

GUIDANCE DOCUMENT

Measuring Duct Leakage, Air Flow and Air Exchange Rates in Commercial Building

ASHRAE Standard 215 Tracer Method (Intelligent Leak Detection)

Mark Modera
Curtis Harrington
Frederick Meyers
Timothy Levering
UC Davis Western Cooling Efficiency Center

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14. ABSTRACT These procedures are designed to measure duct leakage both upstream and downstream of terminal boxes (e.g., variable air volume [VAV] boxes) using a tracer gas to measure duct-section airflow, and powered flow capture hoods to measure the flows entering the space through the diffusers downstream of that duct section. In addition, these procedures provide a measurement of the freshair ventilation rate of the building space being tested, based upon the decay of the tracer gas concentration at the end of the tracer injection period. The tracer gas apparatus and software can also be used to measure overall air handler flows, zone flows, or exhaust-system flows. This is a non-destructive air flow test method, and there are no known health, safety or environmental concerns with the use of CO2 as a tracer gas. This duct leakage measurement procedure is an implementation of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 215, Method of Test to Determine Leakage of Operating Heating, Ventilation, and Air Conditioning (HVAC) Air Distribution Systems (American National Standards Institute/ASHRAE Standard 215-2018). The particular implementation being used can be found in Appendix A (Section A3) of the Standard. This procedure is intended to measure duct leakage to within +/-5 percentage points of the true fractional leakage value with 95% confidence.					
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ACRONYMS AND ABBREVIATIONS

AHU	air handling units
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BAS	building automation system
CAV	constant volume systems
CFM	cubic feet per minute
ESCO	energy service company
EF	exhaust fans
HVAC	heating, ventilation, and air conditioning
ILD	Intelligent Leak Detection
OSHA	Occupational Safety and Health Administration
ppm	parts per million
RTU	rooftop units
VFD	variable frequency drive
VAV	variable air volume

1.0 OVERVIEW

These procedures are designed to measure duct leakage both upstream and downstream of terminal boxes (e.g., variable air volume [VAV] boxes) using a tracer gas to measure duct-section airflow, and powered flow capture hoods to measure the flows entering the space through the diffusers downstream of that duct section. In addition, these procedures provide a measurement of the fresh-air ventilation rate of the building space being tested, based upon the decay of the tracer gas concentration at the end of the tracer injection period. The tracer gas apparatus and software can also be used to measure overall air handler flows, zone flows, or exhaust-system flows. This is a non-destructive air flow test method, and there are no known safety concerns with the use of CO₂ as a tracer gas.

This duct leakage measurement procedure is an implementation of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 215, Method of Test to Determine Leakage of Operating Heating, Ventilation, and Air Conditioning (HVAC) Air Distribution Systems (American National Standards Institute/ASHRAE Standard 215-2018). The particular implementation being used can be found in Appendix A (Section A3) of the Standard. This procedure is intended to measure duct leakage to within ± 5 percentage points of the true fractional leakage value with 95% confidence.

1.1 PRE-TEST LOGISTICS

1. Obtain current as-built mechanical plans (electronic if possible) from the client that include the mechanical schedule and duct layout. Ensure that the drawings are current, and no changes have been made since they were drawn.
2. When no electronic plans are provided, the auditor will request access to physical copies of as-built mechanical plans at the facility.
 - a. The auditor will utilize a cell phone to photograph relevant mechanical plans (Unit schedule, duct layout, etc.).
 - b. If no plans are available on-site the auditor will map the duct construction using visual inspection above ceiling tiles.
 - i. The auditor should plan for longer time on-site when no plans are provided.
3. Review mechanical plans with the team responsible for estimating the cost associated with potential sealing.
 - a. Identify all air handling units to be included in the scope of work (e.g., air handling units [AHU] 1, 3, 6, 9).
 - b. Identify possible locations to perform Intelligent Leak Detection (ILD) from the mechanical plans.
 - i. Refer to Pre-Test Logistics in Detailed Procedures Appendix for guidance.
4. Assure that the sales team engages all key personnel associated with the test site, including the energy service company (ESCO) if one is involved, and the facility manager/facility personnel to assure buy-in and education relative to the audit process.
5. Set up a meeting with the facility manager, customer (e.g., ESCO) and the facility personnel who will be on-site during the audit.

- a. It may be difficult to arrange a meeting with all key personnel, so multiple meetings may be required.
- 6. Agenda for the facility-manager meeting:
 - a. Obtain written permission to use ILD, and to assure access to all diffusers of interest at the time of testing.
 - b. Request access to sections of the building identified from the mechanical plans for prospective ILD testing (3-6 ILD test locations, noting that locations may change).
 - c. Request access to mechanical rooms/roof access for packaged rooftop units (RTU), if applicable (follow Occupational Safety and Health Administration (OSHA) Guidelines for fall protection).
 - d. Request permission to use a tracer gas as the main method for testing leakage within the facility; stress the importance of accurate estimates of leakage for energy savings models (be prepared to address any safety/logistics concerns).
 - e. Request permission to use a ladder to inspect the ductwork above the ceiling tiles (determine whether the client can provide one for the audit crew, or purchase when necessary) (follow OSHA Guidelines for fall protection).
 - f. Request permission to control the flow through the VAV boxes in all possible test sections, or the fan for constant volume systems (CAV) (this could include control of the building automation system (BAS), and/or manual control of VAV dampers).
 - i. For CAV systems, assure that the customer locks the fan speed.
 - ii. For VAV systems, assure that all the VAV boxes in the specified test areas are locked to full-flow position for the duration of the test.
 - iii. In both cases, explain the time period required, and get client approval for that time period.
 - g. If BAS controls are non-operational or non-existent:
 - i. For CAV systems, assure that system schedule does not change during the test period.
 - ii. For VAV systems, manually lock all VAV boxes in the test section to full-flow damper position for the duration of the test (BEFORE ADJUSTING DAMPER TO FULL FLOW, MARK THE RELATIONSHIP BETWEEN THE SHAFT AND COLLAR).
 - iii. In both cases, explain the time period required, and get client approval for that time period.
 - h. Once the details are confirmed, discuss dates for site visit and execution plan in accordance with the customer's schedule.
 - i. Obtain contact information for key personnel on site and share your information with them.

1.2 ON-SITE TEST PROCEDURE

- 1. Visually Inspect the ductwork for indications of leakage or tightness (before ILD testing).
- 2. Inspect AHUs in mechanical room or packaged RTU (i.e., all units within the scope of work).
 - a. Obtain nameplate data, AHU #, variable frequency drive (VFD) speed, (document with photos).
 - b. Check discharge/canvas connections for leakage. Are there dust trails at the connections/

- discharge of the supply ductwork (document with photos)?
- c. Are there disconnects, holes in the duct, mechanical issues that need to be addressed (document with photos)?
 - d. Visual inspection is performed to corroborate ILD results, and to provide on-site intel to the implementation crew prior to them arriving on-site.
3. Identify the locations within the facility for ILD testing.
 - a. Ensure that the mechanical plans match the actual layout in the building.
 - b. Trace supply ductwork and identify all supply diffusers.
 - c. Locate your injection point and assure that it is workable (i.e., enough length for downstream mixing, and preferably no 90° bends just upstream of the injection point).
 - d. Start ILD mobile application.
 4. Use flow hood to measure all flows and record the cubic feet per minute (CFM) measurements for chosen section.
 - a. If flow is low (below 100 CFM /diffuser for Retrotec MK2 hood) or high (>325 CFM for Retrotec MK2 hood), consider pivoting to other identified duct locations. If not possible to choose another location, be sure to use flow corrections for high and low flows with MK2 hood).
 5. Perform tracer gas measurement of incoming air flow.
 - a. Place CO₂ sensors outside and send calibration commands.
 - b. Complete necessary prep work at injection point.
 - i. Refer to Pre-Test Logistics in Detailed Procedures Appendix.
 - c. Place calibrated CO₂ sensors into diffuser airflow.
 - i. Wait two minutes before starting ILD CO₂ injection.
 - ii. Refer to Pre-Test Logistics in Detailed Procedures Appendix for choice of locations.
 - d. Start injection of CO₂.
 - i. Use mobile application to record pre-injection CO₂, injection CO₂, and post injection CO₂ concentrations.
 - ii. If CO₂ concentrations are not similar (e.g., within 100 parts per million [ppm] of each other), adjust injector and repeat process.
 - e. Collect data from ILD mobile application.
 6. Repeat ILD process for all identified ILD locations.
 7. Compile leakage results and update estimates in energy savings models.

