Collection of Air Samples for LEED, WELL, and Living Building Challenge Indoor Air Quality Assessments and General Indoor Air Quality Investigations

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Introduction

This guide is intended for LEED v4 and v4.1, WELL v2 Pilot and v2, and Living Building Challenge (LBC) 4.0 Indoor Air Quality assessments and for general Indoor Air Quality (IAQ) investigations. It covers air sampling onto commercial DNPH cartridges for subsequent laboratory analysis of formaldehyde and acetaldehyde by High-Performance Liquid Chromatography (HPLC) and air sampling of volatile organic compounds (VOCs) onto sorbent tubes for subsequent laboratory analysis of individual and total VOCs (TVOC) by thermal desorption GC/MS. Establishing an appropriate sampling strategy is the critical first step to achieving the study's objectives. Additionally, field air samples must be collected properly to obtain meaningful results.

This guide includes procedures for the control and monitoring of the sampling process, and also for minimizing sources of contamination. The guide refers to ASTM D5197, Standard Test Method for Determination of Formaldehyde and Other Carbonyl Compounds in Air (Active Sampler Methodology), and U.S. EPA Method TO-17, Determination of Volatile Organic Compounds in Ambient Air Using Active Sampling onto Sorbent Tubes. Sampling and analysis may also be performed by ISO standards, ISO 16000-3, Determination of formaldehyde and other carbonyl compounds in indoor and test chamber air — Active sampling method and ISO 16000-6, Determination of organic compounds (VVOC, VOC, SVOC) in indoor and test chamber air by active sampling on sorbent tubes, thermal desorption and gas chromatography using MS or MS FID.

Sampling Strategy

1. For LEED v4 and v4.1 IAQ assessments, select testing locations that have the least ventilation with potentially the greatest concentration of VOCs and other air contaminants. The number of testing locations selected depends on the size of the building and the number of ventilation systems but must include all occupied spaces. Position the measuring equipment in the breathing zone, ideally between 3 and 6 feet (0.9 – 1.8 m) above the floor. Testing should take place during normal occupancy hours with the HVAC system starting at the normal start time and delivering outdoor air at the minimum rate. An IAQ test report should include two key elements:

    - A narrative detailing procedures and how locations were determined
    - Dates, times, and results of each test

    There are significant changes in VOC testing requirements between LEED v4 and LEED v4.1. With LEED v4.1, the contaminant list has been shortened to 12 VOCs (including formaldehyde) with defined threshold concentration limits that must be met; however, the TVOC limit has been removed. Exemplary performance is offered to projects that test for all of the target VOCs specified in CDPH Standard Method v1.2- 2017, Table 4-1, and that do not exceed the full CREL levels for these compounds. The maximum allowable concentrations of formaldehyde, acetaldehyde, and other VOCs are outlined in USGBC LEED v4.1 Building Design and Construction April 9, 2019, EQ Credit: Indoor Air Quality Assessment Table 2, page 127 (https://new.usgbc.org/leed-v41).

For WELL v2 Pilot, v2 Features A01 and A05, and LBC 4.0, refer to program-specific VOC testing requirements (https://www.well.support/home~ae534dff-4934-4d6c-a21b-741c8b71aa11, and https://living-future.org/lbc/resources/).

2. For other building IAQ investigations, it is recommended that air samples be collected from several indoor locations and either one outdoor location or one indoor location as a reference. If you are investigating a complaint building, consider collecting samples from the areas in the building with the highest complaint levels and at least one sample from an area in the building with a low complaint level to serve as a control. An outdoor sample may be collected to serve as a background reference. The outdoor location should be carefully selected to be representative of the ventilation air entering the building. For example, avoid hanging samplers immediately outside open windows, as air may be flowing out of the building through them.

3. If a measure of sampling and analysis precision is required, collect two samples at one or more locations. Ideally, these duplicate samples should be co-located and collected simultaneously.

4. In addition to an outdoor reference sample, it may be advantageous to include a field blank. Typically, only one blank sample is needed per building. The blank sampler should remain unopened but be handled, transported, and stored identically to the other samplers.

Descriptions of the Samplers

1. We recommend using Sep-Pak® XPoSure™ Aldehyde Samplers (Part No. WAT047205, Waters Corp) as these samplers are designed for air sampling with a very small pressure drop in vacuum sampling mode (20" water). They come with a manufacturer's 'Certificate of Analysis' and have low background levels of formaldehyde, acetaldehyde, and acetone. XPoSure samplers are packed with 350 mg of acid-treated 500-1000 µm chromatographic grade silica, coated with 1.0 mg of purified 2,4-dinitrophenylhydrazine (DNPH). It is recommended that the female Luer end serves as the air inlet end during sampling. Berkeley Analytical (BkA) may be able to supply samplers in small quantities (inquire in advance).

