FIELD EXPERIENCE WITH SEALING LARGE-BUILDING DUCT LEAKAGE WITH AN AEROSOL-BASED SEALING PROCESS

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ABSTRACT

This paper describes a limited set of large-building applications of a process that uses aerosolized sealant particles to seal leaks in duct systems, focusing in particular on sealing duct leakage in exhaust systems. The process was first commercialized for sealing residential ducts in the late 1990's, but has been applied increasingly to larger-building duct systems. The technology has been applied in a variety of large-building exhaust duct sealing applications, ranging from sealing leakage in large exhaust systems in laboratory buildings, to sealing leaks in exhaust systems in hospitals, to sealing toilet exhausts in large commercial office buildings, to sealing leaks in toilet/kitchen exhaust shafts in low- and high-rise apartment buildings and hotels. Observed initial leakage rates, sealing accomplished, and some of the issues encountered in these applications are presented. The rationales for having this leakage sealed are presented, as are some of the techniques applied when conducting this type of sealing. Overall, the average duct leakage encountered in these buildings was 28% of fan flow, and aerosol process sealed over 90% of that leakage.

KEYWORDS

Aerosol, duct, exhaust, sealing, shafts

1. INTRODUCTION

Over the past 15 years, the subject of duct leakage in buildings other than single family residences has received considerable attention by various researchers (Cummings et al 1996, Delp et al 1998, Delp et al. 1998b, Franconi et al. 1998). This work has included characterizing the stock of duct systems in large commercial buildings (Modera et al. 1999), characterizing duct leakage levels and efficiency metrics for commercial-building thermal distribution systems (Diamond et al. 2003), field testing the impact of supply duct sealing in an office building (Diamond et al. 2003) and a light commercial building (Sherman et al. 2002), as well as the development and application of an aerosol based sealing technology applicable to large commercial buildings (Diamond et al. 2003).

Duct-system research at Lawrence Berkeley Laboratory (LBNL) also resulted in the development of a technology for sealing duct leaks from the inside by Carrie and Modera (Carrie and Modera 1998, Modera et al. 1996). This technology seals leaks in ductwork from the inside by pressurizing the duct system with a fog of atomized sealant particles. By temporarily blocking all the normal exits from the duct system (as well as any coils or fans) the fog is forced to the leaks. The acceleration of the air through the leaks causes the sealant particles to leave the air stream and deposit on the leak edges. By the right choice of particle size, duct flow rate and duct pressure, the particles remain suspended as they travel through the duct system, and thus only a very small fraction of the particles deposit on the duct walls.

The aerosol sealing technology was initially applied to single-family residences, becoming commercially available for that market in 1999. The first commercial applications of the technology in large buildings started in 2003 with the introduction of a new atomization technology that significantly increased sealing rates, and allowed the sealant to be atomized inside the ductwork instead of externally.

This paper presents some field experiences and results related to sealing exhaust systems in large buildings. The issues touched upon include: 1) impetus for sealing, including duct leakage identification, 2) measured duct leakage levels, 3) duct sealing results, and 4) some techniques applied to accomplish this sealing.

2. IDENTIFYING LEAKAGE IN LARGE BUILDINGS

The impetus for duct sealing in large buildings can come from several different driving forces: 1) test and balance reports that indicate duct leakage and/or inadequate zone flows, 2) code driven requirements for flows or pressures for new construction or renovation, 3) comfort and/or pressure control complaints, and sometimes 4) a desire to save energy. These sources are more or less listed by frequency of occurrence. In general, knowing whether the ducts in an existing large building are leaking is considerably more difficult and expensive than uncovering duct leakage in single family residences. Test and balance reports provide a reasonably certain indication of leakage, however such measurements are generally too expensive to be performed solely to look for duct leakage. Some simplified techniques for quantifying duct leakage in specific applications have been developed, in particular for measuring leakage downstream of VAV boxes (Modera, 2007), and for estimating leakage in modest-length bathroom exhaust shafts.

2.1. Observed Impetus for Sealing Duct Leakage

For the buildings listed in Table 1, which represent a modest subset of the large-building exhaust systems that have been sealed over the past several years, there were several different reasons why the building owner decided to have sealing performed. In the case of the hotels, the reason for sealing varied. For Building 1, which was new construction, the driving force was a need to pass exhaust-duct leakage criteria that turned out to be tighter than the initial construction could pass. For the other two hotels, the driving force was to assure that the pressure-independent bathroom grilles being installed would have enough pressure to work properly.