2.0 DETAILED PROCEDURES AND APPENDICES

2.1 PRE-TEST LOGISTICS

1. Obtain as-built mechanical plans (electronic if possible) from the client that include the mechanical schedule and duct layout. Ensure that the drawings are current, and that no changes have been made. Identify high-flow and high-horsepower AHUs within the facility. Figure 2.1 shows some example fan schedules that can be used to choose which systems are the best candidates for testing and sealing.

FAN SCHEDULE												
MARK	TYPE	MANUFACTURER MODEL NO.	FAN				DRIVE	MOTOR			OPER. WT. LBS.	REMARKS
			CFM	SP (in WG)	RPM	LWA		WATTS	RPM	VOLTS/PH		
CEP 1	CEILING EXHAUST	"GREENHECK" SP-A1050	920	0.25	1095	-	DIRECT	420W	1095	115/1	65	① ② ③
CEP 2	CEILING EXHAUST	"GREENHECK" SP-A780	680	0.25	1600	-	DIRECT	348W	1600	115/1	35	① ② ③
CEP 3	CEILING EXHAUST	"GREENHECK" SP-A200	190	0.25	900	-	DIRECT	48W	900	115/1	30	① ② ③
CEP 4	CEILING EXHAUST	"GREENHECK" SP-A700	400	0.5	1100	-	DIRECT	350W	1100	115/1	35	② ③ ④
SCHEDULE NOTES: 1. CEILING EXHAUST FAN DETAILS ON 1/M5.02.												
REMARKS ① PROVIDE WITH BACKDRAFT DAMPER AND ROOF CAP. ② PROVIDE WITH FACTORY INSTALLED SPEED CONTROLLER. ③ INTERLOCK WITH AHU-1. ④ PROVIDE W/ BACKDRAFT DAMPER.												

AIR HANDLING UNIT SCHEDULE																				
MARK	LOC. AT ROOM	TYPE	FAN							COIL			FILTER		MOTOR (BY M.C.)				REMARKS	ELECT. REF.
			CFM	BHP	RPM	SP* ESP	H ² O TSP	TYPE	MIN DIA.	1ST IN UNIT	2ND IN UNIT	MIN SQ. FT.	TYPE	HP	RPM	ELEC VOLT	STRT BY			
AHU-B1	B224	HDT	12000	6.9	993	1.5	2.3	PLG	32P	CC-B1	--	38.9	2" PM	10	1800	480/3	①		MSBB:11	
AHU-B2	B102	HDT	8500	5.9	1117	1.9	2.8	PLG	29P	HC-B2	CC-B2	31.1	2" PM	7.5	1800	480/3	①	HR-B2	MSBB:12	
AHU-B3	B102	VDI	8500	3.1	580	0.5	1.1	FC	20	HR-B3	--	20	2" PM	5.0	1800	480/3	①	HR-B3	MSBB:13	
① SEE SPECIFICATIONS AND ELECTRICAL PLANS FOR STARTER REQUIREMENTS.																				

Figure 2-1. Example Fan Schedules

The terminal-box schedules (see Figure 2.2) should be used to choose the best duct sections for ILD testing. The schedules provide total flow rates through specific boxes. These flowrates can be used to estimate the CO₂ dilution that would occur when those boxes are included in the test section.

SINGLE DUCT TERMINAL UNIT SCHEDULE								
MARK	INLET SIZE	MAX. COOLING CFM	MIN. COOLING CFM	HEATING CFM	HW FLOW GPM	MBH	TCV	AREA/ROOM SERVED
VAV 1-01	14	1660	450	830	2.0	32	2-WAY	RESTROOMS, & LOBBY
VAV 1-02	12	1200	325	600	1.5	23	2-WAY	CLASSROOM 21
VAV 1-03	12	1200	325	600	1.5	23	3-WAY	CLASSROOM 22
VAV 1-04	16	2200	580	1100	2.5	46	3-WAY	LOBBY
VAV 1-05	12	1260	325	630	1.5	22	2-WAY	LECTURE 13, FRONT
VAV 1-06	16	2520	580	1260	2.5	43	2-WAY	LECTURE 13, REAR
VAV 1-07	14	2130	450	1065	2.0	37	2-WAY	LECTURE 12, REAR
VAV 1-08	10	1065	230	535	1.0	18	2-WAY	LECTURE 12, FRONT
VAV 1-09	14	1620	450	810	2.0	31	2-WAY	LECTURE 11, FRONT
VAV 1-10	14	2160	450	1080	2.5	41	2-WAY	LECTURE 11, REAR
VAV 1-11	10	1080	230	540	1.5	20	3-WAY	LECTURE 11, REAR
VAV 1-12	10	755	230	380	1.0	15	2-WAY	PREP ROOM, & CORRIDOR
SCHEDULE NOTES:						REMARKS		
1. ALL HEATING COILS SHALL BE 2 ROW UNLESS NOTED OTHERWISE 2. HEATING LOAD CALCULATED AT 55°F EAT & 50% COOLING CFM 3. ALL PIPING RUN OUTS TO COIL ARE 3/4" UNLESS NOTED OTHERWISE. 4. PROVIDE BARE BOX WITH CROSSFLOW SENSOR ONLY. 5. FOR VAV MOUNTING DETAILS SEE 2/M5.01. 6. 2/3-WAY VALVE DETAILS ON 6/M5.02 AND 7/M5.02.								

Figure 2-2. Example Terminal Box Schedules

The terminal box schedule (Figure 2.2) can be used to: a) determine which boxes are fan-powered or induction boxes, both of which purposefully draw in ceiling plenum air, which makes those duct sections poor candidates for ILD testing.

The plans or a diffuser schedule can be used to: b) determine the expected flows for each of the diffusers to be tested, noting that flows between 100 and 250 CFM are the best candidates for ILD testing (assuming that the Retrotec MK-2 powered flow hood is being used).

Once the AHUs, RTU and/or exhaust fans (EF) to be tested have been identified, trace the ductwork associated with each AHU/RTU/EF using software for editing drawings (or manually if need be). Check air flowrates, and diffuser flows for each section to be tested (see Figure 2.3).

