Commercial Building Duct Sealing Market Characterization

Final Report

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Prepared by:

JoeDon Breda TRC
Mostafa Tahmasebi TRC
Rupam Singla TRC
Harry Gao TRC
Jingjuan (Dove) Feng TRC
Lake Casco TRC
Marc Fountain TRC

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Executive Summary

The California investor-owned utility San Diego Gas & Electric commissioned the research team to conduct a market characterization study evaluating duct sealing technologies in commercial buildings. The research team analyzed and compared a range of duct sealing solutions, from traditional methods like manual taping and mastic application to advanced technologies such as nontoxic aerosol sealant sprays, to identify cost-effective and impactful options to enhance energy efficiency in existing HVAC systems.

The research team conducted data collection through literature reviews and interviews with industry experts. Several findings emerged as this study developed, supporting the main premise that HVAC airflow leakage contributes to poor energy performance in existing buildings and that effective duct sealing can help customers achieve energy consumption and cost savings. Conditioned supply air leaking from the ductwork wastes not only fan energy, but also cooling and heating energy in that additional air must be cooled and heated to compensate for leakage. Exhaust air leakage into ductwork impacts fan energy and leads to excess infiltration, in which the conditioned supply air equipment must work harder to overcome the unintended infiltration of warm air in the summer and cold air in the winter.

Where percentage leakage is expressed in relation to the total system design airflow, the research team's data collection findings have shown baseline leakage rates of 10 to 20 percent in many existing commercial buildings, with rates reaching as high as 35 percent. This is largely due to historically relaxed duct leakage testing and sealing requirements, and in part to degradation of existing ductwork. A successful duct sealing retrofit effort has the potential to reduce duct leakage down to five percent or less. The optimal sealing method and the results will vary depending on each application. Manual sealing methods tend to perform best for larger leaks, such as openings that are larger than 1/2-inch diameter. For smaller leaks, such as ductwork joints and seams with little-to-no effective sealant, an aerosol sealant tends to perform best. A combination of duct sealing methods will generally achieve the greatest results.

Through market analysis, the research team found that large commercial markets, including healthcare, hotel, and school buildings, tend to be more active participants in duct sealing retrofit efforts, though several other markets present additional opportunities. Examples include applications with centralized exhaust, or those with small commercial single-zone HVAC equipment using constant volume or low-turndown HVAC systems, ductwork installed outside, or ductwork that was never required to pass a leakage test. The research team identified multiple factors affecting market penetration, where implementation costs and industry awareness were two of the most common barriers. The research team anticipates that a measure to incentivize customers to test and seal existing ductwork would help to overcome market barriers and foster greater adoption.

A measure that incentivizes customers to test and seal existing ductwork has significant savings potential, as studies have demonstrated that efforts to seal existing ductwork leakage have yielded annual HVAC energy savings of 15 to 30 percent. It is noteworthy that ductwork leakage is a problem that persists during all hours that HVAC equipment is operating, unlike other HVAC challenges that may be isolated to seasonal conditions.

Abbreviations and Acronyms

Acronym	Meaning
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
CA IOU	California investor-owned utility
CAV	constant air volume
CFM	cubic feet per minute
CL	duct leakage class
CMC	California Mechanical Code
CPUC	California Public Utilities Commission
DEER	Database for Energy Efficient Resources
DOE	United States Department of Energy
EIA	United States Energy Information Administration
ELA	effective leakage area
eTRM	electronic technical reference manual
HP	high pressure
HVAC	heating, ventilation, and air conditioning
in. w.c.	inches of water column
INST	installing contractors
LBNL	Lawrence Berkeley National Laboratory
Lmax	maximum permitted leakage
LP	low pressure

Acronym	Meaning
OWN	building owners and users
P	test pressure, in. w.c.
RES	researchers
SA	total duct surface area for associated duct system
SCE	Southern California Edison
SD	supply duct system
SDG&E	San Diego Gas & Electric
SMACNA	Sheet Metal and Air Conditioning Contractors' National Association
SMUD	Sacramento Municipal Utility District
TAB	testing, adjusting and balancing contractors
UL	Underwriters Laboratories
UTIL	utilities and program managers
UV	ultraviolet
VAV	variable air volume

Introduction

In commercial buildings where forced-air heating and cooling systems are employed, the efficiency of ductwork plays a pivotal role in both energy management and indoor air quality. According to the US Energy Information Administration (EIA), ventilation systems in commercial buildings consume around 1.54 quadrillion British thermal units of energy consumption nationally, or roughly 29 percent of total HVAC energy use in commercial buildings. Another study concluded that air-leakage rates in duct systems can range from 0 to 30 percent, with most measurements falling between 10 and 20 percent. Depending on the existing heating, cooling, and ventilation (HVAC) baseline system types and conditions, prior field studies and energy simulations have shown duct sealing can save 12 to 34 percent fan energy use.

This study is a market research study evaluating duct sealing technologies in commercial buildings. The study lays the groundwork for a subsequent energy savings and cost analysis study as a follow-on project with in-depth quantitative analysis. Taken together, this project and the energy savings and cost analysis project will support development of a commercial duct sealing measure package separately funded by the California investor-owned utility (CA IOU) San Diego Gas & Electric (SDG&E).

The market characterization involves evaluating the availability of technologies, establishing market baselines, potential for adoption, and understanding implementation needs in existing commercial buildings. The project team analyzed and compared a range of duct sealing solutions, from traditional methods like manual taping and mastic application to advanced technologies such as nontoxic aerosol sealant sprays. This comparison emphasized the advantages, disadvantages, and effectiveness of each method, with a particular focus on identifying cost-effective and impactful options. This study also researched different duct leakage tests applicable for commercial buildings, including the leakage to outside test and the total leakage test. The project team conducted a literature review as well as interviews with industry experts, HVAC professionals, and policymakers to understand practical implementation, market trends, and barriers to adoption. The findings from this market research will inform and support development of a commercial building duct sealing measure package.

Background

The duct sealing technology market features a range of methods, each with distinct characteristics, catering to different needs in the HVAC industry. This variety presents a diverse landscape of options for improving energy efficiency in both residential and commercial buildings.

Traditional duct sealing methods like mastic sealants and aluminum foil tape are widely used by HVAC professionals due to their ease of application and effectiveness for a range of leak sizes. Mastic sealants, applied with a brush or caulk gun, are notable for their durability and flexibility — making them suitable for both small and large leaks and therefore favored by both professionals and do-it-yourselfers. Aluminum foil tape, often used for sealing joints in ducts, is known for its ease of use, making it a popular choice for quick fixes.

However, there are more advanced sealing approaches. One manufacturer has developed an aerosolized spray sealant product and application method effective for energy efficiency retrofits or situations with limited duct access, sealing smaller leaks. Researchers have shown this technology offers the ability to seal inaccessible leaks in walls, ceilings, and floor cavities and to seal 70 percent to 90 percent of duct leaks where manual methods typically seal 40 percent to 50 percent of leaks (Desai & Wu, 2022). Despite increased attention and significant positive outcomes, prohibitive costs and specialized equipment required present barriers to widespread adoption.

Other technologies in the market include butyl tape and mechanical fastening. Professionals prefer butyl tape, with its strong adhesive properties and temperature resistance, in commercial or industrial settings rather than residential. Mechanical fastening, often used alongside sealants like mastic, provides a robust physical connection, especially in larger duct systems. However, it requires more labor and technical expertise, limiting its use to professional installations.

Increasing market adoption of duct sealing in commercial buildings faces several barriers: high initial costs, specialized training and equipment, and lack of awareness about the available options. In this project, the research team evaluates different duct sealing technologies, assessing them based on effectiveness, cost, ease of implementation, durability, and risks. By aligning solutions with distinct market segments and building vintages, the research team identifies the most efficient and cost-effective methods for different applications.

The California Public Utilities Commission's (CPUC) Decision Addressing Codes and Standards Subprograms and Budgets and Staff Proposal on Reducing Ratepayer-Funded Incentives for Gas Energy Efficiency Measures has directed utilities to expand their energy efficiency offerings for various measures defined as exempt in the decision. This includes measures that result in gas savings but do not burn gas directly, such as building insulation, sealing, smart thermostats, faucet aerators and building envelope improvements. Prompted by the CPUC decision, SDG&E is developing a commercial duct sealing measure package. In January of 2024 the SDG&E and TRC team submitted a commercial duct sealing measure package plan to the CPUC in the California Electronic Technical Reference Manual (eTRM). The measure package plan directly references this CalNEXT study and the parallel Energy and Costs Savings Analysis CalNEXT study as the main sources of data for the development of the measure package.

Additional objectives of this market study project on duct sealing technologies revolve around understanding the diverse range of available technologies, their cost-effectiveness, energy savings potential, and overall impact on carbon emissions to propose relevant solutions in a measure package offering. This comprehensive analysis is vital in guiding customers, including building and business owners and commercial building managers, towards making informed decisions about enhancing the energy efficiency of their HVAC systems. The central premise of the study is that energy and cost savings can be achieved by customers through effective duct sealing. While nontoxic aerosol sealant spray technology has been shown to recoup its investment in four to five years through energy savings in a case study done by University of California Davis Western Cooling Efficiency Center (Woolley, 2012), this study aims to compare it with other methods like mastic sealants, aluminum foil tape, butyl tape, and mechanical fastening to determine the most feasible and effective solution.

Objectives

The objective of this study is to produce an analysis of the current duct sealing technology market. This research study covers different technologies, their effectiveness, cost implications, and market characteristics and serves as a resource to support measure package development.

Methods and Approach

Data Collection

Literature Review and Case Study Analysis

In this task, the research team combined a review of existing literature with analysis of case studies. The literature review encompasses academic papers, industry reports, and other relevant publications, to provide a comprehensive understanding of the various duct sealing technologies and their development. The case study analysis evaluates real-world applications and outcomes of duct sealing technologies applied to both commercial and residential buildings. This comprehensive approach offers insights into market entry barriers, opportunities, and the impacts of regulations on technology adoption.