2. The multi-sorbent samplers (Custom order, Markes International) for VOCs consist of 3 ½ inch (90 mm) long by ¼ inch (6.4 mm) passivated stainless-steel tubes packed with two sorbent materials. At the inlet, there is a section of Tenax™ TA (60/80 mesh), ~125 mg; this is backed up with a section of a carbon molecular sieve (60/80 mesh), ~100 mg. There is one engraved ring at the inlet end. The air sample ***must*** enter the sampler from the engraved ring end and then escape through the other end connected to a vacuum pump. ***Reverse installation will result in a blank/false sample***. Each sampler has a unique identification number (alpha-numeric) engraved on the body of the sampler. This number should be used to identify the sampler in logs and on the chain-of-custody (COC) form.

Handling, Storage, and Transport

1. For prolonged storage before using the aldehyde samplers, store the factory-sealed pouches in a refrigerator at 4° C. The samplers have a shelf life of 12 months according to the technical data sheet. Alternatively, for short-term storage, the sealed pouches may be kept at room temperature (20-25° C). After sample collection, tightly reseal the sampler with the Luer cap and plug. Place the sampler in the re-sealable foil-lined pouch and label the outside of the pouch. If possible, utilize a refrigerator for storing collected samples. Properly resealed samplers can be stored before analysis for up to two weeks at room temperature, or longer if refrigerated. However, it's advisable to return the samplers to BkA for analysis as soon as possible after collecting the samples.

2. When storing, transporting, and shipping the Multi-sorbent VOC samplers, make sure that they are adequately separated from aldehyde samplers as the aldehyde samplers can be a source of

acetonitrile contamination. As a minimum precaution, it's advisable to keep capped multi-sorbent samplers and aldehyde samplers in separate, sealed polyethylene bags.

3. Avoid subjecting Multi-sorbent VOC samplers to elevated temperatures such as might occur in closed vehicles parked in the sun. It is recommended to transport and ship the samplers in a cooler using an ice pack to maintain cool temperatures. Return the samplers to BkA for analysis promptly after collecting the samples.

4. While multi-sorbent samplers typically can be handled with ungloved hands, it is important to handle them with care to avoid contamination. For example, if your hands are dirty, oily, or treated with hand lotion, it's advisable to wash them and/or use gloves. Clean white cotton or nylon gloves are recommended. When handling the samplers, hold them by the middle and try to minimize touching the ends near the openings. Do ***not*** attach labels directly to the samplers as these labels are a source of contamination. Also, do ***not*** write on the acrylic tubes with marking pens as these tubes are reused. If it is necessary to place labels on the outside of the acrylic tubes, please be sure that these are easy to remove and do not leave an adhesive residue.

5. When submitting samplers to BkA for analysis, clearly indicate the desired services. An IAQ services Chain-of-Custody Record for sample submission can be obtained from the BkA website (https://berkeleyanalytical.com/forms).

Sampling Apparatus

1. If possible, draw air directly into the VOC or aldehyde sampler to avoid connecting tubing to the inlet of the sampler. Only clean Teflon, stainless steel, and copper tubing are acceptable for use upstream of the sampler. Before usage, ensure that any inlet tubing is cleaned by flushing it with methanol and thoroughly drying it.

2. All samplers should be connected upstream of the sample pump. In certain cases, the sampler can be directly connected to the pump's inlet. However, it's often preferable to position the sampler away from the pump and connect them using tubing. For aldehyde samplers, Luer fittings with hose barbs suitable for small-diameter flexible tubing can be obtained from Cole-Parmer Instrument Co., Chicago, IL.

3. Most field investigators utilize battery-operated personal sampling pumps for sample collection. The recommended aldehyde sampler features a low pressure drop and is compatible with this type of pump. These pumps and sampling pump accessories can be purchased or rented from industrial hygiene supply houses. Refer to Figures 1 and 2 for a typical air sampling assembly, which includes a personal sampling pump (SKC AirChek Touch Pump) with both single-tube and tri-tube holders. This kit can be rented through SKC, Inc. (https://www.skcinc.com/categories/rentals).

Ozone Scrubber for Aldehyde Sampling

1. Ozone reacts with the carbonyl-hydrazone derivative and can result in a significant negative interference for formaldehyde and other carbonyls when using the aldehyde sampler. This is a particularly important consideration when sampling outdoors in locations with high ozone concentrations.