The rationale for sealing leakage in exhaust shafts in apartment buildings (Buildings 4-7) included a desire to save energy, a desire to provide more uniform (temporal and spatial) ventilation, and in the case of Building 7, a desire to produce the desired ventilation when switching the shafts from naturally driven to fan-driven flow. In other instances, the rationale has been to reduce overall ventilation rates (e.g. as allowed by code changes in New York City), without risking unreasonably low ventilation rates in some apartments, or under some weather conditions.

In the case of the toilet exhaust in the office building, the driving force for sealing was to address tenant complaints about odors in the men's and women's restrooms. For the hospital denoted as Building 9, the driving force was to meet the exhaust flow requirements needed for occupancy, which were not being met based upon flow measurements at the grilles. For the laboratory building (Building 11), the driving force was a desire to save energy. In such a building, as in a hospital, the HVAC systems are typically single-pass (i.e. 100% outdoor air), which means that any unnecessary exhaust needs to be made up with additional outdoor air that needs to be heated or cooled. In addition, significant fan power savings are made available in such a building by the fact that fan power scales with the cube of the volume flow rate in an exhaust system.

Table 1: Examples of Buildings Seeking Exhaust Duct Sealing

Building Type	Bldg.	Bldg. Age	Bldg. Size [m^2]	Bldg. Stories	Location	Exhaust System
Hotel	1	2007	~150,000	57	Las Vegas, NV	Bathroom
	2	2005	>200,000	45	Las Vegas, NV	Bathroom
	3	2008	>100,000	63	Las Vegas, NV	Bathroom
Condominium/Apartment/Dormitory						
Condominium	4	1971	~70,000	40	Boston, MA	Bath/Kitchen
Dormitory	5	2003	4,600	6	Columbus, OH	Bathroom
Apartments	6	1979	~25,000	23	Camden, NJ	Bath/Kitchen
Apartments	7	1960s	N/A	5	Bordeaux France	Bathroom
Large Office Bldg.	8	1958	300,000	59	New York City	Toilet (one section)
Hospital	9	N/A	N/A	6	San Francisco, CA	General
	10	2012	29,000	3	Abu Dhabi, UAE	General
Laboratory	11	~1965	~4,000	2	Berkeley, CA	General

3. SEALING LEAKAGE IN LARGE BUILDINGS

Some of the sealing data from the buildings identified in Table 1 is summarized in Table 2. In general sealing ducts in large buildings (exhaust systems or otherwise) with aerosol injection is considerably more complicated than sealing ducts in single family homes. For example, sealing exhaust shaft/duct leaks in a multi-family apartment building requires simultaneous access to all of the apartments being served by a specific shaft, which means that occupants must be informed in advance. In addition, in such an application, it is essentially impossible to completely vacate the building during injection, which means that extra care needs to be taken. This problem is easier to handle in a hotel, where the management can select the rooms to be left vacant.

Another issue in tall buildings is the stack effect created by the temperature differential between indoors and outdoors. The stack effect both creates measurement issues (not being sure exactly where to measure the pressure difference between the ducts and their surroundings), and minimal or even negative pressure differentials across the duct walls (which can make the sealing process slow or even impossible). Both of these problems are reduced or eliminated by performing the sealing process at a larger pressure differential, thereby reducing the relative magnitudes of the stack effect.

It should also be noted that there is a distinct advantage associated with sealing vertical ducts/shafts with an aerosol, namely that because the ducts are vertical, the issue of aerosol particles settling onto the bottom of the duct due to gravity essentially goes away. As long as the injection is performed from the top of the ductwork, gravity essentially helps transport the particles to furthest leaks, as opposed to robbing some particles along the way as in a horizontal duct system.

The standard of care is also elevated in a hospital situation, where vacancy is generally not an option, and neither is dispersion of aerosol particles. In the case of Building 9, the sealing process was initiated, and was found not to provide any reduction in leakage. As there appeared to be no good reason for why it did not seal, a camera was dropped down the shaft to look for a gross leak in the system. As it turned out, the problem was an open access door to the duct, one that the long-term building operators claimed did not exist until it was found with the camera and shown to them. In this case, the size of the opening for the access was determined to be roughly large enough to account for the measured leakage flow (~4000 cm^2), and remobilizing to seal the remaining leakage was deemed not to be cost effective.