Duct Sealing Codes and Standards

The research team conducted a review of relevant codes and standards to document both the current practices and the historical regulations and standards of duct sealing and leakage testing. The team reviewed current and historical versions of the following codes and industry standards:

- Sheet Metal and Air Conditioning Contractors' National Association (SMACNA) standards
  - HVAC Duct Construction Standards (4th Edition 2020)
  - HVAC Air Duct Leakage Test Manual (2nd Edition 2012)
  - System Air Leakage Test Standard (1st Edition 2020)
- American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 90.1, versions 1989, 1999, 2001, 2004, 2007, 2010, 2013, 2022
- California Energy Code (Title 24 Part 6)
  - Standard version 2022
  - Referenced California Mechanical Code (CMC) 2019

The research team used this review to inform the expected baseline conditions presented in the market assessment.

Interviews with Industry Experts

For this task, the research team first conducted a gap analysis to identify research topics that could not be sufficiently addressed in the literature and case study reviews. The research team then generated a list of subject matter experts most likely to have the knowledge and experience needed to contribute meaningful information and developed an interview guide to expand upon the research topics with detailed subquestions to address those knowledge gaps. The subquestions were largely focused on experiences and results with different sealing technologies, associated costs, target markets for effective duct sealing retrofit implementations, and barriers to market adoption. Table 1 demonstrates the types of industry experts interviewed, the abbreviated designation used throughout the report, and with the number of interviews conducted for each.

Table 1: List of Interviewee Types and Counts

Interviewee Type	Designation	Interviewed
Installing Contractors	INST	3
Testing Adjusting and Balancing Contractors	TAB	2
Utilities and Program Managers	UTIL	2
Building Owners and Users	OWN	1
Researchers	RES	1

Technology Comparison and Evaluation

The research team analyzed the data collected and used it to compare and evaluate the different duct sealing technologies in terms of ease of implementation, cost, effectiveness and durability, and risks.

Market Assessment

The research team analyzed the data collected to determine the savings opportunities and how to identify them, target markets, market drivers, and market barriers.

Measure Development

The research team determined the key information from the technology comparison and evaluation and market assessment that the CA IOUs need to develop a new measure package for duct sealing in commercial buildings.

Findings

The subsections below present the data collection findings.

Literature Review and Case Study Analysis

The following document some of the key findings from the literature review and case study analysis:

- A study (Proctor Engineering et al., 2002) focused on implementing and analyzing energy saving impacts of duct sealing examined 447 light commercial buildings, primarily equipped with rooftop air-conditioning units. The study team performed leakage testing on all buildings using a fan pressurization test (duct blaster test), with 367 systems sealed using Aeroseal technology. The project was part of a direct install program by Southern California Edison (SCE), with the initial incentive of $1,000 per system. The results showed an average leakage reduction from 36 percent of fan flow to six percent, achieving 80 percent sealing success. The energy savings were significant, with 25 percent cooling and 15 percent heating savings, and a peak demand reduction of 2.4 kW per system — totaling 880 kW across all sealed units.
- A study (Mark Modera, 2005) expanded to include both small and large commercial buildings with various duct configurations, both ducted and plenum return. Using Aeroseal technology, the focus was on Southern California light commercial buildings and an existing large office building. Leakage rates for light commercial buildings before sealing ranged from 40 to 60 cubic feet per minute (CFM) per ton and were reduced to 16 CFM per ton after sealing, achieving an 80 percent reduction. In the large commercial buildings, leakage dropped to less than five percent of fan flow after 25 separate injections of sealant. Energy savings for light commercial buildings reached up to 60 percent, depending on insulation location and climate, while large commercial buildings saw fan power savings of up to 40 percent. The sealing was found to be 80 to 90 percent effective in light commercial settings.
- A field study (Delp et al., 1998) focused on 16 small commercial buildings such as offices, libraries, strip malls, and gyms served by packaged rooftop units averaging five tons. The average supply-side leakage rate across the 25 systems was 26 percent, significantly higher than typical residential buildings. The study also concluded that the effective leakage area (ELA) in these light commercial buildings was nearly three times greater than in California residential buildings. Additionally, 38 percent of the buildings had vented ceiling cavities, resulting in leakage to the outside.
- A case study (Quinnell et al., 2016) in Minnesota examined duct leakage and sealing in commercial and industrial (C&I) buildings across the state. Of the 63 systems initially screened, 27 had their duct leakage measured, and 23 of those were sealed using both conventional methods and Aeroseal. The study found that duct leakage was generally lower than anticipated, with 75 percent of systems having leakage below eight percent. The sealing process was highly effective, reducing leakage by an average of 81 percent and achieving a median sealing rate of 86 percent. Energy savings were substantial, particularly from heating (64 percent), followed by fan energy (29 percent) and cooling (6 percent). Cost savings were mainly due to reduced fan energy, resulting in payback periods ranging from 5 to 142 years, with an average of 31 years. The study also developed screening criteria to identify cost-effective duct sealing opportunities, which reduced the average payback period to seven years in a pilot program. This shows the potential for significant energy and cost savings through targeted duct sealing measures.
- The Sacramento Municipal Utility District (SMUD) initiated a residential duct-sealing program in 1999 to promote energy efficiency. The program focused on using an aerosol-applied vinyl

polymer sealant developed by Lawrence Berkeley National Laboratory (LBNL). Over 1300 homes underwent diagnostic tests, and 593 were sealed. This resulted in reducing duct leakage by an average of 80 percent. SMUD incentivized contractors through subsidies, with a significant increase in activity and additional services sold alongside duct sealing (Kallett et al., 1999.)

- A study by (Ternes & Hwang, 2001) tested aerosol spray duct sealing technology against conventional methods in 80 homes across five states (Iowa, Virginia, Washington, West Virginia, and Wyoming). The aerosol sealant technology was found to be 50 percent more effective at sealing duct leaks and reduced labor time by 70 percent, saving nearly four crew hours. The study recommended further exploration of the technology's integration into the Department of Energy (DOE) Weatherization Assistance Program.

- A study (Modera, 1989) on residential buildings found that air infiltration rates typically double when the distribution fan is turned on in systems passing through unconditioned spaces, and the average annual air infiltration rate is increased by 30 percent to 70 percent due to the existence of the distribution system. In another study of over 100 houses, mostly between five and 15 years old, the average duct leakage was at ten percent supply and 12 percent return.

- A study (Wray et al., n.d.) examining large commercial buildings reported that the measured air-leakage rates as a percentage of the inlet air flow rate varied from zero percent to 30 percent, with most measurements falling between ten percent and 20 percent. Another study (Fisk et al., 2000) on large commercial duct systems found substantial leakage in seven out of ten systems studied, ranging from nine percent to 26 percent of duct inlet flow.

Duct Sealing Codes and Standards

The subsections that follow demonstrate that duct sealing and testing requirements have evolved in the direction of more energy efficient design and application over the last 20years.

National — SMACNA

SMACNA produces multiple standards and manuals that are commonly referenced in the construction, sealing, and testing of HVAC ductwork. Noteworthy active examples include the HVAC Duct Construction Standards (4th Edition 2020), the HVAC Air Duct Leakage Test Manual (2nd Edition 2012), and the System Air Leakage Test Standard (1st Edition 2020). For decades, SMACNA standards and manuals have defined Seal Class ratings to specify where duct sealant is applied:

- Seal Class A — Sealant required at all transverse joints, longitudinal seams, and duct wall penetrations

- Seal Class B — Sealant required at all transverse joints and longitudinal seams

- Seal Class C — Sealant required at transverse joints only

SMACNA standards and manuals have also defined Leakage Class ratings, which are numeric ratings that correlate to a quantity of leakage per 100 ft^2 of duct surface area at 1 inch of water column, in. w.c., static pressure. For example, ductwork that is specified with Leakage Class 4 should leak no more than 4 cfm per 100 ft^2 of duct surface area when pressurized to 1 in. w.c. static pressure.

To associate Seal Class ratings to Leakage Class ratings, SMACNA standards have historically included tools that correlate a Seal Class to a Leakage Class, though it is noteworthy that these correlations have changed over time. For example, the 7th Printing (2003) of the 1st Edition of the HVAC Air Duct Leakage Test Manual includes a table of Applicable Leakage Classes as follows:

- Seal Class A — Rectangular Metal Leakage Class 6, Round Metal Leakage Class 3
- Seal Class B — Rectangular Metal Leakage Class 12, Round Metal Leakage Class 6
- Seal Class C — Rectangular Metal Leakage Class 24, Round Metal Leakage Class 12

The 2nd Edition of the HVAC Air Duct Leakage Test Manual (2012), however, was updated to include a table of Recommended Leakage Classes that were more stringent that those listed above:

- Seal Class A — Rectangular Metal Leakage Class 4, Round Metal Leakage Class 2
- Seal Class B — Rectangular Metal Leakage Class 8, Round Metal Leakage Class 4
- Seal Class C — Rectangular Metal Leakage Class 16, Round Metal Leakage Class 8

Both of these publications, plus the 1st Edition of the System Air Leakage Test Standard (2020), correlate unsealed rectangular metal duct to Leakage Class 48.

Over the years, SMACNA standards and manuals have also included various tables that define duct sealing requirements based on the Static Pressure Construction Class, which is equal to the design duct pressure class rating that is specified by the mechanical designer via the construction contract documents. These duct sealing requirements are summarized as follows:

- Seal Class A is applicable to a Static Pressure Construction Class of 4 in. w.c. and up
- Seal Class B is applicable to a Static Pressure Construction Class of 3 in. w.c.
- Seal Class C is applicable to a Static Pressure Construction Class of 2 in. w.c. or less

While SMACNA standards and manuals define Seal Class and Leakage Class ratings, and even correlate them to a duct pressure class rating, none of them are currently intended to stand alone as a project specification. The 4th Edition of the HVAC Duct Construction Standards (2020) states as much in the following example:

> *Para 1.4.1: "The designer is responsible for determining the pressure class or classes required for duct construction and for evaluating the amount of sealing necessary to achieve system performance objectives. It is recommended that all duct constructed for the 1 in. (250 Pa) and ½ in. (125 Pa) pressure class meet Seal Class C. However, because designers sometimes deem leakage in unsealed ducts not to have adverse effects, the sealing of all ducts in the 1 in. (250 Pa) and ½ in. (125 Pa) pressure class is not required by this construction manual."*

The 1st Edition of the System Air Leakage Test Standard (2020) contains similar supporting language in the following two examples:

> *Para 1.3: "It is incumbent that properly written project specifications for system air leakage testing avoid requiring work that conflicts with local codes and ordinances…"*

> *Para 1.3.2: "When the designer has only required leakage tests to be conducted in accordance with SMACNA or the SMACNA System Air Leakage Testing Manual for verification that any leakage classifications have been met (and has given no other criteria and scope), the designer is deemed to have not fulfilled the responsibilities outlined in Section 2.1 for providing a clear scope of work. When duct construction pressure classes are not identified in the contract drawings and/or the amount of leakage testing is not set forth in the contract documents, any implied obligation of the installing contractor to fulfill the responsibilities under Section 2.2, 2.3 and 2.4 regarding leakage are deemed to be waived by defective specification."*

As outlined in the sections that follow, the major national standards and the California codes include their own requirements for duct sealing and leakage testing.