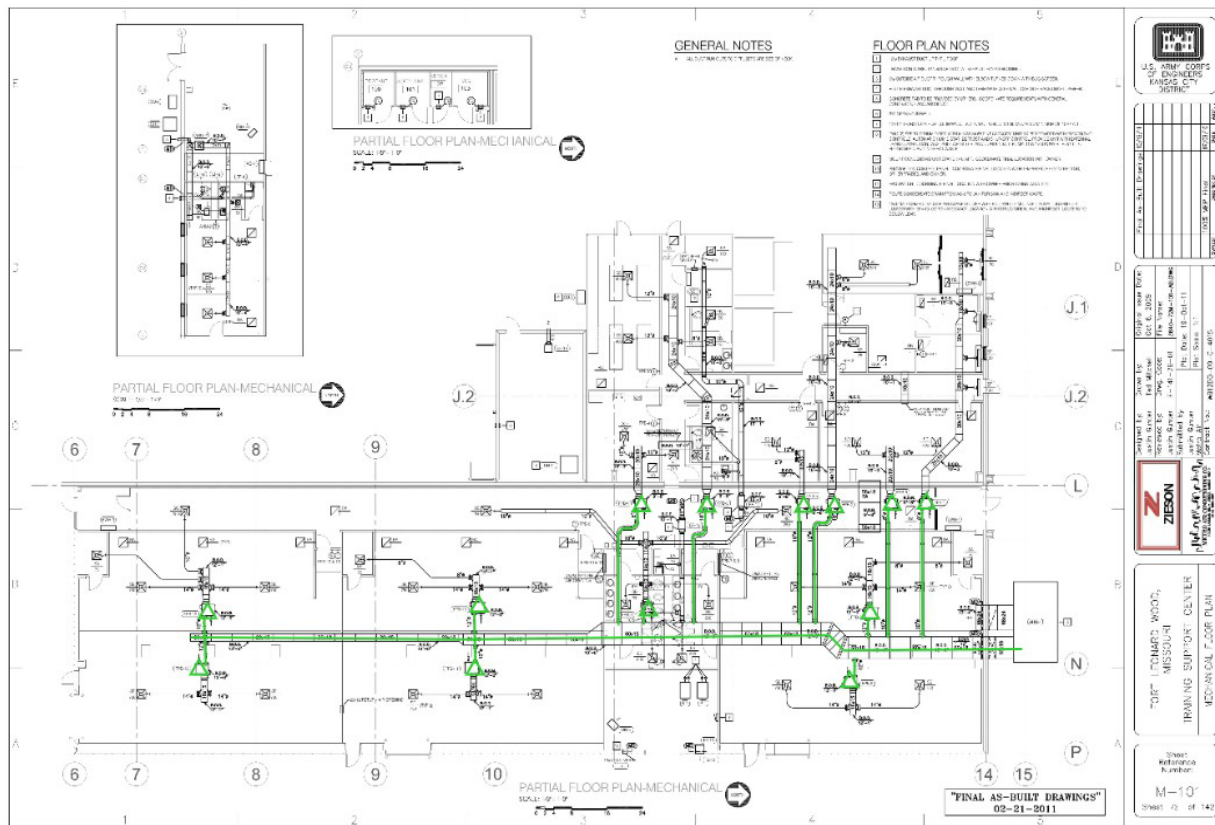


Figure 2-3. Example Mechanical Drawing for VAV system with Test Section Highlighted

- When looking at the plans, be sure to identify duct sections that are not exposed to the conditioned space. Examples of ductwork often exposed to the conditioned space include gymnasiums, auditoriums, manufacturing warehouses, pools, etc. It may be challenging to tell from the plans. When on-site, confirm any questionable locations that may have exposed ductwork (see Figure 2.4).

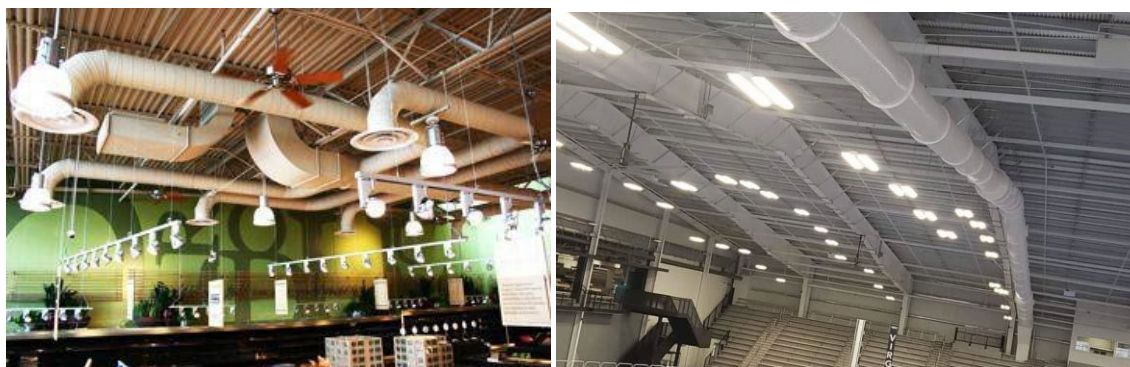


Figure 2-4. Examples of Exposed Ductwork That Is Not the Best Candidate for Sealing

3. How to Read Mechanical Plans: Basics:
 - a. Shown in the Figure 2.5 is an example of a supply diffuser and a return diffuser.

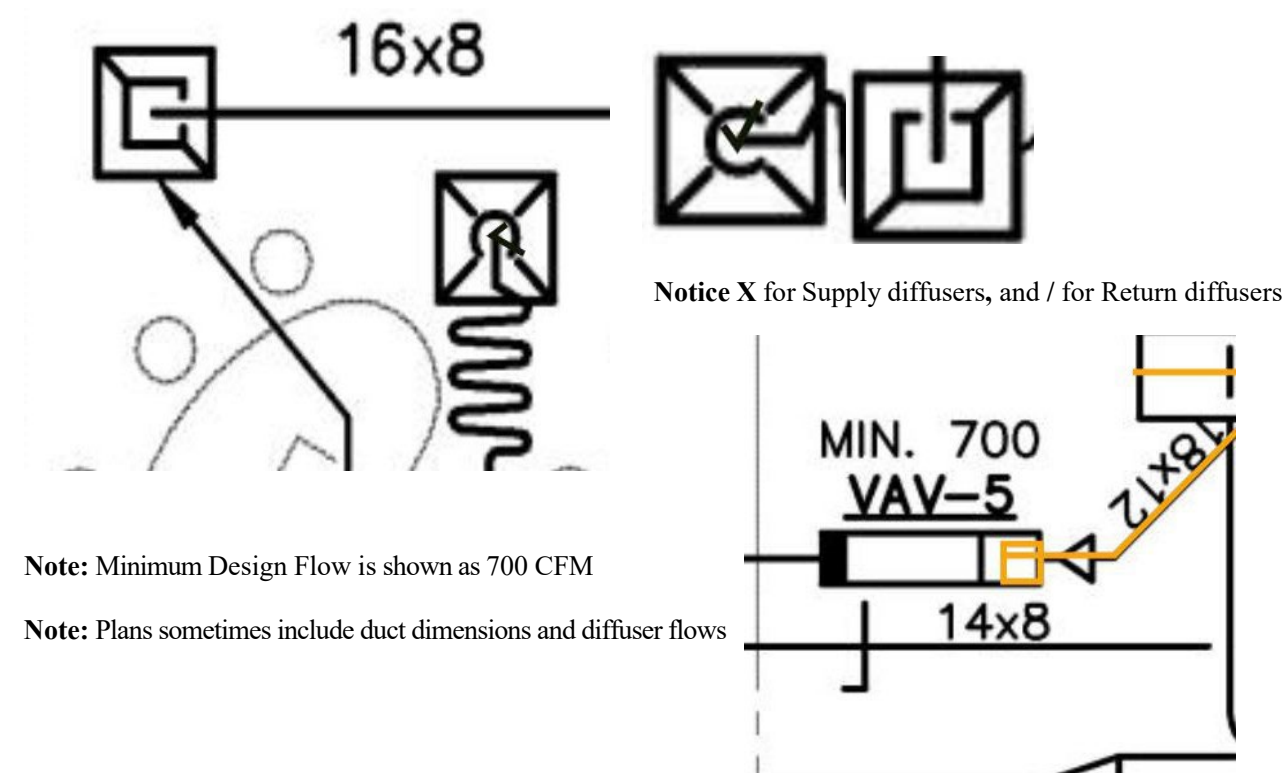


Figure 2-5. Example Drawing Showing Supply and Return Diffusers

4. Identify if the system is a CAV air distribution system or a VAV air distribution system.

- a. Example: The flow through a CAV air distribution system is controlled only by the fan at the unit, which generally has a constant speed/flow (see Figure 2.6). The only other control on a CAV is generally a zone control of the reheat for the air being blown into that zone.

