PROJECT REPORT

SPEED PROGRAM DEMONSTRATION FOR SEALING DUCT LEAKS USING AEROSEAL

The Art Building
UC Davis, CA

March 19, 2014

WESTERN COOLING EFFICIENCY CENTER

UC DAVIS
UNIVERSITY OF CALIFORNIA







PREPARED FOR:

Karl Johnson

California Institute for Energy & Environment
1333 Broadway, Suite 240
Oakland, CA

PREPARED BY:

William Allen
Senior Engineer

David Grupp
Associate Engineer

Paul Fortunato
Outreach Coordinator

Western Cooling Efficiency Center
University of California, Davis
215 Sage Street #100
Davis, CA 95616

wcec.ucdavis.edu

ABOUT THE WCEC

The Western Cooling Efficiency Center was established along side the UC Davis Energy Efficiency Center in 2007 through a grant from the California Clean Energy Fund and in partnership with California Energy Commission Public Interest Energy Research Program. The Center partners with industry stakeholders to advance cooling-technology innovation by applying technologies and programs that reduce energy, water consumption and peak electricity demand associated with cooling in the Western United States.

ABOUT THE STATE PARTNERSHIP FOR ENERGY EFFICIENT DEMONSTRATIONS (SPEED) PROGRAM

The SPEED program is supported by the California Energy Commission and managed through the California Institute for Energy and Environment (CIEE). SPEED demonstrations are coordinated by the CIEE in partnership with the California Lighting Technology Center and the Western Cooling Efficiency Center, both at the University of California, Davis.

TABLE OF CONTENTS

SECTIONS

Figures

TABLES

1.0 EXECUTIVE SUMMARY

UC Davis Art Building in Davis, California

DEMONSTRATION SAVINGS	
Peak Savings	19%
Total Conditioned Energy & Co_2 Savings	19%
Energy Reduction	42,085 kWh/yr
Heating Energy Reduction	3,651 Therms/yr
Lifetime Energy Cost Savings	**$113,060*** (*for 20 yr life based on Table 5)

Ductwork in forced air systems can leak significantly, causing poor air balance, direct losses of conditioned air, short-circuiting between supply and return systems, and increased fan power requirement to achieve desired diffuser flow rates. Sealing ducts in existing buildings is frequently unfeasible due to difficulties accessing the ductwork in shafts and plenums. Aerosol duct sealing is a method for repairing leaks without having to locate and access points of leakage. Instead leaks are repaired by injecting aerosolized sealant into the ductwork and allowing it to find the leaks which are sealed as the sealant deposits on the edges of the leaks.

This report details the sealing of the UC Davis Art building duct system using the Aeroseal process, and describes the savings that can be expected based on measurements of the pre-seal airflows and historic energy usage, combined with measurements of the degree of sealing achieved. Savings are predicted due to both reduced fan energy required to deliver air to the registers, and to the elimination of loss of conditioned air.

Site Overview

The UC Davis Art building is a 32,000 sq. ft. 3-story (plus basement) building. The building is used for a combination of offices and studios and utilizes a 100% outside air ventilation system with ducted supply and exhaust. Outdoor air is drawn into the basement, where three air handling units condition air for supply to the building. Each air handler supplies a single floor, each with three zones, for a total of 9 zones. Three exhaust units on the roof remove air from the building. The exhaust fan speeds are controlled to maintain pressure in the corridors at zero with respect to outdoor air pressure. Both supply and exhaust ductwork runs are primarily in corridors and plenum space and run in and out of conditioned spaces.

2.0 ABOUT THE TECHNOLOGY

This sealing process is a technology that was developed at Lawrence Berkeley National Laboratory and commercialized under the Aeroseal name. It involves the simultaneous injection of aerosolized sealant and carrier air into the duct system, with any desired openings (e.g. fans, air handlers, registers) blocked off. A fan and airflow meter are connected to the duct system to supply and measure carrier airflow to the duct system, pressurizing the duct from the inside. The sealant injector is inserted downstream of the air injection point. The sealant pump supplies room temperature liquid sealant to the injector and a separate stream of heated compressed air mixes with the sealant at the injector nozzle discharge.