National — ASHRAE

Like SMACNA, ASHRAE has included language describing requirements for both duct sealing and duct leakage testing for decades in its Standard 90.1 publication.

The 1989 version of ASHRAE Standard 90.1 required leakage tests for ductwork designed to operate at static pressures greater than 3 in. w.c., in accordance with the SMACNA HVAC Duct Leakage Test Manual. Such leakage tests needed to demonstrate Leakage Class 6 or lower, as defined by SMACNA. Leakage tests were required for a minimum of 25 percent of representative duct sections. For supply ducts and plenums designed to operate from 0.25 to 2.0 in. w.c. and located outside of the conditioned space, joints were to be sealed to Seal Class C as defined by SMACNA.

In 1999, ASHRAE 90.1 expanded its duct sealing requirements to provide additional detail with a table that defined Minimum Duct Seal Level values that were based on the SMACNA Seal Class ratings as follows (see prior section on SMACNA documentation for Seal Class details):

Table 2: ASHRAE 90.1-1999 Duct Sealing Requirements

	Duct Type			
	Supply		Exhaust	Return
Duct Location	≤ 2 in. w.c. †	> 2 in. w.c. †		

Duct Type				
Outdoors	A	A	C	A
Unconditioned Spaces	B	A	C	B
Conditioned Spaces**	C	B	B	C

† Duct design static pressure classification.

**** Includes indirectly conditioned spaces such as return air plenums.**

Note that ducts installed within return air plenums were treated as ducts installed within conditioned spaces. Such supply and return ducts were given less stringent Seal Class ratings than similar ducts installed within unconditioned spaces. Exhaust ducts, which were only required to meet Seal Class C for ducts located outdoors or within unconditioned spaces, were met with more stringent requirements of Seal Class B when located in conditioned spaces.

Leakage test requirements in ASHRAE 90.1 — 1999 were nearly unchanged from 1989, with the exception that round ducts were differentiated from rectangular ducts. For ductwork designed to operate in excess of three in. w.c., round ducts were required to achieve Leakage Class 3, while rectangular ducts were still required to achieve Leakage Class 6. This small revision would better align with the Leakage Class rating correlations against Seal Class A, as defined within SMACNA documentation.

The 2001, 2004, and 2007 versions of ASHRAE 90.1 all included similar requirements for duct sealing and testing, with only minor changes to language and referenced documents. Beginning with ASHRAE 90.1 — 2010, and still current as of ASHRAE 90.1 — 2022, per Section 6.4.4.2.1: "Ductwork and all plenums with pressure class ratings shall be constructed to Seal Class A." Also in 2010, the leakage testing requirement was expanded to include all ductwork located outdoors, in addition to ductwork designed to operate at static pressures greater than 3 in. w.c.

As of ASHRAE 90.1 — 2013, all ductwork subject to leak testing is required to meet Leakage Class 4 or better. ASHRAE 90.1 continues to reference the SMACNA HVAC Air Duct Leakage Testing Manual (Sections 3, 5, and 6) as the test method for duct leakage testing.

State of California

California Energy Code (Title 24 Part 6) includes requirements for ductwork sealing and testing. Since 2022 code cycle, Title 24 Section 120.4 and 120.5 mandate that new and replacement ductwork be sealed to the level of "Seal Class A." This again means sealing all joints, seams, and penetrations as spelled out by SMACNA. Examples of penetrations are those caused by pipe, tubing, rods, and wires. Section 120.4 does not allow joints and seams to be sealed with cloth-backed rubber adhesive duct tapes unless such tape is used in combination with mastic and draw bands.

The testing component includes mandating duct leakage testing either in accordance with California Energy Code Reference Appendix (for single zone, constant volume systems with 25 percent of ductwork in unconditioned space or outdoors and serving less than 5,000 ft^2) or complying with 2019 CMC testing requirements — both for new construction and alterations. For existing buildings, the sealing and leakage testing requirements apply to new ductwork, replacement ductwork, and ductwork that are an extension of existing ductwork, with some exceptions. Since 2005, California Energy Code has included a requirement to test specific ductwork, i.e., serving single zone, constant volume systems with 25 percent of ductwork in unconditioned space or outdoors and serving less than 5,000 ft^2, if the associated space conditioning systems are altered or replaced, including rooftop unit replacement. Equipment replacement alone for other HVAC systems, such as larger commercial or variable volume systems, does not trigger a similar testing requirement. There are no sealing or leakage testing requirements for existing ductwork that is just being sealed, without ductwork being added or replaced.

2022 CMC (Title 24, Part 4) Section 603.9.2 requires duct leakage testing to confirm leakage rates. Under these requirements, which took effect on January 1, 2020, the CMC establishes a maximum permitted leakage for all systems and requires testing to verify leakage rates. The CMC requires leak testing in accordance with the SMACNA HVAC Air Duct Leakage Testing Manual (ANSI/SMACNA 2012) and specifies representative sections of ductwork be tested. Specifically, ten percent of the total installed duct area must be tested. If the ten percent of tested duct area fails the test, then 40 percent of the duct area must be tested. If the sample of 40 percent of duct area fails, then 100 percent of the duct area must be tested. The maximum allowable leakage rate is determined using the same equation that is used to determine the allowable leakage rate for ASHRAE 90.1 — 2019 but using a Leakage Class of six instead of four.

In summary, historical requirements for duct leakage testing in California are as follows:

- Since 2019, CMC has required that at least 10 percent of new ductwork must be tested
- From 2005 to 2019, California Energy Code has required that new or altered ductwork connected to specific systems, i.e., single zone, constant volume with 25 percent of ductwork in unconditioned space or outdoors and serving less than 5,000 ft^2, must be tested

Interviews with Industry Experts

The research team conducted ten interviews with nine industry experts. One interviewee participated in a second interview. The types of industry experts included are listed as follows, including the abbreviated designation used throughout the remainder of the report:

- Installing Contractors (INST)
- Testing, Adjusting and Balancing Contractors (TAB)
- Utilities and Program Managers (UTIL)
- Building Owners and Users (OWN)
- Researchers (RES)

In general, the research team focused questions on different sealing technologies, target markets, market barriers, risks, and leakage testing methods and results. In the following list, the research team documents some of the key findings from interviews:

- *Duct sealing technologies*: three of three INST interviewees described aerosol sealant as typically being the easiest and most effective method to implement in existing ductwork applications. Alternatively, each of the three INST interviewees noted challenges locating and remedying all leaks when applying manual sealing methods.
- *Target markets and opportunities*: three of three INST and six of nine total interviewees discussed hospitals and universities as being preferred markets based on successful experiences. two of nine total interviewees also described hotels as good candidates, with a focus on their 24-hour operation and centralized duct systems, i.e., centralized bathroom exhaust. Two of three INST and one of two TAB interviewees noted poor leakage performance with existing centralized exhaust systems. One TAB and one OWN interviewee described quality control challenges with duct sealing in new construction, where lower pressure systems and exhaust systems generally aren't required to pass a leakage test. Even when testing is required in new construction, five of nine total interviewees shared challenges achieving target leakage rates.
- *Market barriers*: two of three TAB interviewees reported that prospective customers are turned off by duct sealing costs. Seven of nine total interviewees stated that much preparatory labor is needed when applying aerosol sealant in large commercial systems, contributing to costs. Two of nine total interviewees listed small commercial markets as challenging markets to penetrate, due to perceived high sealing costs. Three of nine total interviewees shared that a lack of industry awareness about duct sealing opportunities, and another barrier was emerging technologies .
- *Risks*: eight of nine total interviewees discussed risks to sensitive HVAC components, such as reheat coils and smoke dampers, and stated that these components require protection when an aerosol sealant is applied. Three of three INST interviewees described risks of "glue fog," or a potential condition when the aerosolized sealant leaks from the duct to the surrounding space. The glue fog was mainly described as a risk when large holes, i.e., larger than 1/4-inch or 1/2-inch, exist in ductwork and can be remedied through temporary installation of air scrubbers. For these larger holes, aerosol sealant loses its effectiveness and manual sealing methods are recommended.
- *Leakage Testing*: Two of nine interviewees recommended that a flow hood measurement leakage test is used for an initial leakage analysis. These interviewees noted that this method tends to be more cost-effective compared to pressurization testing but may not be as accurate depending on the ductwork configuration and the care of the technician. Eight of nine total interviewees discussed pressurization testing as a preferred baseline and final leakage test procedure, once the prospective customer has committed to a duct sealing retrofit. Flow hood measurement and pressurization testing are further described in the section: Duct Leakage Measurement — Overview.

The research team referenced findings in relevant sections throughout this report.

Technology Comparison and Evaluation

The research team used the information gathered from the prior data collection tasks to inform the following technology comparison and evaluation. The purpose of this task is to document a comparative evaluation of duct sealing technologies, where they have been assessed based on effectiveness, cost, ease of implementation, durability, and risk. Special attention has been given to identifying suitable solutions for distinct market segments, focused on commercial building applications. In this task, the research team examines how the effectiveness of these technologies varies across applications, offering a tailored perspective on technology selection. This comparison helps identify the most efficient, feasible, and effective methods for different applications and is used to inform measure package development.

Background and Description of Each Technology

In general, duct sealing technologies may be categorized into manual duct sealing and aerosol sealant spray methods. Manual duct sealing methods can be further broken down into subcategories. A description of each duct sealing technology is included in the subsections that follow.

Manual Duct Sealing Methods

The manual duct sealing methods require that leakage sites are both located and remedied through manual human labor and intervention. The leakage sites may occasionally be found via visual inspection, through the ear of a well-experienced technician, from a series of pitot traverse airflow samples, by feeling for air movement, by capturing thermal images, or through the application of smoke or fog where allowable. Once the leaks are located, the following manual sealing methods may be applied.