The laboratory system that was sealed presented some additional complications. These complications included the fact that, like many laboratory buildings, it contained ongoing experiments, some of which are sensitive in nature, and included expensive non-standard equipment. This sensitivity sometimes included access issues, such as to rooms with biological or radiation hazards, or potentially with lasers in operation. This necessitates good communication with the individual investigators in the building, preferably through a trusted building manager. Another challenge encountered in this particular building was the fact that the entire duct system had to be sealed all at once, which entailed blocking all 80 grilles, spread over 4,000 m^2, simultaneously. This necessitates a large crew, and a well-organized system to assure that no grilles were missed. This issue is particularly problematic in a large system with many grilles, as a missing block typically changes the total leakage sensed by the sealing system by only a few percent.

Table 2: Exhaust-System Sealing Results

Building	Nominal Fan Flow [l/s]	Estimated Average Leak Pressure [Pa]	Effective Leakage Area [cm^2]	Estimated Fractional Leakage [%]	Fraction Sealed [%]
1	35,000 (est.)	100	3900	16%	97%
2	128,000 (est.)	50	47,800	36%	93%
3	48,000 (est.)	50	13,700	28%	92%
4	30,000 (est.)	25	11,000	24%	96%
5	7,300	500	512	27%	95%
6	14,500 (est.)	25	8190	36%	81%
7	N/A	80	58	N/A	89%
8	20,400 (treated section)	250	1630	20% (treated section)	96%
9	N/A	N/A	N/A	N/A	0%
10	17,900	250	2340	34%	85% (est.)
11	10,400	150	1670	31%	85%

3.1. Example Sealing Results – Large Office-Building Toilet Exhaust

One sealing application was chosen to be presented in a bit more detail, as this application involved some previously un-encountered issues. The application involved sealing the exhaust ductwork for a large Class-A office building in Manhattan (New York City). The results presented are only for one section of that sealing application, as the remaining data was not immediately accessible. The section reported on is a horizontal run in a mechanical story of the building, combined with a 15-story “express” duct run used to ventilate toilets at least 15 stories below the mechanical story. The nice part of this application was that most of the ductwork was vertical; however because of the size of the building, there was still a long horizontal section on the mechanical story.

The two key issues associated with sealing a large duct system are: a) assuring that an adequate pressure differential can be produced across all the leaks in the system, and b) assuring that the velocity in the horizontal sections is high enough to keep the particles from settling out by gravity. In general, the minimum pressure differential across the leaks for sealing is 10 Pa, however minimum pressures of 25-50 Pa are desired, particularly in a tall building, where the stack effect can change that pressure differential significantly between the top and bottom of the vertical run. The pressure produced by the sealing equipment is a function of the maximum flow that it can provide, as well as by the leakage of the duct system. As the standard fan on the aerosol system can produce a maximum flow of roughly 300 l/s, the most leakage that it could address while maintaining 25 Pa would be roughly 300 l/s@25Pa, which translates to roughly 450 cm^2 of effective leakage area. As the leakage of the treated section of Building 8 has more than three times this leakage (Table 2), it is clear that four separate aerosol system fans would be required.

Turning to the second constraint, the need to maintain adequate velocity to avoid gravitational settling, for the purposes of this paper we will use a target of 1 m/s for that velocity, at least at the beginning of the sealing process. Thus the minimum aerosol fan capacity could also be determined by the cross-sectional area of the ductwork, combined with this 1 m/s target velocity. In this building the horizontal ductwork had a cross-sectional area of roughly 2 m^2, which means that we would need roughly 2000 l/s to produce 1 m/s, or in other words seven aerosol system fans. As this is not a practical or efficient solution, we chose to instead to employ a calibrated "blower-door" fan that can produce up to almost 4,000 l/s under free-air conditions. As these "blower-door" fans are not generally calibrated to operate against the large back pressures associated with the aerosol sealing process (e.g. up to 500 Pa), we had to ask the manufacturer for a special calibration of the fan. In the end, a combination of one aerosol system fan and one blower-door fan (Figure 2) is what was employed in this application, resulting in the sealing plot illustrated in Figure 1. Note that the breaks in the curve correspond to changing the injection point for different portions of the section being sealed.