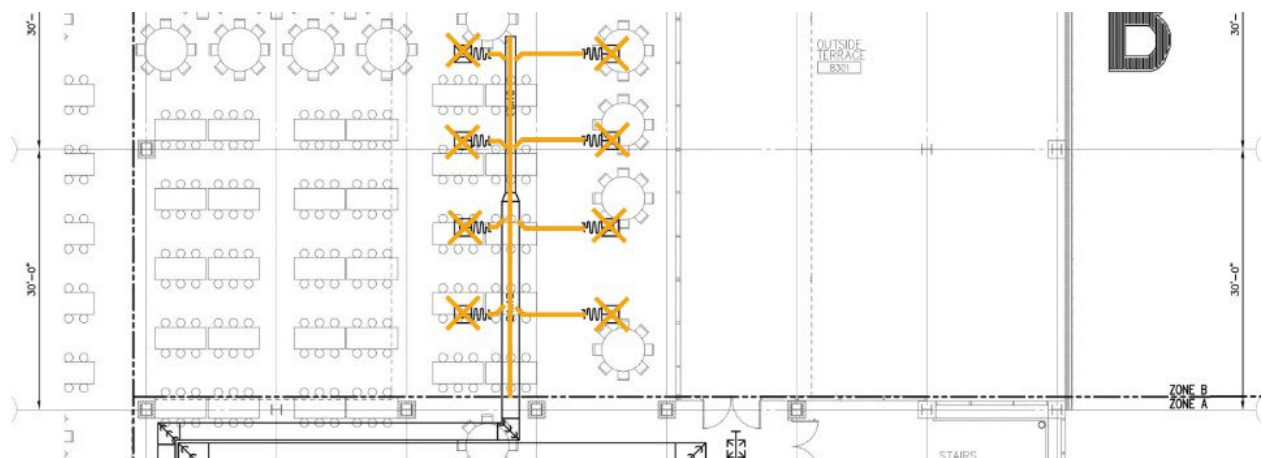


Figure 2-6. Example CAV System Duct Layout

- b. Example: The flow through a VAV system (see Figure 2.7) is controlled both at the fan and at the VAV dampers. The fan is controlled to maintain a constant pressure at a particular location in the duct system (typically 2/3 of the way down the main supply trunk). Thermostats within the room or space control how much air goes through the VAV box serving a particular conditioned space. The damper opens and closes to control the air flow into the specific room. Those same thermostats are used to turn on reheat within the VAV boxes if the room gets too cold at the minimum VAV damper position (which is normally set based upon ventilation requirements).

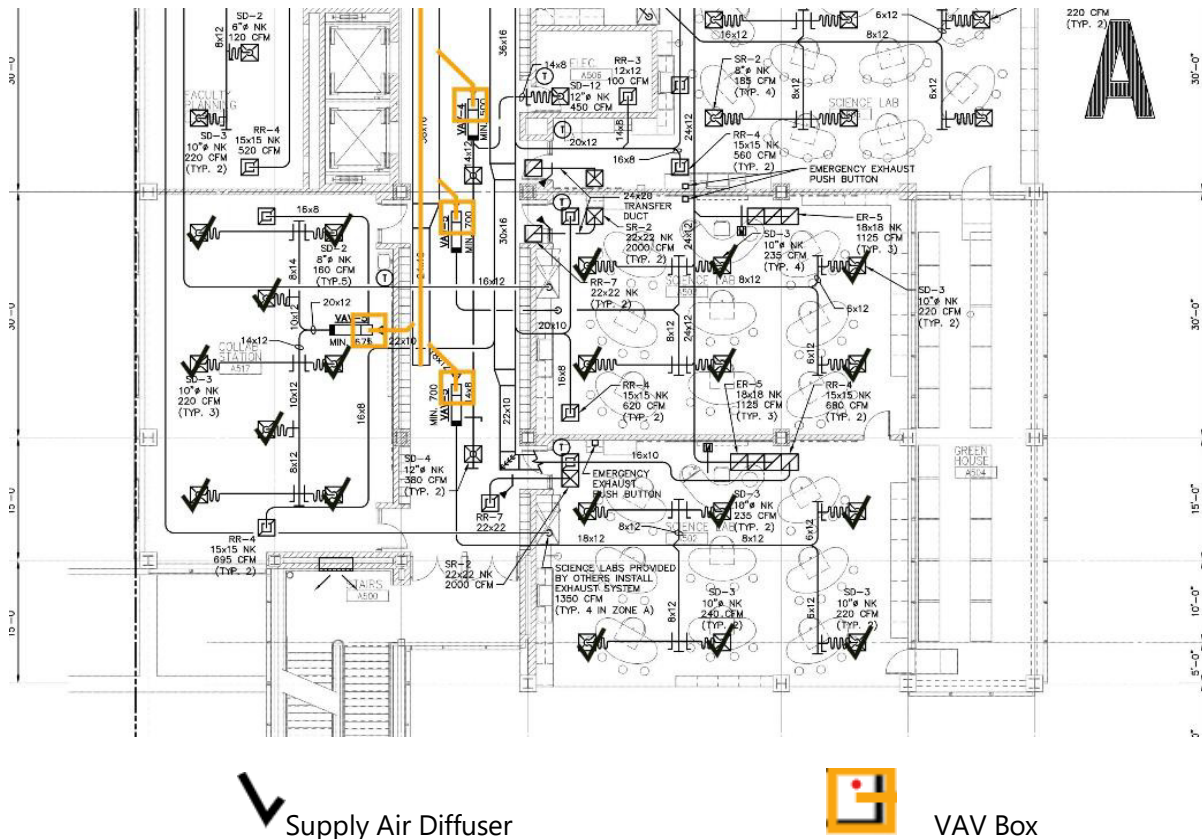


Figure 2-7. Identification of Diffusers, VAV Boxes and Trunk Duct

Note: For the ductwork in Figure 2.7 there are four VAV boxes coming off the main supply trunk line. Each VAV box has multiple supply air diffusers.

5. How to identify locations to perform the ILD process from mechanical plans:
 - a. Identify 3-6 ILD locations from the mechanical drawings (when applicable).
 - b. From the plans, trace the supply ductwork to the end of the line (see Figure 2.8).

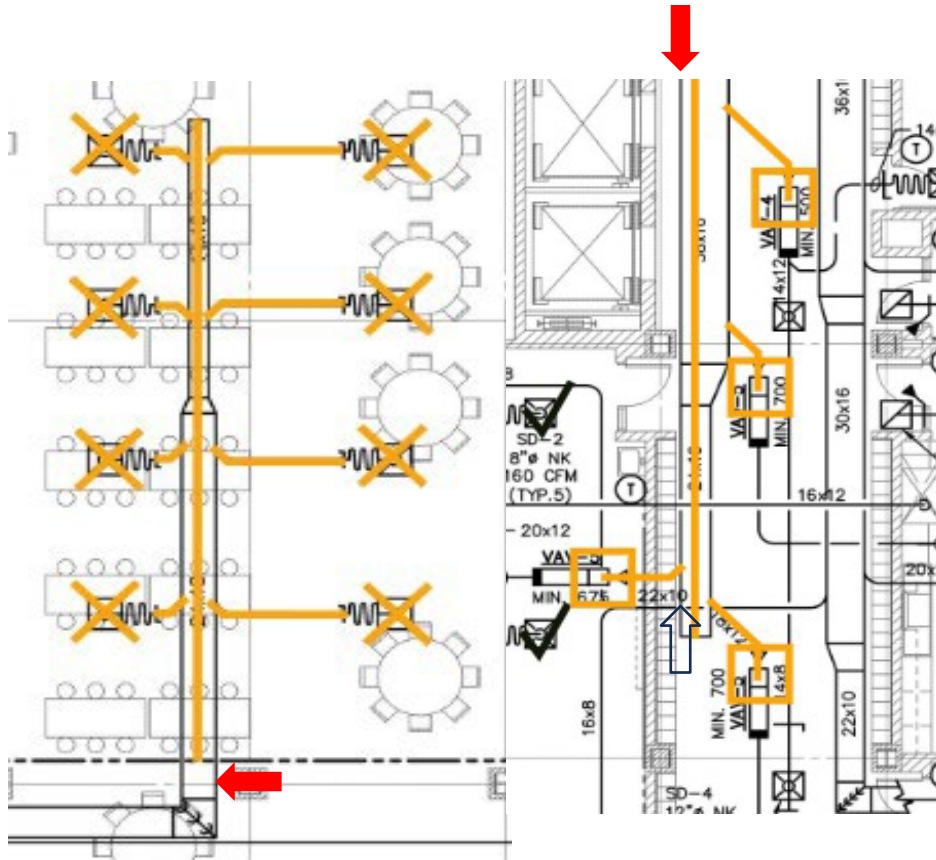


Figure 2-8. Trace of Ductwork to Be Tested.