MANUAL TAPING

In the manual taping method, a duct-sealing duty tape product is applied over each duct opening and adhered to the immediately surrounding ductwork. Manual taping remains a common method in residential and commercial duct sealing projects. A contractor's (Service Champions, 2024) shared the choice between different taping methods, e.g., duct tape, aluminum tape, butyl tape, and mastic is influenced by factors such as cost, ease of application, and expected longevity.

MECHANICAL FASTENING

Mechanical fastening generally involves the application of mechanical fasteners, possibly in combination with additional duct material, across duct openings. As an example, consider a blank-off plate that is fastened over top of a larger hole, i.e., greater than 1/2-inch, with sheet metal screws. Mechanical fastening is often used in conjunction with sealants like mastic to provide a robust and secure physical connection, especially in larger duct systems. This method ensures that ducts remain securely sealed over time, reducing the risk of air leakage.

MASTIC

A mastic sealant is initially applied in a viscous, liquid state. Depending on the application, mastic is typically applied with an assortment of hand tools, such as a paint brush, a hand trowel, or a caulk applicator. Mastic is a widely used sealant for ductwork, particularly in residential and commercial HVAC systems. Its versatility, durability, and flexibility make it a popular choice for sealing both small and large leaks.

Aerosol Sealant Spray Method

Nontoxic aerosol spray sealant is an advanced duct sealing technology that has gained market traction, especially in situations where duct access is limited. Aerosol sealant has been described by installers as an atomized glue-like product that is injected into pressurized ductwork. From there, the aerosol sealant is inevitably carried to each opening by the leaking airstream. Compared to manual duct sealing methods, the aerosol sealant spray method leans toward automation. As described in sections that follow, a fair amount of labor goes into preparation for an aerosol sealant spray implementation, but the leaks are located and sealed automatically as a result of the process.

Ease of Implementation

Sealing existing ductwork is unlike sealing new ductwork. In a new construction project, the installer typically has open access to ductwork well before it's concealed within insulation and building construction. Also, in a new construction environment the installer does not normally need to coordinate building interruptions and HVAC outages. These factors impact the costs and performance results of a duct sealing retrofit project.

Manual Sealing Methods

Manual methods of duct sealing are relatively simple on smaller jobs, so long as the leaks are not too difficult to locate, and the ductwork is accessible. Site conditions, such as concealed ductwork, greater duct surface area, or elevated ductwork lead to greater difficulty achieving effective application of manual sealing methods, often making them impractical on commercial jobs. A general description of the implementation method for each manual sealing method follows.

MANUAL TAPING

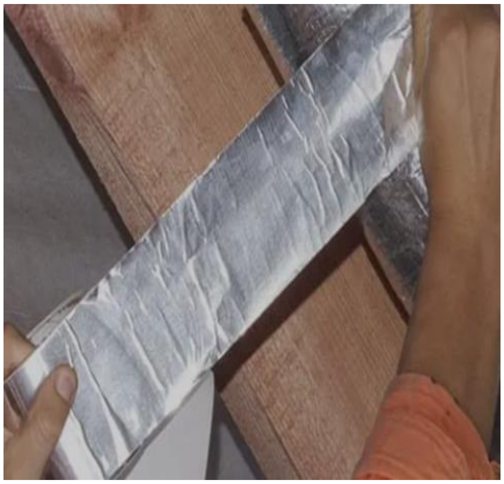
Of the manual methods, manual taping involves applying tape to seal duct joints and seams. Tape application tends to be straightforward, requires no specialized training, plus tapes are readily available.

MECHANICAL FASTENTING

Mechanical fastening requires skilled technicians. The method's application varies by duct type, with rectangular ducts, which are more common in larger buildings, requiring more secure fastening due to their larger size and potential for greater movement. Smaller buildings with round ducts may rely on less intensive fastening methods, as round ducts are inherently more resistant to pressure changes.

MASTIC

Proper application of mastic requires surface preparation and careful handling, as improper application can reduce its effectiveness. When interviewees were asked about manual sealing methods, they indicated that mastic required specialized contractors to implement effectively, but that it might be necessary in certain circumstances, for example when holes are too large for aerosol sealant spray.



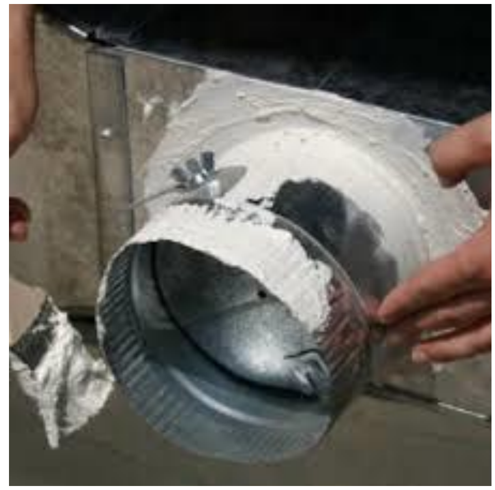


Figure 1: Butyl tape application.

Source: (Art Plumbing and Air-Conditioning, 2023)

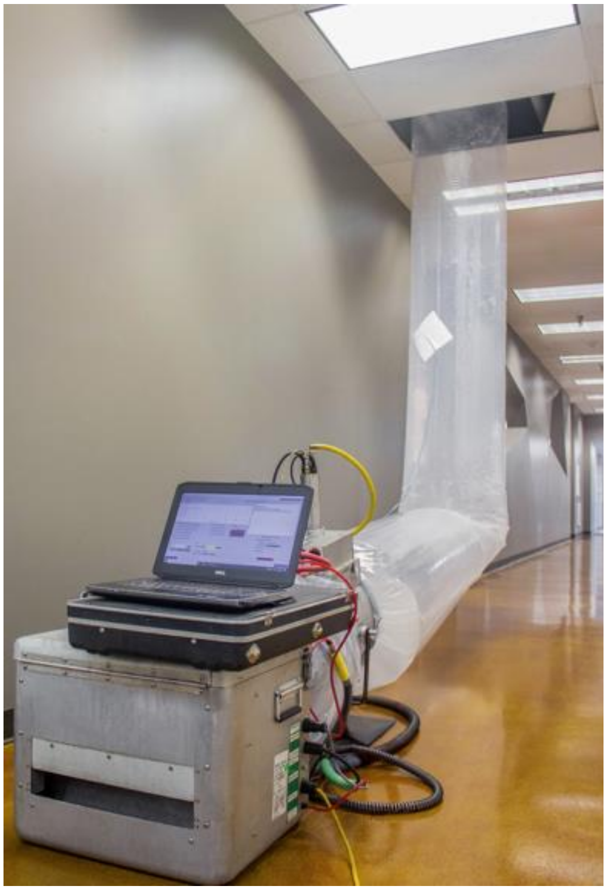
Figure 2: Mastic application.

Source: (Green Building Advisor, 2010)

Aerosol Sealant Spray Method

The nontoxic aerosol sealant spray process involves sealing off air registers, pressurizing the ductwork with an external fan, and injecting an aerosolized sealant into the pressurized ductwork. Additional equipment used during the aerosol sealant process includes a set of process sensors and a small computer station. The computer station is used to monitor and control the process, including continuously recording the duct pressure and the airflow leakage rate. During the initial stages of the process, the data recorded by computer is used to identify the presence of any large duct openings that may require manual sealing methods prior to injecting the aerosol sealant. Because the air registers are sealed off, air in the pressurized duct can only flow out via duct leaks. The aerosolized adhesive particles are carried by the airflow to the leaks, where they adhere to the edges and each other, gradually building up a seal.

All three installing contractor interviewees generally described aerosol sealant spray as the easiest to implement and typically the least time-consuming, as compared to manual methods of locating and sealing leaks. It often only requires a few days of training, though it may be months before a trainee will be ready to direct a crew on their own or to operate the computer station. One building owner who was interviewed noted that the aerosol sealant method significantly reduced the amount of labor performed from heights, such as on ladders or lifts, which offered an element of safety compared to traditional manual sealing methods. According to (Diamond et al., 2003), aerosol duct sealing of an entire duct system is faster to implement than individual application of tape or mastic at each joint. In certain applications, however, aerosol sealant implementation presents challenges. Eight of nine total interviewees discussed provisions required to protect sensitive components, i.e., smoke dampers and reheat coils, to avoid damage. Figure 3, Figure 4, and Figure 5 show the injection machine and how it integrates with duct systems.



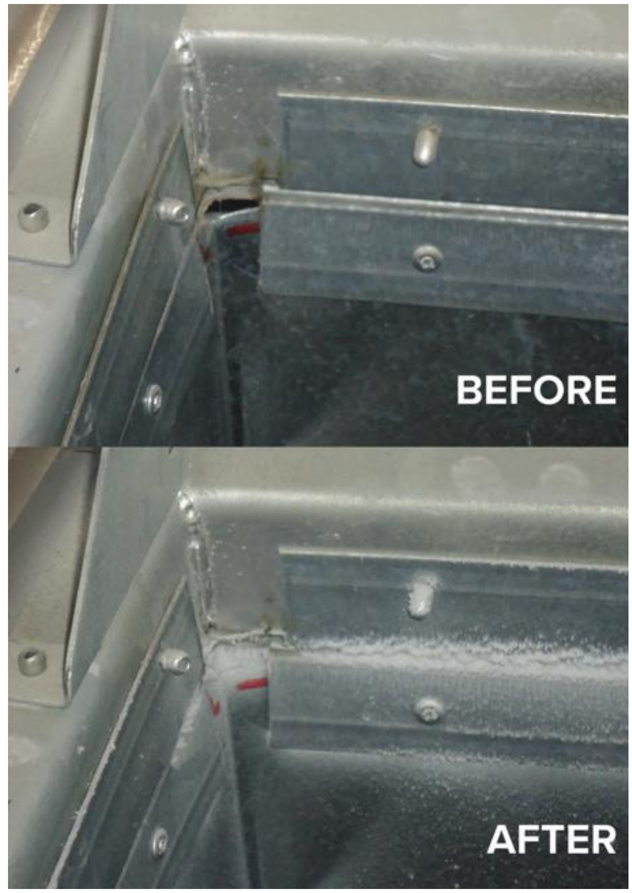


Figure 3: Aerosol sealant injection machine.

Source: 2024 Aeroseal Tech

Figure 4: Sealing in action.