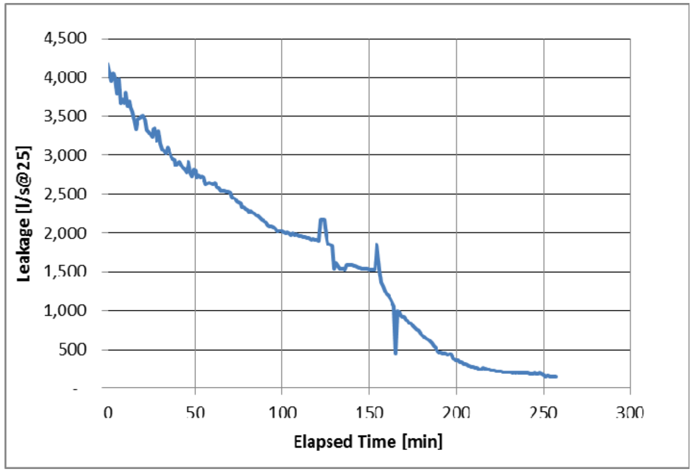

Figure 1: Leakage versus elapsed aerosol injection time for upper section of office-building toilet exhaust that moves 20,400 l/s (Building 8 in Tables 1 and 2)

Figure 2: Blower-door fan being applied in combination with the aerosol sealing system (Building 8 in Tables 1 and 2)

4. CONCLUSIONS

This paper provides a quick look at some of the large-building exhaust duct sealing that has been performed recently with an aerosol-based remote sealing technique. It describes some of the reasons why this sealing was performed, as well as some of the issues encountered in these applications. Based upon what is presented, it is clear that duct leakage was significant in all these applications (averaging 28% of fan flow), and that the aerosol-based sealing process was able to seal roughly 90% of the leakage encountered in small to very-large exhaust systems.

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6. REFERENCES

Carrié, F.R. and Modera, M.P. (1998). *Particle Deposition in a Two-Dimensional Slot from a Transverse Stream*, Lawrence Berkeley Laboratory Report LBL-34829. Aerosol Science and Technology 28(3), March 1998.

Cummings, J. B., Withers, C. R., Moyer, N., Fairey, P., and McKendry, B. (1996). *Uncontrolled airflow in non-residential buildings* Florida Solar Energy Center, FSEC-CR-878-96

Delp, W.W., Matson, N., Dickerhoff, D. J., Wang, D., Diamond, R.C., Modera, M.P. (1998) *Field Investigation of Duct System Performance in California Light Commercial Buildings* ASHRAE Trans. 104(II) 1998, June 1998

Delp W.W., Matson N. E., Dickerhoff D.J., Modera M.P., (1998b) *Field Investigation of Duct System Performance in California Light Commercial Buildings (Round II)* Proc. ACEEE Summer Study 1998

Diamond, R.C., Wray, C., Dickerhoff, D.J., Matson N., and Wang, D. (2003) *Thermal Distribution Systems in Commercial Buildings* Lawrence Berkeley National Laboratory Report LBNL-51860, May 2003.

Franconi, E., Delp W., and Modera, M.P. (1998) *Impact of Duct Air-Leakage on VAV System Energy Use*, Lawrence Berkeley National Laboratory Report LBNL-42417 October, 1998

Modera, M.P., Dickerhoff, D.J., Nilssen, O., Duquette, H., and Geyselaers, J. (1996) *Residential Field Testing of an Aerosol-Based Technology for Sealing Ductwork* Proceedings of ACEEE Summer Study, Pacific Grove, CA, August 1996, Lawrence Berkeley Laboratory Report, LBL-38554.

Modera, M.P., Xu, T., Feustel, H., Matson, N., Huizenga, C., Bauman, F., Arens, E., and Borgers, T. (1999) *Efficient Thermal Energy Distribution in Commercial Buildings* Lawrence Berkeley National Laboratory Report LBNL-41365, August 1999.

Modera M. P. (2007). *Investigation of Leak Sealing for Supply and Exhaust Ductwork* 3rd Industry Workshop - "Energy Efficient Technologies for Buildings – New and Retrofits" Co-sponsored by US DOD, US DOE, ASHRAE, IEA ECBCS Annex 46, Dallas, TX January 25-26, 2007.

Sherman, M.H., Xu, T., Abushakra, B., Dickerhoff, D.J., Wray, C., Wang, D., and Modera, M.P. (2002) *Commercial Thermal Distribution Systems: Measured Energy Impact of Sealing Duct Leaks in Light Commercial Buildings* Lawrence Berkeley National Laboratory Draft Report to the California Institute for Energy Efficiency and the Sacramento Municipal Utility District, Lawrence Berkeley National Laboratory Report LBNL-49470 [DRAFT] April 2002.