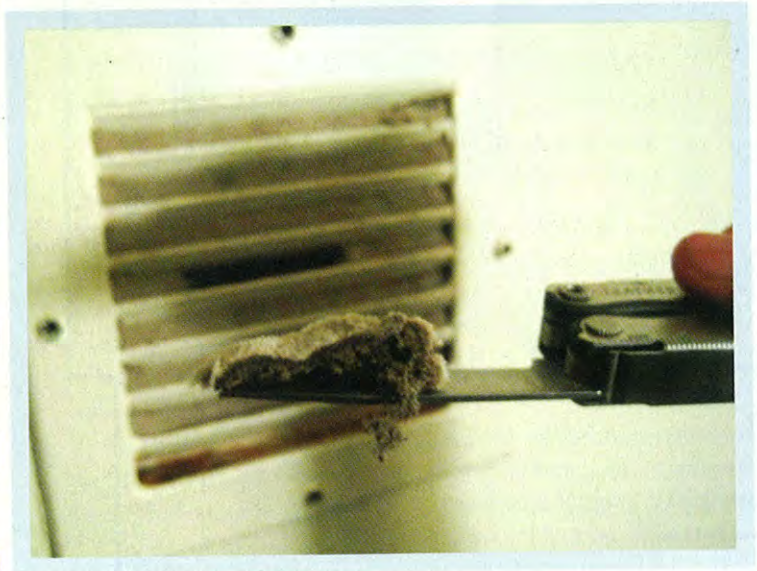
Multifamily Ventilation Retrofits for ENERGY SAVINGS

Photos and Figures by Sean Maxwell

BY SEAN MAXWELL

Ever wonder if there's something you're missing with a multifamily audit—a missed opportunity for energy savings or better indoor air quality (IAQ)? Think about the exhaust ventilation systems that you might have left untouched. It's true—as most tenants will tell you—that they seldom work well. Residents report noise from fans and other apartments, smoke and smells from other apartments, drafts, and too much or too little airflow. Exhaust systems may be passed over during an audit because they seem hard to measure and to retrofit, but there are more options than you may realize.

Most buildings with central exhaust ventilation fall into one of three categories. Case 1 is a building that is generally underventilated, and bringing the building up to levels required by current codes means increasing ventilation rates, and therefore energy use. Case 2 is a building that is overventilated in some areas and underventilated in others, but that has a total ventilation rate that is greater than required by code. Retrofitting this building would mean improving ventilation distribution and reducing overall rates, producing energy savings. Case 3 is a building with a properly functioning ventilation system, which—in our experience at Steven Winter and Associates (SWA) testing both new and existing buildings—is unfortunately rare.



Dirt clogging a bathroom register.

FIRST THINGS FIRST

Before taking a single measurement, take a moment to visually assess the building. Are all the fans working? Are they on timers? What code was the building designed under? If code at the time of construction called for 100+ CFM exhaust from each kitchen, there's a better chance that the building is overventilated by most current codes. Look at an aerial image online—what is the ratio of fans to apartments per floor, and does it seem as if both kitchens and baths have ventilation? Answer these big-picture questions first.

Next inspect the fans themselves. It helps to know whether low flows measured in apartments are due to a poorly operating fan. Many combinations are possible: fans without motors, motors without fans, fans turned "off" but still drawing electricity, loose belts, broken belts, missing belts, and fans rattling around like rock tumblers. Fan timers are also suspect. Over the years, energy auditors and homeowners have installed them to cycle fans off, usually at night. While this practice saves energy, it turns shafts into pathways for pollutants to travel throughout the building when the fans are off. Timers are a bad idea for IAQ.

REGISTER MEASUREMENTS

Once inside the building, the first step in ventilation assessment for most auditors is taking measurements of exhaust

flows from registers in apartments. Various tools—flow hoods and orifice box-type devices—give measurements that show how well the system is balanced. As with supply systems, a large drop in airflow and/or static pressure from the fan to the end indicates leaks in the ductwork, or register openings that are too large to maintain adequate pressure in the system.

We can measure airflows at registers relatively accurately using inexpensive devices, but this tells us only part of the story. A ventilation register may be heavily clogged with dirt or intentionally blocked by the tenant, and the measured flow can be zero. Still, the air that the roof fan draws comes from somewhere. Leaks and disconnects in a duct system also contribute to building exhaust, and many systems are quite good at ventilating wall and ceiling cavities, but terrible at drawing exhaust from where it is actually needed. Figure 1 shows a common scenario in a poorly sealed exhaust system where leaks account for much of the total ventilation load.