Source: 2024 Aeroseal Tech

Figure 5: Aerosol sealant system diagram.

Source: 2018 Mike Holmes

Cost

Duct sealing implementation costs are a prime component in the customer decision process. During interviews with industry experts, two of three TAB interviewees reported that prospective customers have been deterred by quoted costs for duct sealing, even after committing money toward leakage testing in some cases. All interviewees were hesitant to provide normalized cost data, citing uncertain site conditions, such as an unknown quantity of duct sections requiring isolation. One INST interviewee was willing to provide a rough estimate to apply aerosol sealant in a retail space application served by five 10-ton rooftop HVAC units, at a range of $40,000 to $50,000. Based on typical values of 200 to 400 square feet per ton of cooling for retail space, this range can be correlated to $2.00 to $5.00 per square foot of retail building floor area. One other INST interviewee who had performed several duct sealing implementations in hospitals noted that costs could be significantly higher in critical settings where sensitive populations and building components must be protected. Two INST interviewees elaborated that it was normal for duct sealing implementations in hospitals to require overnight labor over a series of evenings to minimize interruptions to hospital functions.

Effectiveness and Durability

Effectiveness and durability are two performance traits of a successful duct sealing retrofit implementation. To be considered effective, duct leakage should be reduced to levels that meet or beat the latest ASHRAE standards. This equates to achieving Seal Class A performance, or Leakage Class 4 as defined by SMACNA and ASHRAE standards. From a durability perspective, the sealing solution should be expected to last at least ten years, or else provisions should be taken to verify performance periodically and remedy any deficiencies. Otherwise, operational costs will rise, and additional capital costs will be required to bring performance back to expected levels.

Manual Sealing Methods

The effectiveness of manual sealing methods is dependent on the ability of the duct sealing technician to locate and access all the leakage points in the system. Case studies demonstrate that manual sealing methods alone typically achieve a 40 to 50 percent leak reduction. Based on responses to the project team's interviews, the remaining leaks are often impractical to locate and remedy with manual methods.

MANUAL TAPING

Taping methods may offer effective short-term solutions if applied appropriately and adequately but lack the durability of mastic application and mechanical fastening methods. The effectiveness and durability of the seal depend on the type of tape used, with each option having its pros and cons.

Duct tape is a commercially available option for quick fixes that typically is not a code-acceptable sealant in new construction, has several disadvantages that limit its effectiveness for long-term sealing:

- *Longevity Issues*: Over time, duct tape can dry out, lose its adhesive properties, and eventually fail. A study by (Sherman & Dickerhoff, 2000) found that duct tape is unsuitable for long-term duct sealing due to its tendency to degrade when exposed to heat and pressure variations.
- *Sealing Effectiveness*: Imperfect sealing can lead to conditioned air leakage, resulting in energy loss and decreased system efficiency. Additionally, in negative pressure situations, duct tape may allow the penetration of dust and allergens, compromising indoor air quality.

Aluminum tape offers a longer lifespan than standard duct tape, with an expected durability of around five years. It is more robust and less prone to degradation, making it a popular choice for those seeking a balance between cost and performance. However, there are still some limitations:

- *Degradation Over Time*: While aluminum tape performs better than duct tape, it still degrades over time, especially when exposed to fluctuating temperatures and humidity.
- *Ease of Use*: Aluminum tape requires minimal surface preparation, but it is more prone to tearing, which can compromise the seal if not applied carefully.

Butyl tape is known for its strong adhesive properties and resistance to temperature variations, making it a preferred choice in commercial and industrial applications. Its durability makes it suitable for long-term use in challenging environments.

- *High Adhesive Strength*: Butyl tape's adhesive strength is superior to that of other tapes, maintaining its bond even in extreme temperatures.
- *Resistance to Environmental Factors*: Unlike other tapes, butyl tape does not degrade significantly under UV exposure or extreme temperature variations, making it ideal for outdoor or exposed ductwork.

During interviews with industry experts, seven of nine total interviewees and all three installing contractors considered tape to be the least effective duct sealing method and stated it should only be used if necessary. One interviewee advised that installing contractors should not even bother with tape.

MECHANICAL FASTENTING

Mechanical fastening is particularly effective in commercial HVAC systems where larger ducts require more secure connections due to movement or vibration. The combination of mechanical fastening and mastic has been found to provide the most durable seal, particularly in larger duct systems (Walker, 2001).

MASTIC

Mastic offers durability and flexibility that make it effective for sealing both small and large leaks. Mastic is known for a long-lasting seal that remains flexible over time.

Seven of nine total interviewees described using manual mastic methods as reasonably effective for residential buildings or small commercial buildings, but less so for larger buildings. Mastic can often be used as an alternative to aerosol sealant spray when holes are too large. Mastic, along with mechanical fastening, may offer the most durable and effective solution in this case.

Aerosol Sealant Spray Method

The nontoxic aerosol sealant spray method is particularly effective for sealing smaller leaks, including those in hard-to-reach areas such as ducts embedded in walls, ceilings, and floors. Case studies reveal that the aerosol sealing method can seal 70 to 90 percent of duct leaks (Desai & Wu, 2022) when combined with manual presealing for larger leaks. This compares favorably to manual sealing methods alone. Aerosol sealant spray's ability to address leaks that are otherwise inaccessible makes it a valuable option in both residential and commercial duct sealing applications.

Interviewees were generally positive about the aerosol spray duct sealing method. All of them praised it as being easier to implement and better at reducing leakage than manual methods. Aerosol spray sealing can also be less time consuming. For a smaller space, one or two evenings is enough to finish a job. Aerosol sealant is durable, but interviewees did not indicate that it was notably more so than mastic. One aerosol sealant product on the market includes a ten-year guarantee, and three different interviewees shared experiences or knowledge of testing that demonstrated 20-year effectiveness. One interviewee, a Testing, Adjusting, and Balancing (TAB) professional, shared his experiences in witnessing a perceptible decrease in fan speed as the aerosol sealant settled and filled leaks.

Risks

Risks related to implementation problems, equipment or property damage, and environmental impacts were considered in this task.

Manual Sealing Methods

Interviews and literature reviews revealed that most applications would require significant labor performed from elevated heights, often from ladders where a technician would be required to work above existing ceilings. This presents a noteworthy safety hazard. No issues with equipment or property damage were noted in relation to manual sealing methods. The biggest performance risks seemed to be the often-impractical task of locating every leak in a commercial duct system, combined with the poor durability of the various taping methods. One installing contractor noted that their manual duct sealing methods use sealant products (DP-1010 and 256p Polytechnical type) that are water-based and more environmentally friendly but are also limited to certain interior space applications. Applied in exterior spaces, these water-based products lose durability and will crack after prolonged exposure to the elements. Hence, an installer may select a less environmentally friendly sealant for some applications.

Aerosol Sealant Spray Method and Size of Leak

Through interviews, it was discussed that aerosol sealant spray is not as effective with larger leaks. Interviewees commented on the effectiveness of aerosol sealant spray, with one of nine interviewees advising that aerosol sealant may lose effectiveness with leaks greater than 1/4-inch, and another interviewee advising that aerosol sealant is effective for holes up to 5/8-inch. The size limitation is difficult to characterize as leak geometries can vary. The actual limiting dimension will depend on the specific application and the geometry of the duct opening.

If the leak is too large, a glue fog can occur, in which case aerosolized sealant leaks from the duct to the surrounding space in a hazy fog. While the fog is nontoxic and will eventually dissipate, it can be alarming to occupants, can settle on surfaces and become sticky, and can be unpleasant to breathe in. To mitigate this risk, one installing contractor temporarily installs an air scrubber in a ceiling cavity to capture any glue fog that escapes the ductwork. The research team recommends that aerosol sealant is not applied during normal hours of occupation, and that air scrubbers are used during application. One major aerosol sealant manufacturer includes temporary air scrubbers as part of their standard operating procedure. If aerosol sealant must be applied during occupied hours, then additional protective measures are recommended, such as physical barriers or room-pressure control strategies.

One TAB professional shared that smoke dampers are UL-listed and must typically be isolated to avoid gumming up the components. This is true of heating and cooling coils also. The interviewee advised that the installers must be aware of the sensitive components and take precautions to ensure they're protected appropriately. Another interviewee stated that coils would most likely need to be replaced if they weren't protected prior to aerosol sealant application, as the sealant would severely gum up the fins and cannot be removed.

Market Assessment

The following sections provide findings from literature review, stakeholder outreach, and review of existing case studies.

Savings Opportunities and Potential

The following subsections document the research team's analysis of baseline leakage conditions against the potential that has been demonstrated by effective duct sealing implementations in existing buildings.

Baseline Conditions

Based on historical codes and standards, one could attempt to estimate baseline conditions by applying duct Leakage Class ratings. For newer construction:

- All commercial duct systems installed in 2020 or later are expected to be constructed to Seal Class A, with an associated Leakage Class of 4.

Prior to 2020, the Seal Class and Leakage Class for commercial duct systems will vary depending on the design pressure class, the year, and the project contract documents. In general, however, the following are likely to hold true:

- Supply ducts operating above 3 in. w.c., i.e. upstream of Variable Air Volume (VAV) boxes, are expected to be constructed to Seal Class A, with an associated Leakage Class of 6.
- Supply ducts operating below 3 in. w.c., i.e. small commercial and downstream of VAV boxes are expected to be constructed to Seal Class C, with an associated Leakage Class of 24.
- Return ducts are expected to be constructed to Seal Class B or Seal Class C, with an associated Leakage Class of 12 or 24, respectively.
- Exhaust ducts are expected to be constructed to Seal Class C, with an associated Leakage Class of 24.

To analyze the predicted leakage of a medium-sized commercial HVAC system, a sample duct take-off was performed for the supply air ducts of an 11,000 cfm VAV air handling system that serves a public police crime lab. Calculations were run based on a Leakage Class of 48 representing an unsealed rectangular metal duct, to estimate a worst-case duct leakage scenario, as shown in Table 3. As designated in ASHRAE Standard 90.1 — 2022, Lmax = CL*P0.65, where:

- Lmax = maximum leakage, cfm per 100ft2 of duct surface area for associated leakage class
- CL = leakage class, cfm per 100ft2 of duct surface area per in. w.c.0.65
- P = test pressure, in. w.c.

