **Cognitive slowing** — Difficulty concentrating, mental fog, slowed processing, and memory difficulties have been associated with VOC and CO exposure
- **Eye irritation** — Burning, stinging, tearing, or redness, particularly associated with formaldehyde and other aldehydes
- **Throat irritation** — Scratchiness, burning, hoarseness, or frequent throat clearing
- **Respiratory irritation** — Cough, wheezing, shortness of breath, or worsening of existing asthma or respiratory conditions

These symptoms are drawn from the diagnostic reference established by the American Lung Association, EPA, Consumer Product Safety Commission, and American Medical Association in "Indoor Air Pollution: An Introduction for Health Professionals."

Chapter 29: Nonspecific Symptoms

Most symptoms reported in indoor air quality complaints are nonspecific — they can result from many different causes. Headache, fatigue, and throat irritation, for example, can be caused by dehydration, allergies, viral illness, medication effects, stress, poor sleep, and many other factors unrelated to indoor air quality.

Because of this nonspecificity, symptom reports alone cannot identify a chemical source. A person reporting headaches after new flooring is installed may be experiencing formaldehyde irritation, may have a coincidental viral illness, or may be reacting to stress about the renovation process.

This does not mean symptoms should be ignored. It means symptoms should be evaluated in context with environmental evidence, not used as standalone proof of a specific chemical exposure.

Chapter 30: Stronger Medical-Environmental Correlation

Symptom reports become more significant when correlated with independent environmental observations. The following correlations strengthen the link between symptoms and an environmental source:

- **Time in building vs. time away** — Symptoms that consistently appear during building occupancy and resolve when the occupant leaves (exposure-recovery cycles)
- **Installation dates** — Symptom onset that corresponds with installation of new materials
- **Odor events** — Symptoms that occur simultaneously with identifiable odors
- **Measured pressure changes** — Symptoms that worsen when pressure measurements confirm contaminant transport pathways are active
- **Measured VOCs** — Symptom timing that correlates with elevated VOC measurements
- **Repeated exposure-recovery cycles** — Multiple episodes of symptom onset during occupancy and resolution after departure
- **Multiple affected occupants** — When several occupants in the same building report similar symptoms, individual medical explanations become less likely
- **Known irritant materials** — Presence of materials documented to emit chemicals consistent with reported symptoms
- **Physician documentation** — Medical records establishing temporal relationships between building occupancy and health effects

PART X — ALTERNATIVE EXPLANATIONS AND CONFOUNDERS

Chapter 31: Outdoor Pollution

Outdoor pollution sources — vehicle traffic, industrial facilities, construction sites, agricultural operations, and wildfire smoke — can contribute to indoor air quality problems. Outdoor pollutants enter buildings through ventilation systems, open windows, and envelope leakage. Wind direction and building orientation determine which units are most affected. Investigators should consider outdoor sources when symptoms correlate with wind conditions or outdoor events.

Chapter 32: Vehicle Exhaust and Garages

Attached or integrated parking garages are common sources of VOCs (benzene, toluene, xylene), carbon monoxide, and particulate matter in high-rise buildings. Vehicle exhaust can migrate into occupied spaces through elevator lobbies, stairwells, utility penetrations, and HVAC system connections. The EPA has documented that carbon monoxide and other exhaust components can be drawn from underground garages into offices and residences via stairwells and elevator shafts when ventilation and sealing are inadequate (EPA, "Building Air Quality: A Guide for Building Owners and Facility Managers," 1991).

Chapter 33: Restaurant Exhaust

In mixed-use buildings with ground-floor or lower-level restaurants, cooking exhaust can infiltrate residential units through shared ductwork, building penetrations, and re-entrainment of exhausted air through windows or air intakes. Restaurant exhaust contains cooking oils, combustion products, and grease particulates.

Chapter 34: Cleaning Products

Commercial and residential cleaning products contain VOCs including glycol ethers, terpenes (from citrus and pine scents), chlorinated solvents, ammonia, and alcohol. Building-wide cleaning schedules can introduce temporary VOC loads that coincide with occupant symptom reports. Investigators should obtain cleaning product inventories and schedules.

Chapter 35: Pesticides

Insecticides, rodenticides, and fumigants applied in common areas, individual units, or building perimeters can enter occupied spaces through the same pressure-driven pathways as other contaminants. Pest control logs should be obtained and compared with symptom timelines.

Chapter 36: Neighbor Activities

Cooking, smoking, painting, using solvents, cleaning with strong chemicals, and hobby activities in neighboring units can introduce contaminants that migrate through shared walls, floors, ceilings, and utility penetrations. These sources are often intermittent and may be difficult to identify without occupant cooperation.