2. A scrubber can be used upstream of the aldehyde sampler to remove ozone from the sample-gas stream. The Sep-Pak Ozone Scrubbers (Part No. WAT054420, Waters Corp.) are often used for this purpose. Each ozone scrubber cartridge contains 1.4 grams of granular potassium iodide. As air containing ozone is drawn through this packed bed, the iodide is oxidized to iodine, effectively consuming the ozone.

Sample Volume and Airflow Rate

1. Aldehyde sampling volume and airflow rate

   - The minimum sample volume for aldehyde sampling is determined by the sensitivity of the analytical system, the blank level, and the concentration of the target compound(s). Blank values for aldehyde samplers are <50 ng of formaldehyde per sampler. A sample volume of 60 L produces a lower limit of quantitation of about 1 ppb for formaldehyde assuming a blank value of <20 ng and using the criterion that the mass collected should be at least four or five times the mass of the blank.

   - Approximately 75 µg of formaldehyde will exhaust one-half of the DNPH on the sampler, which is a safe upper limit for DNPH depletion. This is equivalent to a formaldehyde concentration of about 1.0 ppm for a 60 L sample. However, the maximum safe sample volume is determined by the combined concentration of all of the carbonyl compounds in the sampled air. Therefore, if there are significant concentrations of other carbonyl compounds such as acetone present (ppm levels), it will be necessary to use a smaller sample volume to prevent DNPH depletion and sample breakthrough (typically not an issue in building investigations).

   - Every new aldehyde sampler contains residual acetonitrile which is used as the solvent in the coating of the silica with DNPH. During sampling, this acetonitrile is volatilized. If air samples are also being collected for VOC analysis, the acetonitrile emitted into the air may contaminate the VOC samples. BkA excludes the acetonitrile peak in the analysis of field-collected VOC samples. To mitigate this contamination, a charcoal tube may be attached to the pump's outlet to trap the acetonitrile.

   - Airflow rates for aldehyde sampling typically range from 0.125 to 1.5 L/min. The lower airflow rates are suitable for collecting integrated samples over longer time intervals. Collection efficiencies are greater than 95 percent within this airflow rate range.

   - For LEED v4 and v4.1 indoor air quality assessment, a 60-L air sample collected at 0.5 L/min for 120 min (2 h) is recommended (Table 1).

2. VOC sampling volume and airflow rate

   - The correct sample volume for VOC sampling depends on the concentrations of individual VOCs in the space being sampled. The analytical system has exceptional sensitivity, but limited range. Therefore, it is important to avoid collecting a sample volume that is too large and that may result in overloading of the GC/MS system and in the loss of data for the sample. For most investigations conducted in office buildings or homes, the optimal sample volume is 5 – 6 L, or less. The same volume can be used for outdoor samples. This volume produces lower limits of detection for many individual VOCs that are 1 to 2 µg/m^3, or <0.5 ppb for many compounds. If there is reason to suspect that the TVOC concentration exceeds several mg/m^3, then a correspondingly smaller sample volume should be used. Examples are sampling locations with recent use of solvent-containing products or with strong odors due to VOCs. In situations in which there is uncertainty about the concentration, at least two samples of different volumes should be collected. For example, volumes of 1 and 5 L typically would cover the situation in which the concentration of TVOC could range up to about 10 mg/m^3. Please consult with BkA if you have questions regarding the selection of a sample volume.

   - The VOC sampling airflow rate can range from a low of about 10 cm^3/min up to about 200 cm^3/min. If it is desired to measure the integrated concentration of VOCs over an eight-hour work day, a sample airflow rate of 10 cm^3/min results in a 4.8 L sample volume. The maximum

airflow rate is limited by the pressure drop across the sampler and the capacity of the sampling pump.

- For LEED v4 and v4.1 indoor air quality assessment, a 6 L air sample collected at 50 cm^3/min for 120 min (2 h) is recommended (Table 1).

