Duct Leakage and Retrofit Duct Sealing in Minnesota Commercial and Institutional Buildings

BACKGROUND
Air leakage from distribution ductwork wastes energy by increasing fan power and discarding conditioned air. In Minnesota commercial and institutional (C&I) buildings, HVAC fans consume about 2,800 GWh of electricity per year (EIA 2008). Assuming about 5% duct leakage, approximately 380 GWh of fan power are lost on duct leakage per year. Duct leakage also results in significant heating and cooling energy penalties when conditioned air leakage is discarded from the envelope in exhaust or relief air systems.

Duct leakage has traditionally been framed as a performance issue rather than an energy efficiency issue. However, a significant body of research developed over the last 20 years suggests that duct systems are not particularly tight and may be a major energy inefficiency in building HVAC systems. This discovery coincides with the development of a novel, patented sealing process (Aeroseal) that makes it possible to tightly seal ductwork in retrofit applications. The Aeroseal method requires significantly less access compared to traditional methods, and it may represent a path toward cost-effective energy savings from retrofit duct sealing.

The growing recognition of duct leakage as a major cause of HVAC energy waste provided motivation to explore the possibility of retrofit duct sealing as an energy efficiency opportunity in Minnesota. This project characterized duct leakage in several types of Minnesota C&I buildings, completed retrofit duct sealing on a subset of C&I duct systems, and estimated the energy savings and cost effectiveness of retrofit sealing measures. The project then analyzed the results to develop screening criteria that displace cost-prohibitive leakage measurements and tested the criteria in a short pilot program to identify cost-effective duct sealing opportunities.

How it Works
Conventional duct sealing methods typically utilize tapes and mastics applied via spray or brush. These methods are challenging to apply in a retrofit fashion due to limited accessibility from external insulation and other building elements in a finished building. A relatively new system (Figure 1) developed by Aeroseal for sealing ducts does not share this limitation. Rather, it relies on injecting an aerosolized sealant at a single point in a duct system that is isolated by blocking. The aerosol sealant is delivered by a fan that pressurizes the ductwork, forcing the airflow carrying the sealant to escape through the leaks. As the air escapes through the leaks, the aerosol particles deposit on the surface of the leaks, sealing them over time (Figure 2). The Aeroseal method eliminates most access issues, thus extending the feasibility of retrofit duct sealing measures.

Commercial Duct Sealing Requirements
Minnesota building code was updated in January 2015 to effectively require complete duct sealing on supply and return ducts to Class A (approximately 1% to 7% duct leakage as measured in this study). Prior to this, duct sealing requirements were less stringent for low pressure (<2” w.g.) ducts. However, with the new code, low and medium pressure ductwork (<3” w.g.) is exempt from leakage testing requirements, whereas it is required that 25% of a high pressure ductwork system (≥3” w.g.) is leakage tested. While in theory this increase in sealing specification should reduce duct leakage on low pressure systems, there is still opportunity for retrofit duct sealing on older systems as well as those...
constructed after 2015, due to the absent testing requirements under current code.

Figure 2: Aeroseal sealant accumulates at the small, distributed leaks in a duct system. The left image shows a large 3/8” corner leak filled with sealant (viewed from inside). The right image shows a ¼” test hole filled with sealant (viewed from outside).

METHODOLOGY

This study emphasized understanding ductwork in Minnesota C&I buildings and its applicability toward retrofit duct sealing measures. It consisted of three parts:

1. Characterize ductwork in Minnesota C&I buildings. Surveys and interviews of C&I air distribution design engineers and field personal were used to develop expectations for air distribution systems in C&I buildings. This information was used to develop selection criteria to ensure a representative sample of buildings.

2. Measure the duct leakage of 27 systems, carefully selected from a screening of 63 systems. A pressurization method, tracer gas measurements, and a powered flow hood were used to measure leakage and compare against contractor measurements.

3. Seal 20 of the systems using both conventional methods and the Aeroseal method.

Study Objectives

1. Characterize duct leakage in a variety of Minnesota C&I buildings.
2. Seal ductwork using conventional techniques and the Aeroseal method.
3. Estimate the costs, savings, and payback of retrofit duct sealing measures.
4. Develop a screening protocol to identify opportunities for cost-effective duct sealing.
5. Test screening criteria in a pilot program.

Aeroseal Sealing Process

1. Isolate ductwork — Systems are typically sealed in sections, with fans turned off and a portion of the system blocked. This usually requires taping in place custom cut pieces of rigid foam to fill the cross sectional area. Large blocking may require backer rods to add strength.

2. Setup the Aeroseal equipment — Setup and connect the equipment to an opening in the isolated ductwork, usually through an access pane or diffuser.

3. Measure pre-leakage — The equipment pressurizes the section of ductwork to the operating pressure and measures initial leakage (cfm).

4. Seal the Leakage — Aerosol sealant is injected into the system, slowly sealing the leaks. Sealing typically lasts 45 to 90 minutes.

5. Measure post-leakage — The equipment pressurizes the sealed section of ductwork to the operating pressure and measures final leakage (cfm).

6. Generate report — Remove the blocking and generate a leakage report, calculating the leakage sealed from the difference between pre- and post-leakage measurements.