Chapter 37: HVAC Malfunctions

Malfunctioning HVAC systems can cause air quality problems through several mechanisms: failed filters allowing particulate through, blocked outdoor air dampers reducing fresh air supply, contaminated coils or drain pans supporting biological growth, duct leakage in contaminated spaces, and cross-contamination between zones.

Chapter 38: Humidity and Mold

High humidity (consistently above 60% relative humidity) promotes mold growth, dust mite proliferation, and bacterial contamination. These biological contaminants produce VOCs (microbial VOCs or MVOCs) and allergens that can cause symptoms overlapping with chemical VOC exposure. Low humidity (below 30%) can cause mucous membrane irritation that mimics chemical exposure. Investigators should measure humidity and inspect for visible mold or water damage.

Chapter 39: Psychological Stress

Stress, anxiety, and heightened awareness can amplify symptom perception and lower symptom thresholds. However, competent investigations should evaluate environmental evidence before attributing complaints to psychological causes.

It is not appropriate to dismiss a complaint as psychological without first investigating plausible environmental explanations. Conversely, acknowledging that psychological factors can influence symptom perception does not mean that all symptoms are psychologically caused.

The appropriate approach is to investigate environmental conditions thoroughly and independently of psychological assessment. If environmental investigation identifies no plausible source, pathway, or measurement support, psychological factors may be considered as part of a differential assessment — but never as a first-line dismissal.

PART XI — RULING EXPLANATIONS IN OR OUT

Chapter 40: Differential Source Attribution

The following matrix framework can be used to systematically evaluate competing explanations for a VOC-related complaint.

Column	Description
Hypothesis	The proposed source and pathway
Supporting evidence	Observations, measurements, and records that are consistent with this hypothesis
Evidence against	Observations, measurements, and records that weaken this hypothesis
Needed records	Documents not yet obtained that could confirm or rule out this hypothesis
Needed measurements	Environmental data not yet collected that could confirm or rule out this hypothesis
Confidence level	Low, moderate, or high based on current evidence
Next step	The single most important action to further evaluate this hypothesis

Example entries:

Hypothesis	Supporting	Against	Needed Records	Needed Measurements	Confidence	Next Step
Flooring adhesive off-gassing	New flooring installed 2 weeks before symptoms; chemical odor strongest near floor; SDS lists toluene	Symptoms worse when portable AC runs, not expected for floor source alone	Installation date confirmation; adhesive product SDS	VOC sampling near floor surface; comparison with AC on/off	Moderate	Obtain adhesive SDS from contractor
Garage exhaust infiltration via wall cavity	Symptoms correlate with morning rush hour; unit is above garage; chemical/ exhaust odor	No CO detected in preliminary spot check	Garage ventilation maintenance records	Differential pressure: unit vs. garage; CO monitoring over 24 hours	Low	Install continuous CO monitor for 72 hours

Chapter 41: Decision Tree

The following decision tree guides the source-attribution process:

1. Did symptoms begin after a building event?

- YES → Identify the event (installation, maintenance, renovation, spill). Obtain records. Proceed to question 2.
- NO → Proceed to question 3.

2. Was a new material installed?

- YES → Obtain product identity, SDS, and installation date. Test for off-gassing. Consider in-room source hypothesis.

- NO → Consider maintenance chemicals, disturbed materials, or altered ventilation. Proceed to question 3.

3. Is there an identifiable odor?

- YES → Characterize the odor (chemical, musty, exhaust, solvent, sweet). Odor character can narrow source categories. Proceed to question 4.
- NO → Proceed to question 4.

4. Does the condition worsen with heat or warm weather?

- YES → Consistent with off-gassing (heat accelerates emissions). Also consistent with summer reverse stack effect. Proceed to question 5.
- NO → Proceed to question 5.

5. Does it worsen when HVAC or portable AC operates?

- YES → Consider HVAC-transported contaminant or negative-pressure-driven infiltration. Measure differential pressures with equipment on and off. Proceed to question 6.
- NO → Proceed to question 6.

6. Do symptoms improve when the occupant leaves the building?

- YES → Consistent with a building-related source. Strengthen investigation. Proceed to question 7.
- NO → Consider non-building factors. Still investigate but widen scope to personal products, medical conditions.

7. Are there pressure pathways connecting the unit to potential source areas?

- YES → Measure pressure differentials. Sample air near suspected pathways. Proceed to question 8.
- NO → Focus on in-unit sources and ventilation.