(Note that neither of these injection points are optimal)

- c. Trace the supply ductwork backwards from the end of the line. Count all the diffusers and VAV boxes associated with that supply line. These are the diffusers you will be measuring with the fan-powered flow hood.
- d. When identifying the stretches of ductwork to perform ILD, make sure you have adequate distance from your injection point to where your first VAV box or diffuser is located.
- e. Choose your injection point to maximize mixing (note that locations in Figure 2.8 are not optimal, but that Figure 2.9 shows a better location).
 - i. Mixing is maximized by long duct sections before branches.
 - ii. Try to allow 10 feet from injection to your first branch duct (to VAV or diffuser).
 - iii. The purpose of having your injection point 10 feet before a branch is to ensure that the injected CO₂ disperses evenly throughout the air stream before any air is ejected from the test section.

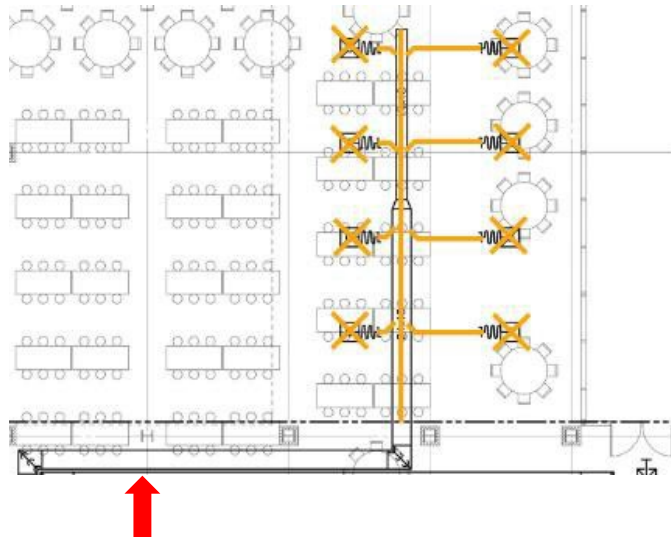


Figure 2-9. CO₂ Injection Point

(note: over 10 ft from first VAV/Diffuser, location relative to previous 90° bend)

Note: Some mechanical plans provide the design CFM from each diffuser (see Figure 2.10). These can be used to estimate approximate CFM from the diffusers along the section of ductwork you have identified for ILD testing.

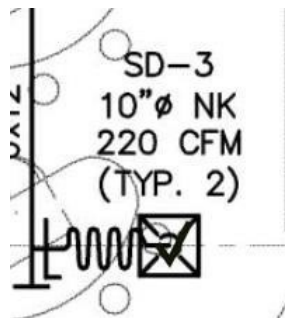


Figure 2-10. Mechanical Plan Showing Design CFM at Diffuser

- f. When identifying an ILD section from mechanical plans, look for sections of ductwork that have approximately 5-15 diffusers with approximately 500-4000 CFM of total flow.
- g. The purpose of ILD is to sample the HVAC supply ductwork to obtain a reasonable estimate of the leakage of the rest of the supply ductwork within the facility based on the ILD results for the tested sections. Thus, the test section should be representative of the rest of the building or AHU system.

Once you have Identified the locations for ILD testing, create a document to present the customer. The document should include:

- Locations within the facility for testing (floor, room number).
- AHU associated with the ILD test sections.
- Specific VAV boxes (when applicable).
- Screen shot of the mechanical plans for each potential test site.

After sharing the document, engage with the customer/facility manager/and facility personnel via a meeting. In the meeting discuss the following:

- a. Request access to sections of the building identified from the mechanical plans for prospective ILD testing. (3-6 ILD test locations/ locations may change).
- b. Present the document on AHUs, VAV box locations, diffusers, and mechanical-plan screen shots.
- c. Request access to mechanical rooms (or roof access for packaged RTU).
- d. Request permission to use CO₂ tracer gas as the main method for testing leakage within the facility; stress its importance for obtaining accurate energy savings estimates from models (be prepared to address any safety/logistics concerns).
- e. Request permission to use a ladder to inspect the ductwork above the ceiling tiles (determine whether the client can provide one for the audit crew or arrange to purchase when necessary).
- f. Request access to the BAS system:
 - i. For CAV systems, ensure the customer will lock the fan speed.
 - ii. For VAV systems, ensure that all the VAV boxes in the specified test areas will be locked to full flow position for the duration of the test.
- g. If BAS controls are non-operational or non-existent:
 - i. For CAV systems, ensure that system schedule does not change during the test period.
 - ii. For VAV systems, manually lock all VAV boxes in the test section to full flow damper position for the duration of the test (BEFORE ADJUSTING DAMPER TO FULL FLOW MARK THE RELATIONSHIP BETWEEN THE SHAFT AND COLLAR).
- h. Once the details are confirmed, discuss dates for site visit and execution plan in accordance with the customer's schedule.
- i. Obtain written permission to use ILD, and access to all locations described above.
- j. Obtain contact information for key personnel on site.

2.2 ON-SITE TEST PROCEDURE:

Required Equipment:

1. Compressed-air tank(s) for CO₂ (need to be empty if brought on an airplane).
2. Compressed-CO₂ mass flow controller with appropriate flow range (e.g., ALICAT Scientific 0-5 S CFM [standard cubic feet per minute]).
3. Compressed-CO₂ pressure regulator (to drop tank pressure to operating range of mass flow controller).
4. Compressed-CO₂ heater (to manage gas temperature leaving the regulator to avoid freezing).
5. Battery-powered CO₂ concentration sensors (e.g., HOBO MX CO₂ logger).
6. Cell Phone to connect to CO₂ concentration sensors.
7. Fan-powered flow capture hood (e.g., Duct Blaster Flow Hood w/ fan controller or Retrotec Mk-2).
8. Digital Manometer (e.g., Energy Conservatory DG-1000) for measuring fan-flow pressure differential and duct pressure.

9. Rigid plastic tubing hose for compressed CO₂, and flexible plastic tubing for duct pressure measurements.
10. Extension cords/power strip.

When you first arrive, visually inspect:

- Ductwork for base knowledge of leakage (before ILT testing).
 - AHUs in mechanical room or packaged RTU (i.e., units within the scope of work).
1. Obtain motor plate date, AHU #, VFD speed/frequency, (document with photos—see Figures 2.11 and 2.12).
 - Record the nameplate data; ensure the mechanical plans and the actual unit are the same.
 - When applicable, record the VFD speed:
 - VFD typically shows fan speed in HZ and or %.
 - 60 HZ typically indicates the fan is running at 100%.
 - Lower HZ typically correspond to % of 60 Hz (and therefore % of full speed).
 2. Record various static pressures throughout the duct system (see Figure 2.13).
 - Discharge of the supply fan.
 - Tracer gas injection point.
 - Downstream of one or more VAV boxes.
 - One or more diffusers.
 3. Check supply-fan discharge canvas connections for leakage (and for return fans if present) (see Figure 2.14).
 4. Check for dust trails all along the supply ductwork (Document with photos).
 5. Check for duct disconnects and holes in the ducts (see Figure 2.14).
 6. Look for any other mechanical issues that need to be addressed.