Sealant particles are created by atomization and drying of the liquid sealant stream leaving the injector nozzle. The carrier airflow transports the sealant particles to the leaks, there the particles collide and accumulate with the edges of the leaks and seal them. To pressurize large duct systems, or systems with high leakage rates, multiple fans can be used (see Figure 1).

Monitoring the duct pressure and the fan airflow allows continuous determination of the effective leakage area and hence the sealing rate. As leaks seal the effective leak area decreases and the carrier airflow decreases. This lowers the sealing rate due to a reduction in particle transport in the carrier air. The process is stopped when the sealing rate becomes impractically slow or a predetermined level of leakage reduction is achieved.

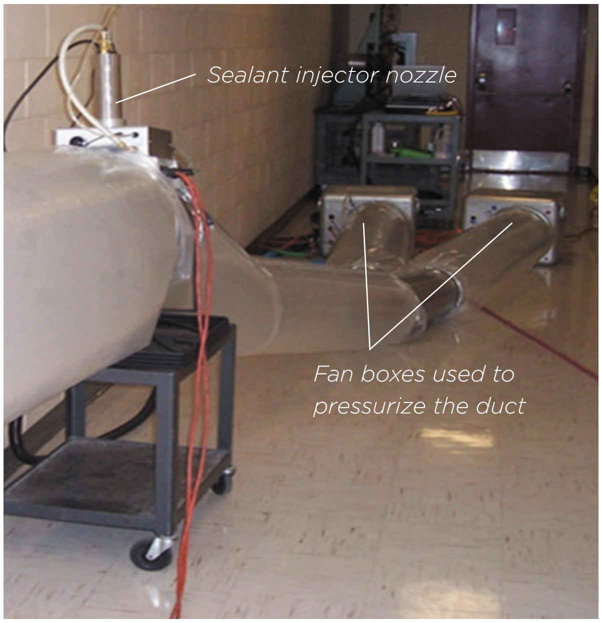

Figure 1: Two fan boxes connected in a Y configuration to the sealant injector nozzle

Figure 2: Close up of the sealant injector nozzle

3.0 DEMONSTRATION: THE ART BUILDING AT UC DAVIS

The UC Davis Art Building is a three story building and is served by three large air handlers setup to supply 100% outside air to the building. Each air handler supplies air to a single floor, with the exception of the first air handler which also supplies air to the basement. Three large exhaust fans located on the roof maintain proper pressure inside the space. These exhaust fans are controlled by pressure sensors set to maintain neutral pressure in the corridors where there are large exhaust vents. Any conditioned air leaking into the corridors will therefore be exhausted from the building before it can condition the classrooms, studios, or offices. The reduction in leakage rate will therefore translate directly to a reduction in required airflow yielding both fan power savings and heating and cooling savings.

In addition to not conditioning the occupied working space, leaks from the supply into the corridors will also cause the exhaust fans to run at higher speeds to maintain neutral pressure in the corridor. This results in more air being exhausted unnecessarily from the rooms and increases the building load.

Sealing was scheduled to be carried out over a 10 day period in September 2013 when the Art building at UC Davis was unoccupied. Sealing was carried out sequentially on the 9 zones of the supply system and the three exhaust ducts. During sealing it was found that the shaft for Exhaust Fan 1 was leaking to such an extent that it was not possible to sufficiently pressurize the duct to allow the Aeroseal system to work. Inspection suggested that the leaks were occurring where the vertical concrete shaft joined the horizontal duct branches. Sealing of the ductwork for this exhaust fan was postponed until the major leaks could be manually sealed. This was undertaken by lowering an operator on a bosun's chair into the shaft to manually apply caulk to the joints.