8. Are there garage, trash, restaurant, or maintenance sources nearby?

- YES → Investigate these specific sources. Correlate symptoms with source activity schedules.
- NO → Focus on building materials, neighbor activities, outdoor sources.

9. What measurements support or weaken each remaining explanation?

- Conduct targeted air sampling, pressure measurements, and material sampling as needed to evaluate remaining hypotheses using the differential attribution matrix.

Chapter 42: Weight-of-Evidence Framework

Low confidence — A single line of evidence suggests a possible source, but no confirming evidence exists. Example: an occupant reports a chemical odor, but no measurements, records, or additional observations support a specific source. Action: gather additional evidence before drawing conclusions.

Moderate confidence — Multiple independent lines of evidence converge on a source hypothesis, but significant gaps or alternative explanations remain. Example: symptoms began after adhesive installation (temporal correlation), a chemical odor is present near the floor (spatial correlation), and the adhesive SDS lists irritant chemicals (plausibility), but no air sampling has confirmed elevated levels. Action: conduct targeted sampling and evaluate alternatives.

High confidence — Multiple independent lines of evidence strongly support a source hypothesis, measurements are consistent, alternatives have been evaluated and do not adequately explain the observations, and the proposed pathway is supported by building science. Example: temporal, spatial, and measurement evidence all point to the same source, and competing explanations have been systematically evaluated and found insufficient. Action: the investigation supports the hypothesis, though certainty is never absolute in environmental attribution.

PART XII — DOCUMENTATION STANDARDS

Chapter 43: Daily Exposure Log

The following template should be completed for each day symptoms or odors are observed. Consistent daily logging over several weeks is far more valuable than occasional notes.

Field	Entry
Date	
Time (onset, duration)	
Location (room, area within room)	
Odor description (character, intensity 1-10)	
Symptom description	
Severity (mild, moderate, severe)	
Duration	
Temperature (indoor, outdoor if known)	
Humidity (if measured)	
Weather (clear, cloudy, rainy, windy, wind direction)	
Window position (open, closed, which windows)	
HVAC status (on/off, mode)	
Portable AC status (on/off, type, hose configuration)	
Fan status (on/off, location)	
Building activity observed (construction, cleaning, deliveries)	
Garage activity observed (heavy traffic, idling vehicles)	
Neighbor activity (cooking, smoking, renovation)	
Recovery time after leaving	
Photos/videos taken (yes/no, description)	
Witnesses	

Chapter 44: Maintenance Event Log

Field	Entry
Date	
Time	
Worker/contractor (name, company)	
Work performed (description)	
Materials used (product names, quantities)	
Location (unit, common area, building system)	
Photos taken (yes/no)	
Odors noticed (during work, after work)	
Ventilation during work (windows open, fans, HVAC)	
Symptoms after work (onset, description, duration)	
Requests made to management	
Responses received	

Chapter 45: Evidence Preservation

Preserving evidence contemporaneously is essential. Once conditions change — materials are removed, spaces are cleaned, systems are repaired — the opportunity to document original conditions is lost.

Preserve:

- **Photos** — Date-stamped photos of materials, labels, installations, penetrations, and conditions
- **Labels and packaging** — Retain or photograph product labels, including batch numbers and manufacturer information
- **Communications** — Save all written communications (emails, text messages, letters) with building management about air quality concerns
- **Work orders** — Obtain copies of all maintenance work orders for the affected area

- **SDS sheets** — Request SDS sheets for all materials used; if refused, document the refusal in writing
- **Screenshots** — Capture any digital records, online communications, or building management portal entries
- **Logs** — Maintain daily exposure and maintenance event logs as described above
- **Medical notes** — Keep copies of all medical records, visit summaries, and physician letters documenting symptoms and their temporal relationship to building occupancy

PART XIII — PRACTICAL APPENDICES

Appendix A: Glossary

ACH (Air Changes per Hour) — The number of times the volume of air in a space is completely replaced in one hour.

Air balancing — The process of adjusting airflow in an HVAC system to achieve desired pressure relationships and ventilation rates.

ASHRAE — American Society of Heating, Refrigerating and Air-Conditioning Engineers, the organization that publishes ventilation and indoor air quality standards.

ATSDR — Agency for Toxic Substances and Disease Registry, a federal agency that provides health information about hazardous substances.

Building envelope — The physical boundary between the conditioned interior and the unconditioned exterior, including walls, roof, floor, windows, and doors.

Differential pressure — The difference in air pressure between two spaces, measured in pascals (Pa).

Dual-hose portable AC — A portable air conditioner with separate intake and exhaust hoses for condenser air, avoiding significant room depressurization.

Exhaust air — Air mechanically removed from a building or space.