Leakage Points in a Poorly Sealed Duct System

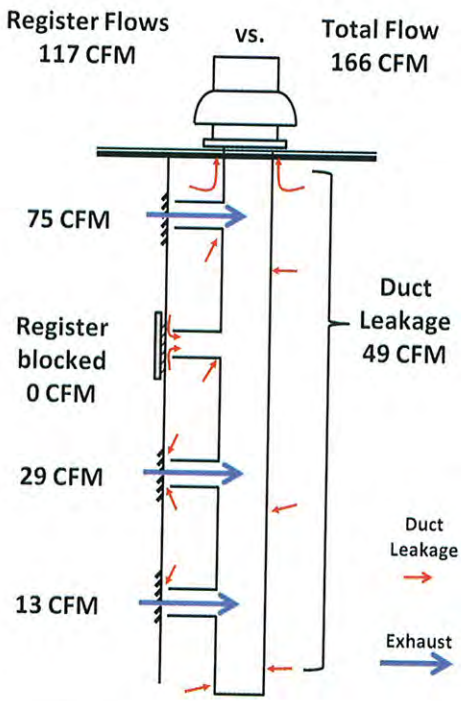


Figure 1. In a poorly sealed exhaust system, leaks can represent a major portion of the total ventilation load.

The practice of measuring only the exhaust flows from apartments always underestimates the energy cost of ventilation because it does not take into account the cost of duct leakage. Measuring the total airflow leaving the building, including leaks, is the best way to determine the potential for energy saving. Unfortunately, it can also be quite a tricky proposition. Each of the three methods described below has its advantages and its disadvantages.

VELOCITY TRAVERSE

In some multifamily buildings, a plenum, mechanical room, or attic on the top floor allows access to a straight section of ventilation duct near the roof. You can directly measure total airflow through this duct using a velocity traverse there. This test measures airflow at many points on a cross-section of duct, and the average is multiplied by the area to calculate the total flow rate at that point (velocity x area = flow). There are many devices you can use to find the velocity in a duct, but in our experience the simplest way to do it is with a hot-wire anemometer. It's small, versatile, and easy to use, but you'll need to have access to a straight section of ductwork away from turns or obstructions.

Results of a 25-point hot-wire velocity traverse are shown in Table 1. Note that even in this straight duct, airflow is not uniform, with higher velocities toward the center-right of the duct. The purpose of using many sampling points is to take into account these often uneven patterns of airflow. Use a spreadsheet to handle calculations, and choose sampling points according to established protocols available from ASHRAE.

A technician performs velocity traverse on a straight section of duct near the roof of a multifamily building.

DUCT LEAKAGE TESTER

Another way of measuring airflow from roof fans makes use of a duct leakage tester, a common piece of building performance testing equipment. The idea is to simulate the performance of the existing fan with the duct leakage tester, and then measure the flow. Let's look at an example.

A given roof fan is exerting a measured static pressure of -75 Pa at the top of the exhaust shaft, and we want to know how much air it is moving. The roof fan is temporarily removed and replaced with a duct leakage tester, which is then used to bring the top of the shaft to the same static pressure of -75 Pa. The airflow produced by the roof fan at -75 Pa should be the same as the airflow produced by the duct leakage tester at -75 Pa, but using the calibrated duct leakage tester allows us to measure the airflow fairly accurately.

This method has certain limitations. First, the total measurable airflow is limited by the capacity of the duct leakage tester with one of its flow rings installed—somewhere around 900 CFM for common models. Second, the roof fan to be tested must be removed, which is not always a simple task, and power to the fan must be disabled first.

These limitations mean that some fans are not easy to test by this method. Where feasible, this method is time consuming but accurate.

Table 1. Results of a Hot-Wire Velocity Traverse (in FPM)

Point		A	B	C	D	E
	inches	1.1	4.3	7.5	10.7	13.9
1	0.6	215	100	180	180	211
2	2.3	272	320	305	380	275
3	4.0	225	330	450	445	411
4	4.0	340	400	500	510	450
5	7.4	280	445	410	465	400

CAPTURE HOOD METHOD

Building on ideas, prototypes, and advice from Terry Brennan of Camroden Associates, Incorporated, Gary Nelson of The Energy Conservatory, and Jim Fitzgerald of the Center for Energy and Environment, SWA constructed a tent-based device that uses the powered flow hood concept.