Airflow Rate Measurement and Leak Checking

1. The sampling system should be checked for air leaks before use, preferably with the sampler in place. With some types of pumps, this can be accomplished by capping the inlet of the sampler and checking that the airflow rate at the outlet of the pump drops to zero.
2. It is imperative to know the airflow rate of air through the sampler and the sampling interval elapsed time to calculate the sample volume. For the highest accuracy and precision, the airflow rate through the sampler should be maintained at a constant rate and monitored continuously, or at least frequently, during sampling. These objectives are best accomplished using electronic mass flow controllers in combination with a vacuum pump or a calibrated personal sampling pump. Alternatively, a pump with integrated flow control or a separate needle valve may be used to maintain a constant airflow rate.
3. The airflow rate through each sampler should be measured during sampling. For airflow regulation schemes other than those using individual electronic mass-flow controllers, it is necessary to directly measure the airflow rate. At a minimum, this measurement should be made both near the beginning and the end of the sampling interval. If possible, the measurement should be made downstream of the sampler, preferably at the outlet of the pump. A bubble flow meter, positive displacement device, or a calibrated rotameter may be used for downstream measurements. If the measurement must be made upstream of the sampler, briefly attach a correlated flowmeter with a suitable range to the inlet of the sampler. ***Do not attach a bubble flow meter upstream of the sampler as this will contaminate the sampler.*** Additionally, record the air temperature and the atmospheric pressure so that the airflow rate can be converted to standard indoor conditions (i.e., 25 °C, 1 atm). 150-mm correlated flowmeters without valves can be procured from VWR (https://us.vwr.com/store/) and other vendors. These flowmeters can be calibrated in-house against a reference flowmeter.

Sample Collection for IAQ Assessments

1. A typical indoor air sampling assembly for LEED, WELL, and LBC indoor air quality assessments is shown in Figure 3. The assembly includes:
   - Tripod used to position air samplers in the breathing zone, 3 to 6 feet above the floor
   - Battery-powered sampling pump (500 to 5000 mL/min)
   - Constant pressure controller (CPC) 20” water, if available
   - Tygon Tubing with Luer fittings as required
   - Adjustable low flow Tri-tube manifold (5 to 500 mL/min) which holds two multi-sorbent tubes and one aldehyde sampler. If using a single low-flow tube holder, two tripods with two pumps are recommended to sample VOCs and aldehydes simultaneously.

2. Recommended procedures:

- If the Tri-tube manifold is used, set the sampling pump to approximately 800 cm^3/min to accommodate the sampling flow of two sorbent tubes at ~50 cm^3/min each and one aldehyde sampling flow at ~500 cm^3/min. If the single low-flow tube holder is used, set the sampling pump to the desired airflow rate.
- The sampling report should document the sampling date, locations, start and end times of the sampling intervals, airflow rates near the beginning and end of sampling intervals, average sampling airflow rates for the sampling intervals, and temperatures and atmospheric pressure at the sampling location.
- The samplers need to be warmed to room temperature before use. Retain all of the sampler caps, plugs, and tubes as they are needed to reseal the samplers.
- Check the sampling airflow rates near the beginning and end of the sampling intervals using appropriately sized rotameters.
- After sampling, tightly reseal each aldehyde sampler with the Luer cap and plug, place the sampler in the reusable foil-lined pouch, and label the pouch with the sample identification. Tightly reseal each VOC sampler inside its tube container. Do not overtighten the caps as this will damage the seals. Record the sampling information on a chain-of-custody form, including the number printed on the tube. ***Do not write on the body of the sampler or attach labels to the sampler.***
- A photographic record of the sampling set up at each sampling location is recommended.
- See attachment – IAQ Air Sampling Assembly and Shipping Instructions

Other Sampling Precautions

1. Avoid exposing samplers used outdoors to direct sunlight. Use aluminum foil to create a basic sun shield if necessary.
2. Whenever feasible, avoid collecting samples in rainy or high-humidity conditions. The VOC sampler will collect excess water vapor, potentially leading to sample loss during GC/MS analysis. If sampling in such conditions is unavoidable, be sure to note the humidity conditions on the sample chain-of-custody form. Excess humidity can be removed in the laboratory by purging with dry helium before analysis.

Table 1. Suggested sampling airflow rates and volumes

Project Type	Aldehyde Sampling			VOC Sampling		
	Airflow Rate, cm^3/min	Duration, Min	Volume, L	Airflow Rate, cm^3/min	Duration, Min	Volume, L
IAQ Investigation (8-h day)	125	480	60	10	480	4.8
IAQ Assessment (2 h)	500	120	60	50	120	6
IAQ Assessment (1 h)	1000	60	60	100	60	6

*For LEED v4 and v4.1 Indoor Air Quality assessment, the 4-h minimum sampling time required in LEED 2009 is removed.

Figure 1. Air Sampling Assembly Using SKC AirChek Touch Pump, and Tri-tube manifold

Figure 2. Air Sampling Assembly of SKC AirChek Touch Pump, Constant Pressure Controler, and Single Tube Holder

Figure 3. A sampling tripod was set up in an open-plan office.

Attachment: IAQ Air Sampling Assembly and Shipping Instructions