Figure 2-11. Air Handler Name Plate



Figure 2-12. Variable Frequency Drive (VFD)



Figure 2-13. Handheld Digital Manometer for Measuring Duct Static Pressures



Figure 2-14. Duct Hole and Hole in Canvas Connector

7. Identify the locations within the facility for ILT testing.
 - a. Trace ductwork visually to ensure mechanical plans match the actual layout in the building.
 - i. Inspect the location identified for ILT testing by removing ceiling tiles based on the plan.
 - 1) If no plans or poor plans are given, trace ductwork visually to identify actual VAV box count and diffuser count.
 - ii. Ensure that you have access to all rooms associated with ILT plan.
 - iii. Use flow hood before setting up ILT system to ensure you have air flow from diffusers.
 - 1) If BAS controls are available with no air flow from diffusers, request specific VAV dampers to be opened for ILT testing.
 - a) VAV boxes are typically labelled on the name plate of the VAV.
 - 2) If BAS controls are not available, adjust thermostats in rooms to open VAV dampers for ILT testing.
 - a) Note: VAV dampers will close once the setpoint has been reached within the specified room, so be sure to make the setpoints very low.
 - b) Note: Thermostats typically only provide a 4-5°F range within the specified room and will close once the setpoint has been achieved.
 - i. In some cases, you may need to lock the VAV damper in place manually to maintain constant flow from diffusers during testing.
 - I. In these cases, mark the position of the damper prior to manually changing, so as to assure the same damper/Drive relationship once ILT testing is completed.
 - iv. Trace supply ductwork from point of injection to diffusers for CAV systems.
 - 1) May require lifting multiple ceiling tiles to determine exact route of supply ductwork.
 - 2) Note: during the inspection of the mechanical rooms, ensure that the constant volume CAV unit planned for testing is running (note VFD speed if available).
 - 3) Note: if ILT is being performed after normal operating hours, assure that the unoccupied schedule does not turn off the fans or reset the duct static pressure.
 - b. Start ILT mobile application (if available).
 - i. If not using mobile application, open spreadsheet application for recording data.
 - c. Be sure that you know how to operate the RetroTec MK2 Flow Finder (See Figure 2.15).
 - i. Refer to the manual_for_flowfinder_mk2.
 - ii. Utilize validate mode for diffuser measurements.
 - iii. Ensure a tight seal on the 2' by 2' diffusers.
 - d. Use flow hood to measure all flows and record the CFM measurements in the mobile application or spreadsheet application (see Appendix I).
 - i. If flow is low, manipulate the BAS system to achieve airflow (when BAS controls are given).
 - ii. If low flow cannot be corrected, pivot to a different identified ILT testing location.

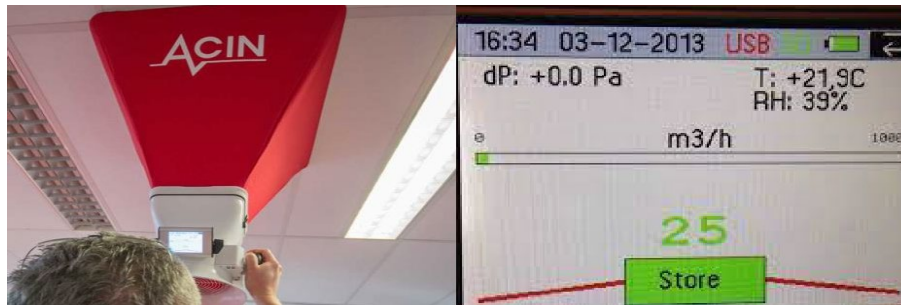


Figure 2-15. Retrotec MK-2 Flow Finder Application and Display

- e. Place all CO₂ sensors outside, and then send them the calibration command (this sets them to 400 ppm).
- f. Locate your injection point and complete necessary prep work.
 - i. Drill the appropriate size hole in the sheet metal ductwork (to allow the injector to be installed) (see Figure 2.16).
 - ii. Make sure the injection nozzle is placed in the center of the duct flow.
 - iii. When injecting into internally lined ductwork make sure the injection nozzle penetrates well into the duct stream.
 - iv. Insert injector nozzle into supply duct run.

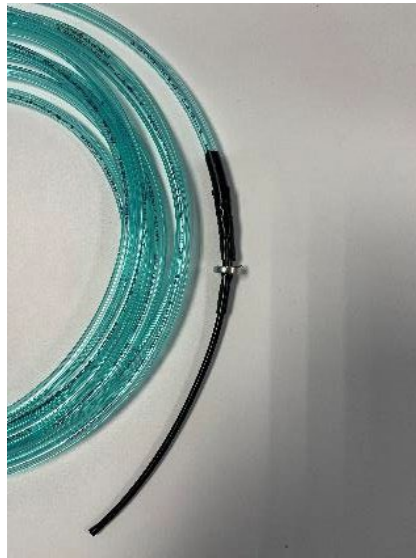


Figure 2-16. Whip Injector

- g. Place calibrated CO₂ sensors into diffuser airflow (See Figure 2.17).
 - i. Choose three different diffusers, located so as to represent different portions of the flow being measured, for example downstream of three different VAV boxes, or on three different branches (close, far and medium-distance relative to the injection point).
 - ii. Wait 2 minutes before starting ILD CO₂ injection.