During rebalancing it was also discovered that more

Figure 3: Pre-install testing and recording of flow rates from each of the registers in the building

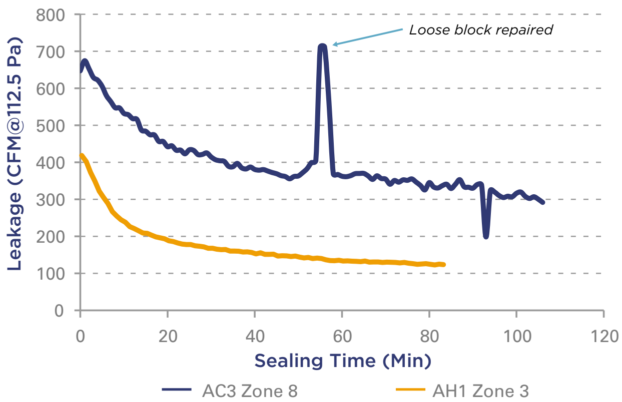

Figure 4: Sealing rates for two separate zones at the UC Davis Art Building. Instantaneous verification allowed the researchers to find and fix a problem with AC3 Zone 8

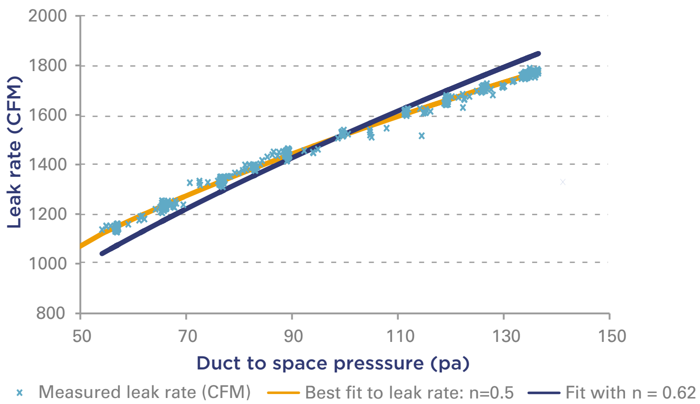

Figure 5: Duct leakage model

than two-thirds of the balance dampers were frozen and required replacement. These were replaced, and the final air balance of the building was completed in March 2014.

Relationship between actual leakage rate and sealing measurements

Leakage rate is given by the formula **$Q=C\Delta P^n$** where Q is the leakage rate, C is a constant, ΔP is the duct-to-space pressure differential. n is a constant that is dependent on the geometry of the leaks. Typicially n varies between 0.5 for circular leaks and 0.6 to 0.65 for rectangular leaks. The leakage rate in a duct in the third floor corridor was measured over a range of pressures. The results are shown in Figure 5. The clear fit to a value of n = 0.5 suggests that the leakage in this system is dominated by circular leaks rather than long slot-like leaks.

Using this value the overall leakage class (the value of C in the formula above) was determined for each air handler from the measurements made during sealing by considering the initial and final leakage rates measured. The resulting information was used to predict expected leakage rates at operational pressures, using the leakage rates measured at low pressure during the duct sealing process.

Leak rates in duct systems will change depending on the duct pressure at any given point in the duct and could vary greatly depending on the airflow demanded in any particular branch of the duct. To determine estimates for energy savings without direct observation over many years, an estimate based on measurements and modeling was used.

As a first step, the leakage rate was measured at a low duct pressure of 25 Pa. This is the pressure at which the aerosol sealing process operates and the measurements are taken immediately before and after the sealing process. (TABLE 1)

Using the leakage rate observed at 25 Pa, and with the knowledge that the three air handlers are set to run at 0.9 inches of water, or 225pa, a prediction for leakage rate at operational pressures can be made. Using these assumptions the modeled pre and post

Air handler	Pre seal leakage rate CFM25	Post seal leakage rate CFM25
AH1	1,046	173
AH2	1,024	158
AH3	759	256

Table 1: Measured leakage rates at 25Pa duct pressure

Air handler	Pre seal leakage rate CFM225	Post seal leakage rate CFM225
AH1	3,469	573
AH2	3,396	524
AH3	2,517	849
Total	9,382	1,946

Table 2: Modelled leakage rates at 225 Pa duct pressure

Air handler	Full speed airflow at air handler (CFM)	Sum of diffuser airflows (CFM)	Pre Seal Leak rate (CFM)
AH1	17,218	14,434	2,784
AH2	20,166	15,506	4,660
AH3	22,185	19,267	2,918
Total	59,569	49,207	10,362

Table 3: Pre-seal measured leakage rates at full speed operation

Air handler	Pre seal airflow CFM	Modelled Reduction in leakage CFM	Post seal airflow required CFM	Percentage of preseal flow required
AH1	17,218	3,469	13,749	80%
AH2	20,166	3,396	16,770	83%
AH3	22,185	2,517	19,668	89%
Total	59,569	9,382	50,187	84%

Table 4: Percent of airflow required after sealing

seal leakage in CFM for the three air handlers at normal operating settings and full speed (Table 2) was determined.