Formaldehyde — A VOC (CH2O) classified as a probable human carcinogen by the EPA, commonly associated with pressed-wood products, adhesives, and some insulation materials.

HVAC — Heating, Ventilation, and Air Conditioning.

Infiltration — Uncontrolled air leakage into a building through cracks, gaps, and penetrations, driven by pressure differences.

Make-up air — Air supplied to replace air removed by exhaust systems.

Manometer — An instrument that measures pressure differences between two points.

Negative pressure — A condition where air pressure in a space is lower than in surrounding spaces, causing air to flow into the space through available openings.

Neutral pressure plane (NPL) — The height in a building where indoor and outdoor pressures are equal during stack effect conditions.

Off-gassing — The release of gaseous chemicals from a solid or liquid material into the surrounding air.

Pathway — The route through which a contaminant travels from its source to an exposure point.

PID (Photoionization Detector) — A portable instrument that measures total VOC concentration in real time.

Positive pressure — A condition where air pressure in a space is higher than in surrounding spaces, causing air to flow out of the space.

Receptor — The person or population exposed to a contaminant.

SDS (Safety Data Sheet) — A standardized document describing a chemical product's composition, hazards, handling requirements, and exposure controls.

Single-hose portable AC — A portable air conditioner with one exhaust hose that vents room air outdoors, creating negative pressure in the room.

Source — The material, product, or activity that releases a contaminant.

Source attribution — The process of determining which source, through which pathway, is responsible for an observed exposure.

Stack effect — Buoyancy-driven air movement in buildings caused by indoor-outdoor temperature differences, causing warm air to rise and creating vertical airflow through building shafts and leakage paths.

TVOC (Total Volatile Organic Compounds) — A single measurement representing the aggregate concentration of all detectable VOCs in an air sample.

VOC (Volatile Organic Compound) — A carbon-based chemical that evaporates readily at room temperature.

Appendix B: VOC Investigation Checklist

- ☐ Conduct structured occupant interviews

- ☐ Document symptom onset date and timeline
- ☐ Identify temporal patterns (time of day, day of week, season, weather)
- ☐ Identify spatial patterns (room, unit, floor, building zone)
- ☐ Request maintenance and construction records for 12 months prior to symptom onset
- ☐ Obtain SDS sheets for all materials used in affected area
- ☐ Identify all portable AC units and their installation configuration
- ☐ Inspect all visible building penetrations
- ☐ Assess HVAC system operation and condition
- ☐ Measure differential pressures under multiple operating conditions
- ☐ Assess ventilation rates and air distribution
- ☐ Conduct air sampling at appropriate locations and times
- ☐ Consider material sampling if specific materials are suspected
- ☐ Evaluate competing explanations
- ☐ Complete differential attribution matrix
- ☐ Document all findings with photos, measurements, and records

Appendix C: Building Walkthrough Checklist

- ☐ Identify building type, age, and construction materials
- ☐ Locate all vertical shafts (elevator, stairwell, utility, trash)
- ☐ Identify garage, loading dock, and mechanical room locations
- ☐ Identify restaurant or commercial spaces (if mixed-use)
- ☐ Assess hallway pressurization design
- ☐ Inspect HVAC system type and configuration
- ☐ Identify exhaust systems (bathroom, kitchen, garage, laundry)
- ☐ Note visible penetrations, gaps, and openings
- ☐ Assess envelope condition (windows, doors, walls)

- ☐ Note odors and their locations
- ☐ Photograph representative conditions
- ☐ Identify recent renovation or maintenance areas

Appendix D: Portable AC Inspection Checklist

- ☐ Identify unit type (single-hose, dual-hose, window unit)
- ☐ Identify manufacturer, model, and capacity
- ☐ Inspect hose routing and condition
- ☐ Inspect window panel or wall penetration seal quality
- ☐ Check for gaps around hose connections
- ☐ Check for hose leaks or damage
- ☐ Identify where replacement air enters (if single-hose)
- ☐ Measure room pressure with unit on vs. off
- ☐ Note any odors when unit operates vs. when it is off
- ☐ Photograph installation configuration

Appendix E: Building Penetration Inspection Checklist

- ☐ Inspect all wall penetrations for AC hoses, cables, and pipes
- ☐ Check seal condition around all penetrations
- ☐ Identify unsealed or open penetrations
- ☐ Note materials used for sealing (tape, foam, caulk, fire-stop)
- ☐ Check age and condition of sealing materials
- ☐ Inspect electrical outlets on exterior and shared walls for air leakage
- ☐ Check plumbing penetrations at walls and floors
- ☐ Inspect utility chase access panels
- ☐ Note any penetrations that appear recently created or modified