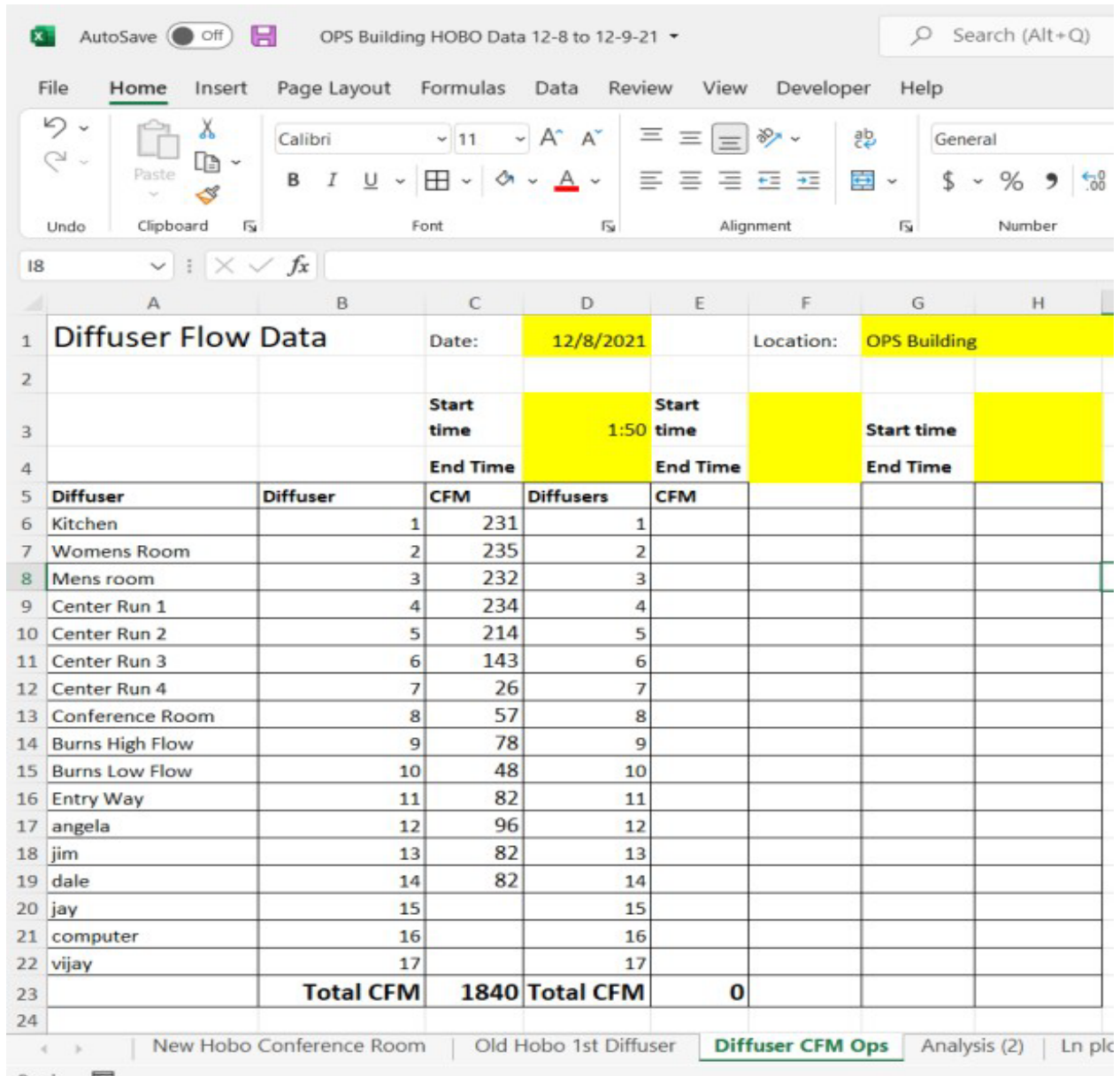


Figure 2-17. HOBO CO₂ Sensor Installation

- h. Obtain adequate steady pre-injection CO₂ concentration data before starting injection.
 - i. Record pre injection CO₂ concentrations for all sensors.
- i. Start injection of CO₂.
 - i. Record injection-period CO₂, concentrations for all sensors.
 - ii. Assure that all sensors are reading the same increase in CO₂ concentration associated with injection.
 - iii. If CO₂ concentrations are not similar (i.e., within 100 ppm), adjust injector positioning and repeat process.
- j. Turn off CO₂ injection and continue recording concentrations.
 - i. Record all post injection CO₂ concentrations.
- k. Return system to conditions at the start of the test.
 - i. Reset normal control of VAV dampers by BAS system or set damper shaft collars to original positions.
 - ii. Patch the CO₂ injection hole with foil tape.
8. Repeat ILD process for all identified ILD locations.
9. Compile leakage results and update leakage estimates used in energy savings models.

APPENDIX A SPREADSHEET APPLICATION FOR DATA RECORDING AND ANALYSIS

Using the powered flow hood obtain CFM at each diffuser record in the **Diffuser Flow Data** sheet.



1	Diffuser Flow Data		Date:	12/8/2021	Location:	OPS Building
2			Start time	1:50	Start time	Start time
3			End Time		End Time	End Time
4	Diffuser	Diffuser	CFM	Diffusers	CFM	
5	Kitchen	1	231	1		
6	Womens Room	2	235	2		
7	Mens room	3	232	3		
8	Center Run 1	4	234	4		
9	Center Run 2	5	214	5		
10	Center Run 3	6	143	6		
11	Center Run 4	7	26	7		
12	Conference Room	8	57	8		
13	Burns High Flow	9	78	9		
14	Burns Low Flow	10	48	10		
15	Entry Way	11	82	11		
16	angela	12	96	12		
17	jim	13	82	13		
18	dale	14	82	14		
19	jay	15		15		
20	computer	16		16		
21	vijay	17		17		
22		Total CFM	1840	Total CFM	0	

- a. Using the software, input the Total CFM Into the **Estimated Duct Flow [CFM]** of the diffusers (Total CFM from all diffusers).

	A	B	C	D	E	F	G	H	I	J	K	L
1	Calculating Supply Duct Leakage with a Tracer Gas						VAV Flow from Direct Flow		Altitude-Temp	Altitude	Measured Diffuser	Altitude-Temp
2	Mark Modera (7/12/21)						VAV Flow #	Press Diff [Pa]	Corrected VAV Flow	Corr BAS VAV	Flows	Corrected Diff Flow
3	Target Concentration Differential [ppm]	1000						Diameter [in]	Flow [cfm]	Flow [cfm]	Flow [cfm]	Flow [cfm]
4	Estimated Duct Flow [cfm]	1840	SCFM									
5	Required CO ₂ slpm setpoint	52.1		1.840								
6	Altitude [ft]	1000	Time [hh:mm]									
7	Pre-injection Concentration [ppm]	1040			Assumes							
8	Concentration during injection [ppm]	1821			HOB0							
9	Post-injection Concentration [ppm]	1040			altitude							
10	Actual CO ₂ slpm setpoint from Alicat	52.21		1.845	correction							
11	Actual Concentration Differential [ppm]	781.0	Duct Temp [°F]									
12	Calculated Incoming air flow [cfm]	2394	65									
13			Inputs				Calculated VAV air flow [cfm]		0	0		1867
14			Results						Upstream		DownStream	Total
15							Calculated LEAKAGE [cfm]		2394	2394	0	527
16							Calculated LEAKAGE [%]		100%	100%	0%	22%

- b. The spreadsheet automatically calculates the flow rate of CO₂ (**Required CO₂ SLPM** [standard liter per minute] **setpoint**) to inject into the duct system so as to achieve the desired CO₂ concentration differential (Cell C3).
- c. The desired CO₂ concentration differential should be 1000-4000 ppm. In general, higher differentials produce higher accuracy, but use more CO₂, potentially requiring more than one tank on-site.
- d. The desired CO₂ concentration differential should be chosen so that the flowrate through the injector exceeds 1 SCFM (28 SLPM) to assure good mixing by the injector.
- e. **Altitude [ft]** at the site location needs to be input into the software.
- f. **Duct Temp [°F]** is input from HOB0s placed at diffusers.

APPENDIX B HOBO CO₂ SENSOR PROTOCOL

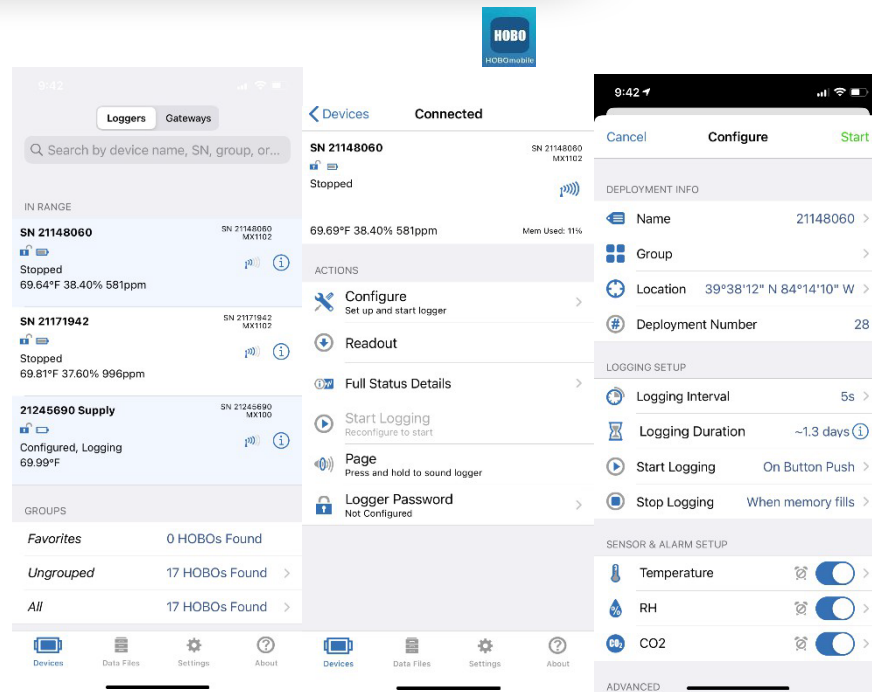
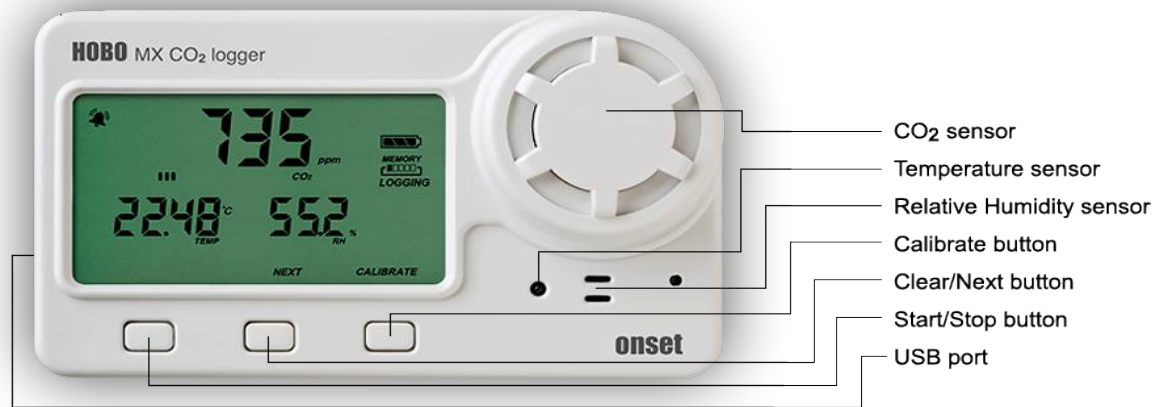