RESULTS

Duct Leakage

Duct leakage for C&I ductwork systems was one-half to two-thirds less than anticipated, between 0% and 29% of measured flow rates:

- 75% of systems tested had leakage below 8%.
- Systems with prior sealing had duct leakage that was less than 2%.
- Duct leakage fractions and other leakage metrics were not well correlated to operating conditions or system characteristics.
- Duct leakage measurements taken from tracer gas and pressurization testing methods are prohibitively expensive for identifying retrofit duct sealing opportunities.

Duct Sealing

Retrofit duct leakage sealing was very successful:

- Retrofit duct sealing was successful in 75% of systems using both traditional and Aeroseal methods. Unsuccessful sealing projects had system characteristics that indicate they should be avoided and are easily identified for future work.
• An average of 81% leakage was sealed and the median sealing rate was 86% (Figure 3).
• The Aerosel method was effective in a variety of scenarios, often reducing leakage effectively to zero including:
  - Initially tight and leaky ductwork;
  - Supply and exhaust ductwork; and
  - Upstream and downstream ductwork.
• Blocking ducts for pressurization and sealant delivery is the most expensive component of the Aerosel method.

Figure 3: Percent of original duct leakage sealed via retrofit duct sealing. The systems that were included in the pilot are designated in blue.

Energy & Cost Savings from Duct Sealing
In most sealed systems, the largest fraction of energy savings was from heating energy, followed by fan energy and cooling energy (Figure 4). For a typical system, 64% of energy saved was from heating (natural gas), 29% was from fan energy (electrical), and 6% was from cooling (electrical).

Figure 4: Energy savings from retrofit duct sealing.

The largest portion of cost savings come from reduced fan energy due to the higher cost of electricity (Figure 5). For a typical system, 66% to 75% of cost savings are from reduced electricity, and 25% to 33% of cost savings are from heating (natural gas). Simple payback periods range from 5 years to 142 years, with an average payback of 31 years and a median payback of 17 years.

Figure 5: Cost savings from retrofit duct sealing.

Simple Screening Criteria
The following four criteria can be used to eliminate systems with poor payback and identify systems that are good candidates for cost-effective retrofit duct sealing:

1. **System Type**: Exhaust systems, especially those traversing unconditioned space; supply systems located in ceiling plenum returns; or supply systems with fully ducted returns are preferred.
2. **Operating Pressure**: Operating pressure of at least 0.5” w.g. are acceptable, above 1.0” w.g. are preferred.
3. **Design Flow**: Design flows greater than 4,000 cfm are acceptable, greater than 10,000 cfm are preferred.
4. **Apparent Tightness**: Systems with existing sealant and systems of apparently tight construction are rejected (e.g. spiral, flanged & gasketed ductwork).

Pilot Results
Screening potential systems according to simple criteria in lieu of measuring duct leakage provided a dramatic improvement in cost-effectiveness (Figure 6):

• Average payback was reduced from 31 years to 15 years when the screening criteria were back-tested to original 20 systems.
• Average payback was reduced to 7 years (n = 5) when screening criteria were used as the basis of system selection in a short pilot program.
RECOMMENDATIONS FOR CIP
As energy efficiency upgrades become harder to identify, duct leakage in existing buildings has emerged as a new opportunity. Although measured leakage rates were lower than anticipated, project results suggest that about 10% to 15% of C&I buildings have leakage rates high enough to justify retrofit duct sealing work with moderate to good payback of 7 years or less. In the small sample, careful screening efforts successfully identified the following utility program opportunities.

Measures in Existing Programs
Retrofit duct sealing should be incorporated as a savings measure into existing commercial auditing, recommissioning, and turn-key savings programs. A duct leakage screening process is necessary to quickly identify and rule out systems that are unlikely to prove cost effective. A process based on the results of this report can be immediately included into these services to identify the 10% to 15% of systems that are likely to achieve cost-effective retrofit duct sealing savings. Considering retrofit duct sealing merits alongside more established energy efficiency measures already included in commercial programs may lead to increased adoption, especially when bundled with other measures.

Outreach
Significant outreach efforts are necessary to inform and educate vendors and trade allies about the benefits of tight ductwork and potential retrofit duct sealing measures. Targeted outreach efforts are necessary so that informed vendors can evaluate retrofit duct sealing opportunities and recommend them where feasible.

New Construction
While not considered in this project, one of the most promising applications of commercial Aeroseal duct sealing is new construction. In light of code changes requiring the sealing of all commercial ductwork to Class A specification, the Aeroseal method should be able to compete with traditional duct sealing measures in new construction. Medium and high pressure ductwork requires testing so the total cost of the Aeroseal method may be competitive with traditional duct sealing and separate testing processes. Even without testing requirements, lower pressure ductwork can benefit from sealing and testing upon construction, especially small systems, where it will be difficult to achieve cost effectiveness with retrofit opportunities.

In addition, sealing ductwork prior to balancing and commissioning offers guaranteed savings. These savings would be significant and could qualify for rebates, even if one assumes the moderate rates of leakage encountered in this project.

FUTURE WORK
While this research validated the potential of retrofit duct sealing in Minnesota C&I buildings, continued efforts are necessary to refine the understanding of opportunities, savings, and costs. In light of the uncertainties regarding the cost effectiveness of retrofit duct sealing measures, we recommend collaboration with duct sealing and commercial program vendors to create and maintain a database of screening and sealing results that will allow for continued improvement of screening efficiency and the ability to predict energy and cost savings.

Author Contact:
Josh Quinnell, Ph.D.
Senior Research Engineer
(612) 244-2437
jquinnell@mncee.org

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