Additional variables used in this analysis include:

- SA = total duct surface area for associated duct system
- SD = supply duct system, further broken down by high pressure (HP) and low pressure (LP)
- cfm/ft^2 = airflow per square foot of duct surface area per high and low pressure system

Table 3: Sample Duct Take-off Example Leakage Calculations

Duct System	User Inputs				Resulting Outputs				
	Airflow cfm	SA, ft^2	Leakage Class, C_L	Test Pressure, P, in. w.c.	cfm/ ft^2	L_{max}	$P^{0.65}$	Leakage cfm	Percent Leakage
$SD_{HP\text{-}rect}$	11,000	3,000	48	2.0	3.28	75.32	1.57	2260	20.5%
$SD_{HP\text{-}round}$		350	48	2.0		75.32	1.57	264	2.4%
$SD_{LP\text{-}rect}$	11,000	1,600	48	0.5	3.79	30.59	0.64	489	4.4%
$SD_{LP\text{-}round}$		1,300	48	0.5		30.59	0.64	398	3.6%
TOTAL	**11,000**	**6,250**			**1.76**			**3410**	**31.0%**

In this case, the total supply air leakage is estimated to be 31.0 percent.

Similar calculations were run with Leakage Class set to 24, 12, 6, and 4 to demonstrate the predicted effects of different duct sealing strategies, where a Leakage Class of 4 is expected to correlate to Seal Class A construction in the latest ASHRAE and SMACNA standards. Results are summarized as follows:

- Leakage Class 48 yields 31.0 percent leakage
- Leakage Class 24 yields 15.5 percent leakage
- Leakage Class 12 yields 7.8 percent leakage
- Leakage Class 6 yields 3.9 percent leakage
- Leakage Class 4 yields 2.6 percent leakage

Note that the above leakage rates do not account for degradation of existing duct conditions, such as from damage, lost test plugs, or expansion and contraction, which would contribute to additional leakage in existing systems. Also note that this exercise is intended to demonstrate an approximate percentage leakage rate for a particular commercial HVAC system, and that project airflows and duct quantities need to be appropriately accounted for before applying this analysis in other applications.

During interviews, worst-case observed leakage rates of 30 to 35 percent of total supply airflow were revealed. This range correlates well with the 31 percent leakage rate estimated in the previous example. Interestingly, one TAB professional shared that installing contractors tend to fail duct leakage tests about 50 percent of the time during their initial tests for new construction projects. Per the same TAB professional, the quality of duct sealing varies across the industry. Two different contractors might both meet Seal Class A construction, but on average, only one of the two will achieve a Leakage Class of 4 on the first attempt.

Opportunities

Baseline leakage rates of 10 to 20 percent are expected in many existing commercial buildings, and leakage rates as high as 35 percent have been demonstrated. In the example system analyzed prior, a range of 10 to 20 percent leakage aligns with Leakage Class 24 per SMACNA and ASHRAE. This further aligns with older SMACNA definitions of Seal Class C, where some but not all duct joints are sealed. Leakage rates around 30 percent align with Leakage Class 48, in which case ducts are either unsealed or the existing seal is ineffective. Data gathered by the research team indicates that an effective duct sealing retrofit implementation can reduce leakage rates to achieve Leakage Class 4 or better. In the example, a Leakage Class 4 system may achieve a three percent initial leakage rate.

Energy and Cost Savings Potential

Findings from the literature review, detailed in the Literature Review and Case Study Analysis section, suggest that duct sealing has a savings potential of between 15 and 30 percent annual HVAC energy use according to extensive anecdotal and empirical sources. Savings estimates vary based on several factors, including the leakage rate of the baseline system, the sealing method, HVAC system configuration, and system operating hours.

Non-energy Benefits

(Energy Star, 2024) offers an overview of the non-energy benefits of duct sealing. The focus is residential but many of the same benefits translate to the commercial sector.

- *Improved air quality*: Reduce the risk of pollutants entering and circulating through ducts.
- *Safety*: Reduced risk of back drafting of exhaust gases from fuel burning appliances in certain applications.
- *Thermal comfort*: Duct leakage can cause air distribution imbalances leading to either warm or cold discomfort.
- *Saved money*: Duct sealing improves HVAC system efficiency, saving energy and money.
- *Avoided environmental harm*: Reducing the amount of energy generated by burning fossil fuels reduces pollution and contributes to climate change avoidance.

Target Markets

The effectiveness and applicability of duct sealing varies depending on the building's size, complexity, and the specific characteristics of its HVAC system. This section explores the relevance and impact of duct sealing in residential, small commercial, and large commercial buildings.

Building Vintage and Use

This study has focused on various vintages of commercial buildings, and the project team has further broken down this category into small and large commercial building types. The subsections that follow analyze the market potential of buildings based on their vintage and use. Residential buildings, while not the focus of this study, may offer data that is useful in some commercial building applications and, therefore, some content regarding residential buildings has been included.

BUILDING VINTAGE

While one TAB professional shared that older buildings tend to have looser, leakier ductwork, another TAB professional had observed poor duct leakage performance over a range of buildings that included both a 60-year-old hospital and a brand-new school that suffered from poor quality control during construction. The second interviewee also advised that quality control is not always kept up throughout a project. The installing contractor will do what needs to be done to pass the higher-pressure testing requirements, then they will relax their quality process as the lower pressure duct is installed. The interviewee noted that plenum boxes attached to grilles and registers are often lacking a sealed connection, and this deficiency alone can allow 30 percent of the intended design airflow to leak.

Based on these interviews, it can be concluded that any ducted system that has not been previously required to pass a system leakage test should be considered a potential candidate, regardless of building system age. To better focus efforts, however, it is more likely that any building constructed prior to 2020 will include some ducts that are not constructed to Seal Class A. Also, as energy codes have evolved over the years, it is more likely that the older duct systems were sized to operate at pressures that would be considered excessively high by today's standards, and therefore would be expected to suffer the most from duct leakage. Lastly, degradation is expected to contribute to leakage in existing buildings as ducts are subject to damage, lost test plugs, and expansion and contraction that would contribute to additional leakage.

SMALL COMMERCIAL BUILDINGS

Small commercial buildings, such as retail spaces, offices, and restaurants, present a unique opportunity for duct sealing due to their often-overlooked duct systems. These buildings frequently have leaky duct systems and inefficient HVAC operations that result in significant energy waste. Duct sealing in this segment can lead to substantial energy savings, particularly during peak demand periods. Aerosol sealant spray, for instance, has been effectively applied in various studies such as (-Proctor Engineering et al., 2002) and a pilot program by targeting light commercial buildings in southern California to seal ducts, yielding measurable reductions in energy consumption and peak load demand. These buildings, like residential buildings that are described in a following paragraph, have smaller size and relatively straightforward HVAC configurations, making them suitable candidates for duct sealing interventions. As discovered during interviews with industry experts, however, project costs and tenant-landlord contract structures have made it difficult to get good market penetration into these types of buildings via duct sealing retrofits.

LARGE COMMERCIAL BUILDINGS

Large commercial buildings present more complex challenges due to their extensive and intricate HVAC systems with multiple zones and large duct networks (Harrington, 2014). For example, sealing leaks in a large multiuse or multitenant building may require access to all units during the same period in time, protection for occupants who cannot vacate, e.g. in hospitals, and countering the stack effect impacts on particle dispersion and validation of successful sealing. Despite these challenges, duct sealing can be highly beneficial in these buildings. A study by (Harrington, 2014), which included a sample of 11 buildings, of which nine were 'large,' showed an initial fractional leakage of 36 percent with a post-procedure sealed rate of 96 percent was achieved. Furthermore, the project interviews revealed that university campus buildings and healthcare facilities have demonstrated some of the best market adoption of duct sealing retrofit work. It is noteworthy, however, that the process tends to be more challenging due to the scale and stringent regulatory requirements that must be met.

RESIDENTIAL BUILDINGS

Duct sealing in residential buildings is a well-established energy efficiency measure, with standardized approaches and guidelines available, such as the Technical Reference Manual measure SWSV001-06. This measure outlines the methods and expected savings from duct sealing in residential settings. Typically, residential buildings have relatively simple HVAC systems, making them ideal candidates for duct sealing. The primary benefits include reducing energy consumption, improving indoor air quality, and enhancing overall comfort. Given that ductwork in residential buildings is often accessible, the implementation of sealing measures is straightforward and cost-effective. While residential duct sealing is outside the primary scope of this study, understanding its methodologies and market impact provides valuable context for the broader analysis of duct sealing across different building types.

HVAC System Type

SMALL SINGLE-ZONE SYSTEMS

Small single-zone systems are often associated with small commercial building applications. Historically, these systems operated at constant volume, in which case the duct pressure was held nearly constant and there is little-to-no variation in duct leakage with changes HVAC loads. Also, these systems have long been subject to less stringent duct sealing requirements and were rarely subjected to duct leakage testing. The combination of constant or near-constant high-speed operation, minimal duct sealing, lack of leakage testing, and large portion of market share make markets with these systems attractive.

LARGE MULTI-ZONE VAV AND CAV SYSTEMS

During interviews with industry experts, three interviewees had said they observed significant leakage occurring downstream of VAV boxes, suggesting that lower pressure ductwork should be considered. One researcher interviewed had described a pilot program where standalone duct sealing was performed using aerosol sealant in hundreds of light commercial buildings achieving significant performance improvements (Proctor Engineering et al., 2002). Large Constant Air Volume (CAV) and VAV systems offer substantial savings opportunities, especially for healthcare, airports, and fabrication or manufacturing buildings. Duct sealing on the higher-pressure side of the terminals in these building types is particularly effective as they all have high percentage of outdoor air requirements and long operating hours.

CENTRAL EXHAUST SYSTEMS

Two of three INST and one of two TAB interviewees noted poor leakage performance with existing centralized exhaust systems. One RES interviewee also noted that exhaust air leakage can be a big problem, as it affects building pressure, infiltration, and toilet room odor. One INST interviewee had stated that some hotels experienced annual energy cost savings of tens of thousands of dollars after sealing centralized exhaust systems that were running at constant volume during all hours of the year.