Figure A-1. Screenshots from HOBO App

- Each HOBO has its own serial number by which they can be identified in the app.
- Upon arrival on site, the HOBOs need to be calibrated outside in the fresh air using the Calibrate button (5 minutes).
- HOBOs are placed in diffusers with the CO₂ Sensor facing directly into the airflow.
 - Use tape if necessary.
- Place one HOBO furthest from injection and one HOBO centrally located along the duct run.

APPENDIX C CO₂ INJECTION CASE



- **Components of CO₂ injection system:**
 - (10-lb CO₂ tank) connected to heating unit, which is in turn connected to the pressure regulator, which in turn connects to the Alicat Mass Flow Controller, which finally connects to the injection line.
- **Pressure Regulator:**
 - Pressure on the high side (heater side) should read 800PSI, which is the pressure of liquified CO₂.
 - Pressure on the low side (Alicat) cannot exceed 125PSI.
- **Alicat Mass Flow Controller:**
 - From the estimated duct flow and desired increase in CO₂ concentration (1000-4000 ppm) the spreadsheet calculates the amount of **CO₂ required for injection (SLPM)**.
 - Set the Alicat setpoint (SLPM) using the controls on its front panel.
 - The Alicat will inject CO₂ at that exact setpoint.



APPENDIX D OPERATION DETAILS

- **Injection of CO₂**

- From the mechanical plans the injection point should be at the furthest upstream point of the duct section being tested. As noted elsewhere, the distance to the first branch should be maximized.
- The injection line runs from the Alicat directly into the ductwork.
 - Ideally you want your CO₂ injection rate to be at least 28 SLPM (1 SCFM) to assure good mixing in the duct.
 - You can adjust your **Target Concentration Differential (ppm)** to achieve 1 SCFM, assuring that the differential is not above 4500 ppm, otherwise the concentration could exceed the measurement range of the HOBO sensor.
- Placement of the injection nozzle should be in the middle of the duct run (make sure it gets through internally lined insulation and made airtight with metal tape).

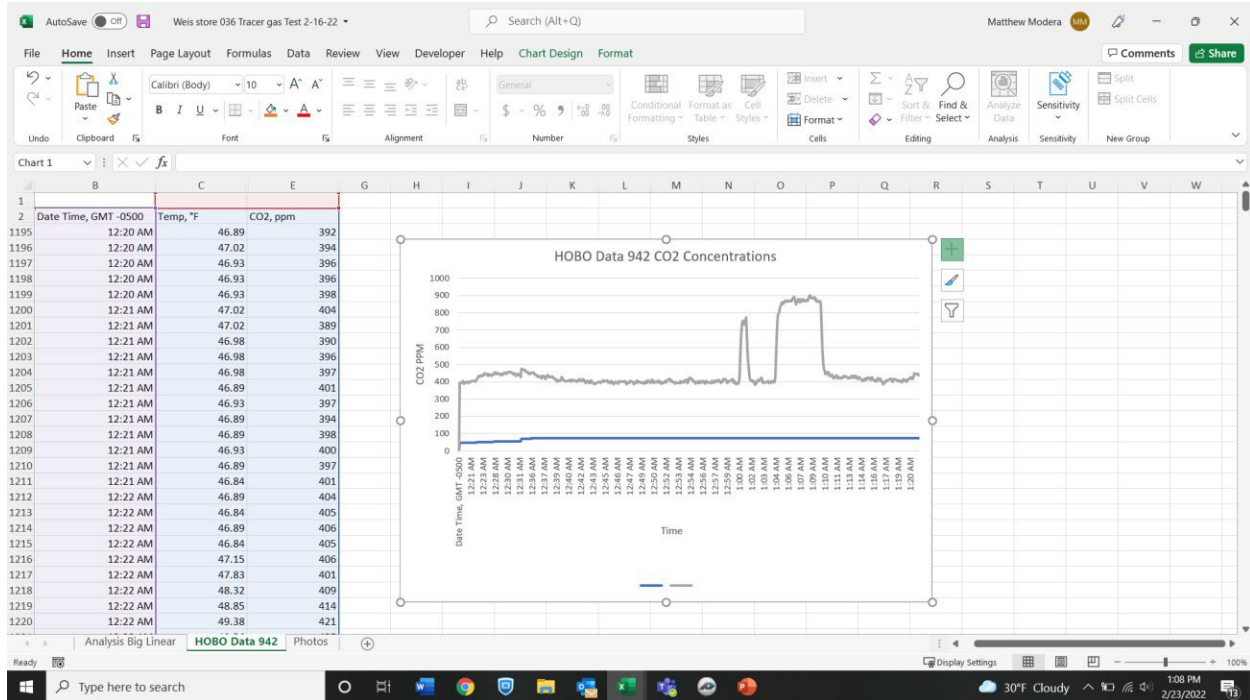
- **Pre-Injection Concentration (ppm)**

- is taken from the HOBOS and input into the spreadsheet prior to injection.
- This is the baseline CO₂ concentration in the duct.

- **Injection Concentration (ppm)**

- Once the injector case has been set up (see above), open the 10-lb CO₂ tank to start injecting CO₂ into the system.
 - May need to adjust the pressure regulator to achieve SLPM setpoint on the Alicat.
- Inject CO₂ while monitoring HOBO sensors.
 - Once CO₂ concentrations on the HOBO app have leveled out, **continue injection for at least 5 minutes.**
 - Set Alicat to 0 SCFM, and close 10-lb CO₂ tank.
- **Post-Injection concentration (ppm)**
- Continue to monitor the HOBOS until CO₂ concentrations have reached steady state (normally same as baseline concentration).
 - Let HOBOS run for 5 more minutes and then stop HOBO readings.
 - Download data from HOBO mobile application into Excel format Via **Readout** icon.

- **Post Testing Analysis**



- The data **Readout** from the HOB0 shows PPM, Temperature and Time. Turn the columns into a line chart to view the PPM concentration of CO₂ over time.
- Average **Pre-Injection Concentration (ppm)** and input into **Analysis** sheet of spreadsheet application.
- Average Concentration **During Injection (ppm)** and input into **Analysis** sheet of spreadsheet application.
- Average **Post-Injection Concentration (PPM)** and input into **Analysis** sheet of spreadsheet application.

The spreadsheet calculates the **Incoming Air Flow [CFM]** for the section of ductwork and provides **Leakage Percentage [%]** by comparing incoming flow with total diffuser flow.