☐ Photograph all penetrations with close-up detail

Appendix F: HVAC Records Request Checklist

☐ System design specifications and as-built drawings

☐ Air balancing reports (most recent)

☐ Filter change schedule and records

☐ Coil and drain pan cleaning records

☐ Duct cleaning records

☐ Outdoor air damper position and operation records

☐ Thermostat and controls settings

☐ Maintenance and repair logs

☐ Refrigerant charge records

☐ Complaints related to HVAC operation

☐ Any air quality testing related to HVAC system

Appendix G: SDS Review Checklist

☐ Obtain SDS for each product used in or near the affected area

☐ Review Section 2 for hazard classification and signal words

☐ Review Section 3 for chemical composition and CAS numbers

☐ Review Section 4 for symptoms of overexposure

☐ Review Section 8 for exposure limits and ventilation requirements

☐ Review Section 9 for vapor pressure and evaporation rate

☐ Review Section 11 for toxicological information

☐ Compare SDS-listed chemicals with reported symptoms

☐ Compare SDS-listed chemicals with air sampling results (if available)

☐ Note any chemicals classified as carcinogens, mutagens, or reproductive toxins

Appendix H: Symptom Tracking Form

Date	Time Start	Time End	Location	Symptoms	Severity (1-10)	Odor? (Y/N)	Odor Description	AC On?	Windows?	Weather	R Ti A L

Appendix I: Pressure Measurement Form

Date	Time	Location 1	Location 2	Pressure Difference (Pa)	Direction of Airflow	HVAC Status	Portable AC Status	Windows	Weather	Notes

Appendix J: Air Sampling Planning Form

Sample ID	Date	Time Start	Time End	Location	Height	Equipment	Target Compounds	Conditions During Sampling	HVAC Status	AC Status

Appendix K: Competing Explanations Matrix

Hypothesis	Supporting Evidence	Evidence Against	Needed Records	Needed Measurements	Confidence (L/M/H)	Next Step

Appendix L: Source Attribution Decision Tree

(See Chapter 41 for the complete decision tree. This appendix provides a condensed reference version.)

1. Building event preceded symptoms? → Identify event, get records
2. New material installed? → Get SDS, test for off-gassing
3. Identifiable odor? → Characterize odor to narrow sources
4. Worsens with heat? → Consider off-gassing, stack effect
5. Worsens with HVAC/AC operation? → Measure pressures, check pathways
6. Improves when leaving? → Building-related source likely
7. Pressure pathways to source areas? → Measure differentials
8. Nearby garage/trash/restaurant/maintenance? → Investigate, correlate timing
9. What measurements confirm or weaken? → Targeted sampling

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Change Log

Differences Between This Handbook and the Original Proof-of-Concept

The original 9-page proof-of-concept document titled "Comprehensive Guide to Indoor Air Quality & VOC Source Attribution in High-Rise Buildings" has been completely rebuilt into this handbook. The following summarizes the changes:

1. **Structure** — Expanded from a flat, single-document format to 13 Parts containing 45 chapters and 13 appendices.

1. **Citations** — The original contained numerous malformed citation artifacts (garbled reference IDs such as numeric strings with special characters). All citations have been replaced with properly formatted references to identified, verifiable sources.

1. **Depth** — The original provided surface-level treatment of most topics. This handbook provides detailed explanation of each concept with practical guidance for investigators.

1. **Investigation methodology** — The original lacked structured investigation procedures. This handbook includes occupant interview templates, record request checklists, the differential attribution matrix, the decision tree, and the weight-of-evidence framework.

1. **Building science** — The original mentioned stack effect and pressure differences briefly. This handbook provides detailed chapters on air movement, stack effect, seasonal effects, pressure zones, and their relationships to contaminant transport.

1. **Portable AC coverage** — The original mentioned single-hose units. This handbook provides separate chapters on single-hose, dual-hose, and window units, including installation defects and the negative-pressure mechanism with DOE regulatory citations.

1. **Alternative explanations** — The original touched on competing sources. This handbook devotes nine chapters to specific alternative explanations and confounders, with guidance on how each should be evaluated.

1. **Documentation standards** — The original lacked practical forms and templates. This handbook includes daily exposure logs, maintenance event logs, evidence preservation guidance, and nine appendix checklists and forms.

1. **Tone** — The original occasionally shifted between educational and advocacy tones. This handbook maintains a consistent investigation-focused, evidence-based, non-accusatory tone throughout.

1. **Formatting** — The original contained broken characters, garbled text, and rendering artifacts. This handbook uses clean, professional formatting throughout.