Identifying Opportunities

Within the target market(s), candidate buildings may be selected based on various factors. Through industry expert interviews, the following criteria were identified as supportive of a strong duct sealing retrofit candidate:

- Buildings that operate at or near 24 hour/day, 7 days/week

- Constant volume HVAC systems, or systems with limited turndown where the duct pressure remains elevated
- HVAC systems with high outside air percentages
- Healthcare, manufacturing, and airport buildings
- Large central exhaust systems
- Systems with ductwork installed outside, such as with some rooftop HVAC units
- HVAC systems with fans consistently operating at or near max speed, or where equipment can no longer satisfy demands due to inadequate airflow
- Office buildings and small commercial buildings with a motivated owner

A strong retrofit candidate need not meet all the criteria, but meeting multiple criteria could increase the energy savings potential.

Duct Leakage Measurement — Overview

Once a prospective building is identified, duct leakage should be quantified to confirm the opportunity. If a recent TAB report is available, then a qualified technical professional may first review the TAB report. If such a TAB report is not available, then leakage testing should be performed. Different measurement techniques are better suited to different building types and HVAC configurations, each with specific strengths and limitations. In the following sections, the project team describes several methods for measuring duct leakage, followed by recommendations on which method to use when assessing potential opportunities.

PRESSURIZATION TEST

The pressurization test is a method used to assess duct leakage by creating a pressure difference between the inside and outside of the duct system using a calibrated fan. The airflow required to maintain this pressure difference is measured at specific pressure levels to estimate overall duct leakage. This test is best suited for residential and small to medium commercial buildings, particularly in new construction or retrofits where duct systems are relatively easy to access and seal. However, it requires access to the entire duct system, which can be challenging in some buildings.

While it provides a good overall estimate of leakage, it may not pinpoint exact leak locations. During interviews with industry experts, eight of nine total interviewees described pressurization testing as a preferred baseline and final leakage test procedure. The interviewees also shared that live pressurization testing may be conducted simultaneously with sealing implementation to demonstrate immediate performance results and ensure that a target leakage rate is preferred, when possible. Note that ASHRAE Standard 215 — Method of Test to Determine Leakage of Operating HVAC Air Distribution Systems — 2018 documents a procedure that allows for pressurization testing of segmented portions of a larger duct system, where pressurization testing is preferred but the entire duct system cannot feasibly undergo a single pressurization test.

FLOW HOOD METHOD

The flow hood method involves assessing the airflow entering and exiting the duct system at various points using a flow hood at the discharge outlets or suction inlets and a pitot tube traverse measurement at the duct main. The difference between the measured airflow values is used to calculate duct leakage. The flow hood method is ideal for initial analysis of large commercial buildings with large, multi-zone HVAC systems where direct access to ductwork is limited. It provides reasonably accurate measurement of duct leakage in complex systems, although it is subject to some amount of inaccuracy and requires specialized equipment and expertise.

During interviews with industry experts, two interviewees recommended the flow hood method as typically being a more cost-effective strategy for initial investigations to confirm a prospective duct sealing retrofit candidate, as compared to pressurization testing that tends to be more labor intensive. Unlike pressurization testing, the flow hood method does not require that every diffuser, grille, or other opening is sealed off to conduct testing. Also, consider that existing TAB reports, if available, can be used to perform an initial assessment when an experienced TAB professional already took diffuser and main duct traverse airflow readings.

TRACER GAS METHOD

The tracer gas method is similar to the flow hood method described above, except that it uses tracer gas measurements instead of pitot tube traverse measurements. The tracer gas method involves injecting a known quantity of a nonreactive gas into the duct system. The concentration of the gas is then measured at various points to determine leakage. This method is highly accurate and is often used in research and detailed diagnostic studies. This technique is best suited for laboratory settings and high-performance buildings where precision is critical. It is applicable to any type of HVAC system but is particularly useful in complex or high-stakes environments such as healthcare facilities. The tracer gas method offers an effective alternative to a pitot tube traverse, as it yields higher accuracy when measuring the total airflow in the duct main.

THERMAL IMAGING

Thermal imaging uses infrared cameras to detect temperature differences caused by air leaks in duct systems. While not a direct measurement of leakage, this method is useful for identifying leaks and areas of poor insulation in ducts. Thermal imaging can be applied in any building type, especially older buildings where insulation and duct sealing may be degraded. It is compatible with any HVAC system and is a quick, noninvasive method to identify potential leak areas. However, it does not quantify leakage and may not detect smaller leaks.

PHYSICAL INSPECTION

Physical inspection cannot typically be relied on to accurately quantify duct leakage, but it can be an effective method to identify a prospective candidate if and when ductwork can be observed. Physical inspection may include any or all of the following: visual inspection, auditory examination, smoke or fog injection and observation, or simply feeling for air currents.

Duct Leakage Measurement Recommendations

While each of the prior-described duct leakage measuring strategies will outperform others in various applications, it is possible to recommend an approach that balances cost and accuracy. Once a candidate building is selected, it is generally recommended that a flow hood measurement is first conducted. A flow hood measurement can be executed with minimal space interruption and without needing to block off various air devices throughout the building. The risk with a flow hood measurement is that care must be taken, especially when performing duct traverse readings, to ensure accuracy. The research team recommends that the baseline assessment team reference ASHRAE Standard 215 when conducting duct leakage measurements, as it contains recommendations to help the measurement technician to address challenges with various uncertainties that may arise in existing settings.

One interviewee, both a TAB professional and an installing contractor, said that they use airflow traverse probes to calculate the total airflow, then sum up the inlets vs. outlets where the difference is calculated as leakage. This interviewee confirmed that this was typically their first step in evaluating a candidate building.

If the flow hood measurement successfully confirms that a candidate building offers a worthwhile opportunity, then a physical inspection and a pressurization test should follow. The main purpose of the physical inspection is to identify any large openings and repair those first. The pressurization test should occur simultaneously, such that the results of repairing the large openings can be recorded, and a baseline pressurization leakage can be confirmed before performing the final duct sealant implementation. In the case of an aerosol sealant spray application, it is expected that the pressurization test will continue until the aerosol sealant implementation is complete, at which point the final pressurization test data will be recorded.

Market Drivers

Market drivers for duct sealing are various. High energy bills often prompt building owners to seek ways to reduce consumption, with duct sealing proven as one effective method. Uneven heating and cooling across different rooms can also be a driver, resulting in comfort complaints that necessitate duct sealing. Additionally, poor indoor air quality, worsened by leaky ducts introducing dust, allergens, and pollutants into indoor spaces, drives the demand for better air quality solutions.

System upgrades or renovations often include recommendations for duct sealing to ensure the efficiency and longevity of the new system. Similarly, energy audits frequently identify duct leaks as a major source of energy loss, motivating building owners to invest in sealing efforts. Inadequate zone flows within HVAC systems can lead to discomfort and inefficiencies, prompting duct sealing to restore balanced airflow and improve overall comfort. Perceived or projected energy savings offer a compelling reason for many property owners to start duct sealing projects. In some cases, code-driven requirements necessitate duct sealing, particularly when new construction does not meet initial duct leakage criteria. For instance, a study (Harrington, 2014) highlighted this issue as a common motivation for sealing ducts. The same study also noted that insufficient pressure differentials across bathroom grilles can also necessitate duct sealing to ensure proper operation.

Interviewees shared that problems with leakage into centralized exhaust systems may be another market driver. There are multiple reasons to support this. First, exhaust systems tend to be leaky as they have historically had looser code requirements for sealing and installing contractors do not always see the value in being concerned with air that is being sucked out of the building. One interviewee noted that 35 percent leakage rates as a function of total design airflow have been observed in many existing applications. Next, leakage impacts building pressure and infiltration. As an example, consider a central exhaust fan that needs to extract 13,000 cfm at its inlet to meet a 10,000-cfm total demand as summed from the individual air devices. The building in this example is now losing 3,000 cfm of air that must be compensated for via increased outdoor air intake at either the HVAC equipment (controlled) or through infiltration (uncontrolled). This infiltration may have a significant impact on energy and may also cause severe discomfort on lower floors if and when cold or hot unconditioned air is drawn in through the doors and building envelope. Lastly, a leaky exhaust system may result in toilet rooms that are unable to meet their design exhaust requirements, and therefore become smelly and cause occupant complaints.

Market Barriers

The market barriers for duct sealing technologies can be broadly categorized into several key areas. One significant barrier is the cost associated with the technology and sealant materials. Advanced sealing technologies, such as aerosol sealants, often involve higher upfront costs for both the equipment and the materials used. These costs can be prohibitive for some building owners or managers, particularly in smaller commercial buildings or residential settings where budgets are tighter.

During interviews, multiple interviewees shared that customers are turned off by the costs of a duct sealing effort. One TAB professional shared that it was not uncommon to perform a paid leakage test for a customer, only to hear that they were not going to follow through with the duct sealing effort due to the high price. The same TAB contractor noted that small commercial applications tend to be considered cost prohibitive to the building owner. A professor with duct sealing expertise shared difficulties with contract structures in small commercial applications. As an example, many retail store tenants enter into short-term, i.e., five to ten year contracts to lease retail space from a property owner. The property owner passes the costs for the utilities down to the tenants, so the property owner does not realize any profit from implementing a duct sealing retrofit. The tenant, depending on the length of their lease agreement, is often unable to realize the payback that could otherwise be achieved. Another cost factor that came up during interviews was focused on the efforts needed to appropriately prepare for an aerosol sealant application. An interviewee noted that large VAV systems will have many heating coils distributed throughout the ductwork, and that each coil will require protection to avoid damage. This type of preparation adds time and costs to a prospective duct sealing retrofit effort. The cost-effectiveness of these solutions needs to be demonstrated clearly to overcome this barrier.

Workforce training and contractor availability is another challenge. Duct sealing technologies, particularly those involving new or advanced methods, require skilled technicians who are properly trained to execute the sealing process effectively. The current workforce may not be sufficiently trained, leading to a skills gap that slows down the adoption of these technologies. One installing contractor interviewee noted challenges hiring, training, and retaining talent. Duct sealing implementations are often expected to happen during nights and weekends, such that interruptions to business operation can be avoided. This off-hour requirement often does not appeal to prospective employees. Once hired, there is a cost to train the employee. If a well-trained employee leaves the company, there is also the cost of that loss. This interviewee estimated that it costs their company about $50,000 a year.