To validate these modelled results, comparisons were made to actual measured leakage rates measure during operation. To do this the full speed airflow rate was measured using a duct traverse method at each air handler prior to the duct sealing. The flow rate measured at the air handler was then compared to airflow measured at all the diffusers to determine actual leakage rates. (Table 3).

Comparing the modelled prediction for leakage rate based on the low pressure measurement of Table 1 to the measured results of Table 2, it can be seen that the actual leakage rate is approximately 10% higher than the rate predicted by the low pressure measurements. This suggests that actual savings may be higher than what might be predicted by the low pressure testing.

Based on the measured reduction in leakage rate, the fans can be adjusted to deliver less air to the duct system while still maintaining the intended flow to each room. (Table 4)

This analysis shows that significant savings can be expected from duct sealing and properly adjusting supply fan flow rates to take advantage of reductions in duct leakage. It should be noted that this analysis only takes into account the power saved from re-ducting the supply flow rate, the additional power saved by reducing exhaust fan flow should result in even more savings than this analysis predicts and will be the subject of further study. This extra savings not accounted in this analysis may be on the order of and additional 10% - 15%.

3.1 Economic Evaluation

	Supply fan energy	Exhaust fan energy	Heating energy	Cooling energy	Total
Actual use	36,451 kWh	14,210 kWh	22,816 therms	132,883 ton-hr.	
Cost	$2,114	$824	$20,078	$7,707	**$30,723**
Modelled post sealing use	18,228 kWh	11652 kWh	19,165 therms	111,579 ton-hr.	
Modelled cost	$1,057	$676	$16,865	$6,472	**$25,070**
Savings (per year)	$1,057	$148	$3,213	$1,235	**$5,653**

Table 5: Cost and savings analysis based off of modelled data

UC Davis Facilities Management uses a cost of $0.072/kWh for electricity. For cooling, the central chiller uses 0.8kW/ton giving a cost of $0.058/ton-hr. The cost of gas is $0.70/therm and a boiler efficiency of 80% giving a cost of $0.88/therm of heating delivered to the building. Table 5 summarizes the total energy use by the building over the course of the 2011/2012 academic year and compares the measured values before sealing with the modelled values after sealing. The largest savings, in percentage terms, are in the supply fan energy use, where a relatively small reduction in airflow results in significant power savings.

For this case study it was found that the cost of the sealing process was $78,175, with savings expected to be $5,653 per year. This results in a 14 year simple payback period. As previously detailed, it is likely that the actual savings will be higher than the modeled savings due to reduced infiltration after rebalancing and additional exhaust fan power savings.

While energy savings results was the main focus of this study, many other important findings were made. Consideration should be made for allowing ample time to quote the project as currently there are only a handful of contractors able to perform this work. Scheduling also needs to be taken in consideration for periods when the building is the most free of occupants. Extra benefit can be captured by performing other deferred maintenance simultaneously, such as replacing inoperable dampers and performing duct cleaning.

Challenges remain in predicting the energy savings that can be expected from implementing this technology. With this work complete, savings due to duct sealing will be directly measured over the next years of operation to further refine the energy and financial models used in this report.

4.0 Collaborators

California Energy Commission provided funding for the pre- and post-sealing airflow measurements. UC Davis Facilities Management funded the sealing and post seal balancing. Air flow measurements were made by Penn Air. California Institute for Energy and Environment, UC Davis Western Cooling Efficiency Center, provided project management, technical guidance, and performance evaluation.

Any questions about this project, including technology costs, can be directed to:

WILLIAM ALLEN
UC Davis
Western Cooling Efficiency Center
wdallen@ucdavis.edu
wcec.ucdavis.edu

KARL JOHNSON
California Institute for Energy and Environment
Karl.johnson@uc-ciee.org
uc-ciee.org

For more resources and information, including technology catalogs, business case studies and demonstration maps, visit PARTNERSHIPDEMONSTRATIONS.ORG.