Another common barrier across all sectors is the documentation and verification of results. In commercial buildings, it can be challenging to document and quantify the actual reduction in duct leakage achieved through sealing. Building owners and facility managers may be hesitant to invest in duct sealing if the results cannot be measured and verified. This issue becomes even more challenging in large commercial buildings with complex HVAC systems and ductwork networks as it becomes increasingly challenging to isolate and assess the impact of duct sealing. For example, in large commercial buildings, there is a need for extensive testing to ensure that duct leakage has been sufficiently reduced. This process can be costly and challenging.

Another barrier mentioned by an interviewee with experience implementing similar utility programs was focused on challenges achieving target leakage rates. In some applications, the existing construction did not allow adequate sealing to be implemented. For example, large holes were concealed behind walls that could not be removed, and the holes were too large to be addressed with aerosol sealant applications. Even though noticeable reductions in leakage were measured, the final results were not good enough to meet the target, and therefore no incentive could be paid out. The interviewee suggested that an incremental savings plan could be implemented to ensure that some improvement still gets rewarded.

Market perception and awareness of duct sealing technologies is another factor that plays a crucial role. Many building owners may not be fully aware of the benefits of duct sealing or may underestimate the extent of duct leakage in their building. Interviewees shared thoughts supporting the lack of awareness. One building owner and one installing contractor each noted an industry perception that aerosol sealant is viewed as a last resort, as many building owners are uncomfortable implementing a new technology that differs from the manual methods that are more common with new construction.

Utility Program Measure Development

The following section presents some of the market characterization findings and analysis that utilities need in order to develop a new measure package for duct sealing in commercial buildings. Other findings and analysis will be presented in a following CalNEXT study on Energy and Cost Savings Analysis. Together the two studies will support the development of a new measure package for duct sealing in commercial buildings.

Market Segment

The research team determined applicable and target markets based on Database for Energy Efficient Resources (DEER) prototype buildings. The applicable building types are those that are likely to have HVAC system types with ductwork that may benefit from duct sealing. The target building types are those that have characteristics described in the Identifying Opportunities section above, the most common of which are:

- Buildings that operate at or near 24 hour/day, 7 days/week
- Constant volume HVAC systems, or systems with limited turndown where the duct pressure remains elevated
- Healthcare, manufacturing, and airport buildings
- Systems with ductwork installed outside, such as with some rooftop HVAC units

Table 4 summarizes the applicable and target markets by building types.

Table 4: Applicable and Target Markets by DEER Prototype Building

Name	Description	Applicable Market	Target Market
Asm	Assembly	X	
ECC	Education - Community College	X	X
EPr	Education - Primary School	X	X
ERC	Education - Relocatable Classroom	X	X
ESe	Education - Secondary School	X	X
EUn	Education - University	X	X
Fin	Financial buildings, incl. banks	X	
Gro	Grocery	X	
Hsp	Health/Medical - Hospital	X	X
Htl	Lodging - Hotel	X	
Lib	Libraries	X	
Mtl	Lodging - Motel	X	
Nrs	Health/Medical - Nursing Home	X	X
OfL	Office - Large	X	X
OfS	Office - Small	X	X
RFF	Restaurant - Fast-Food	X	X
RSD	Restaurant - Sit-Down	X	X

Name	Description	Applicable Market	Target Market
Rt3	Retail - Multistory Large	X	X
RtL	Retail - Single-Story Large	X	X
RtS	Retail - Small	X	X
SCn	Storage - Conditioned	X	
WRf	Warehouse - Refrigerated	X	

Technology

The most common duct sealing technologies are:

- *Manual taping*: In the manual taping method, a duct-sealing-duty tape product is applied over each duct opening and adhered to the immediately surrounding ductwork. Manual taping remains a common method in residential and commercial duct sealing projects, though it lacks the durability of other methods. Due to concerns with durability, the research team discourages the use of manual taping for small leaks less than 1/4-inch and recommends that it is reserved for limited applications where other manual methods cannot feasibly address larger duct leaks. When needed, a manual taping product must demonstrate durability of at least five years of effective performance, such as with some butyl tape products, and the customer should confirm its performance annually.
- *Mechanical fastening*: Mechanical fastening generally involves the application of mechanical fasteners, possibly in combination with additional duct material, across duct openings. Mechanical fastening is often used in conjunction with sealants like mastic to provide a robust and secure physical connection, especially in larger duct systems.
- *Mastic*: A mastic is a type of sealant that is initially applied in a viscous, liquid state. Depending on the application, mastic is typically applied with an assortment of hand tools, such as a paint brush, a hand trowel, or a caulk applicator. Mastic is a widely used sealant for ductwork, particularly in residential and commercial HVAC systems.
- *Aerosol sealant spray*: Nontoxic aerosol spray sealant is an advanced duct sealing technology that has gained market traction, especially in situations where duct access is limited. Aerosol sealant has been described by installers as an atomized glue-like product that is injected into pressurized ductwork. From there, the aerosol sealant is inevitably carried to each opening by the leaking airstream.

Eligibility and Feasibility Considerations

Any existing building within the applicable building types could be eligible for the duct sealing retrofit measure. To confirm the savings potential of a candidate building, a flow hood measurement test should be done to estimate the baseline leakage rate. A flow hood measurement test is typically, but not always, an effective strategy for candidate identification. For applications where a flow hood measurement test is impractical, a pressurization test may be performed.

After the building has been confirmed as an ideal candidate for duct sealing, a pressurization test should be conducted to more accurately record the baseline leakage. This baseline will be compared to a final pressurization test to calculate actual performance results.

While any building may be a candidate, there are some considerations that may make a duct sealing retrofit challenging:

- Leaks are difficult to locate and could potentially be large. Manual methods may work well where the leaks are easy to locate and are accessible. Aerosol sealant works well for smaller leaks. Large and hard to locate and reach leaks may not be feasible to seal. A small number of such leaks could prevent a duct sealing retrofit from meeting specific target leakage rates. Therefore, it is recommended that any future measure packages set up measure eligibility to be based on leakage reduction percentages rather than absolute leakage rates. Furthermore, some systems may require multiple methods of sealing, i.e., mechanical for large leaks and aerosol for many small leaks in order to effectively treat leakage. Therefore, it is recommended that any measure package include eligibility for various sealing methods to be used.
- Newer construction and older construction that were built and tested to a high-pressure class may already have relatively low leakage rates and may only see marginal benefits from a duct sealing retrofit.
- Buildings with short operating hours may have smaller overall energy savings opportunities from duct sealing.
- Large commercial systems with many sensitive components, i.e., reheat coils and smoke dampers may require significant labor to protect those components during an aerosol sealing process, affecting costs and HVAC downtime. Therefore, simpler systems such as single zone or rooftop unitary systems are likely easier targets for deemed measures.
- Buildings with 24-hour occupancy present challenges in situations where occupants must be vacated from the space while the sealing labor is performed and the HVAC equipment is down.

Expected Improvement

Baseline Existing Conditions

Historical codes and standards demonstrate that various amounts of duct leakage have always been permissible depending on the publication year, the duct system type, and the ductwork design operating pressure. Until 2020, many ductwork systems were only required to be sealed such that leakage would not exceed roughly 20 percent, though some systems were allowed to reach up to roughly 35 percent leakage. Furthermore, duct leakage testing is only required in limited applications, such as portions of ductwork that operate at relatively higher pressures, usually greater than three in. w.c., or portions of ductwork that are installed exterior to the building.

End Condition

An effective duct sealing retrofit can decrease leakage by 70 to 90 percent. Consider that an existing duct system with an initial condition of 30 percent leakage may be reduced to about five percent leakage or better, where percent leakage is expressed as percent of total system airflow rate. Specific results will vary depending on each application. A combination of aerosol sealant and manual sealing methods will generally achieve the greatest results. The research team recommends that a measure package include an incremental savings plan to ensure that some improvement may be awarded in situations where existing conditions will not allow for optimum leakage reduction.

Conclusions

This study produced an analysis of the current duct sealing technology market.

Table 5 summarizes the comparison and evaluation of the four major duct sealing technologies: manual taping, mechanical fastening, mastic, and aerosol sealant spray. Each technology has its strengths and weaknesses and is the best option for some situations. Aerosol sealant spray is a good fit for applications where the leak openings are smaller and are difficult to locate or the ductwork is not accessible. This is common of existing ductwork that has unsealed joints, seams, or penetrations. If the leaks are easy to locate and the ductwork is accessible, then mastic, or mechanical fastening combined with mastic, may be a good application. A durable duct-sealing-duty tape, such as butyl tape, may be considered for leaks that cannot feasibly be repaired with other methods.

Findings from this study will help inform a measure to incentivize customers to test and seal existing ductwork. Historically weak duct leakage testing and sealing requirements yield a large market with duct leakage rates of 10 to 20 percent or higher. Any duct system that has not been previously required to pass a duct leakage test presents an opportunity. Conditioned supply air leaking from ductwork has significant energy impacts in existing buildings, in that fan energy, cooling energy, and heating energy are all wasted. Exhaust air leakage into ductwork impacts fan energy and leads to excess infiltration, in which the conditioned supply air equipment must work harder to overcome the unintended infiltration of warm air in the summer and cold air in the winter.

Such a measure has huge savings potential, as studies have demonstrated that efforts to seal existing ductwork leakage have yielded annual HVAC energy savings of 15 to 30 percent. It is noteworthy that ductwork leakage is a problem that persists during all hours that HVAC equipment is operating, unlike other HVAC challenges that may be isolated to seasonal conditions, i.e., economizer or heating inefficiencies.

Table 5: Summary of Technology Comparison and Evaluation

	Good Applications	Training/ Expertise Required	Cost	Effectiveness	Risks
Manual taping	Leaks are easy to locate and ductwork is accessible	No specialized training	Low	Low	Safety risk when working at elevated heights Poor long-term performance
Mechanical Fastening	Leaks are easy to locate and ductwork is accessible. Leaks with openings greater than 1/4-inch Round duct common in small buildings	Requires specialized training	High	Low when used alone High when combined with mastic or aerosol sealant	Safety risk when working at elevated heights
Mastic	Leaks are easy to locate and ductwork is accessible	Requires specialized training	High	Medium	Safety risk when working at elevated heights Environmental impacts with some mastics
Aerosol sealant spray	Leaks with smaller openings Ineffective or unsealed duct joints, seams, penetrations	Requires significant specialized training	High	High when openings are smaller	Sensitive equipment needs to be protected (coils, smoke dampers) Aerosol can leak out into building if large holes remain, and precautions are not taken

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