The powered flow hood uses a capture device to corral airflow and a fan to measure it. (The concept is illustrated in Figure 2.) A large tent is placed over the roof fan and a calibrated blower is placed in its air-impermeable fabric. Obviously, air blowing out of the roof fan will inflate this tent, so the blower is powered up until the tent deflates and there is no pressure difference from inside to outside the tent. With a pressure difference of zero, we can presume (1) that the flow entering the tent equals the flow leaving the tent and (2) that leakage into and out of the tent is also minimized, because there is no pressure difference across its surface. In this way, airflow coming out of a roof fan, which is normally extremely hard to measure directly due to its swirling, uneven pattern, is allowed to organize and enter the blower, which takes a relatively straightforward measurement.

There are several advantages to this method. It is very simple to set up, requiring little equipment other than a standard blower door fan, a manometer, and a rapid-deployment construction tent such as those used by utility companies to shelter manholes. You can test very large fans, limited practically to the capacity of the blower fans used. SWA has measured flows of more than 3,500 CFM with one blower door fan with its largest ring installed. No access to either mechanical rooms or apartments is required, and fans can remain in operation during the whole procedure. Fans of many sizes can be tested without the need for separate adapters for different roof curb sizes. You don't need to remove fans, which can be difficult for very large fans and potentially damaging to roofs or fans. This method measures airflow in a fairly direct way and is faster, easier, and simpler than either of the other two methods. We compared data gathered by this method with data obtained from hot-wire velocity traverses on four shafts, and the results were within ±12%.

This method also has its disadvantages. Using the roof fan tent on a windy day is tricky at best and dangerous during high winds. Chasing what is essentially a very large box kite off the roof of a tall building would be embarrassing, to say the least. All exhaust airflow methods are affected by wind, but with this one it is vitally important to plan for a calm day, and it is advisable to use at least two people to handle the tent.

These limitations considered, SWA has found the roof fan tent to be the fastest and easiest way to estimate exhaust flow on a large multifamily building. We have used this method to assess the total airflow coming from 20+ roof fans on a 17-story building, within three hours with a staff of two. Within that time, an auditor can make an extremely valuable assessment of the economics of any ventilation retrofit. Even with the possible inaccuracies presented, an error of 20% would yield some knowledge of the overall ventilation level in a building—a factor that is usually unknown.

RETROFIT OPTIONS: SEALING

After measuring total airflow, check some critical construction details before specifying a sealing regimen. Ventilation shaft construction can vary widely, and so can the airtightness

Figure 2. Prototype roof fan tent (top) and roof fan test in use.

of common shaft materials, such as sheet metal, gypsum board, firebrick, and cinder block. The best candidate is continuous sheet metal, while the worst may be old masonry. In some buildings, the ductwork may be simply dead spaces in the walls of the building that are meant to lead up to the fan. These systems will never give good performance without major work.

At the roof level, there is sometimes a poor connection between the ventilation shaft and the fan roof curb, and the fan effectively ventilates the attic space as well. Throughout the system, the connection of the register to the main shaft is also a critical link. Gaps at these critical points may contain more leakage than many linear feet of ductwork, but you need to remove the roof fan and some apartment registers to uncover them.

You can use a duct leakage tester to measure roof fan flow.

Assuming serviceable ductwork, options for sealing retrofit range from the complicated and proprietary to the simple and manual. With simpler duct systems in decent shape, well-trained building staff using traditional duct-sealing materials—brush-applied mastic, caulk, and mastic tapes—can do the job. After sealing the fan roof curb, the largest gaps may be at register connections, and these can be sealed as part of a long-term operations and maintenance plan. In many cases this retrofit may be the most cost-effective improvement.

Every ventilation retrofit must ensure airtight register connections, but sometimes more-advanced sealing of the shafts is necessary. There are a few approaches. Aeroseal is a proprietary technology that uses a pressurizing fan to force an aerosolized spray into ductwork. The pressurized air exits through leaks, depositing the sealant material as it passes. The sealant builds on itself until leaks are completely plugged. A relatively new approach uses sprayable duct mastic. A remote camera is lowered into the shaft to guide operations, and a rotating head directs the spray over cracks in the ductwork.

Both shaft-sealing options have their limitations. Neither technology can fix gaps larger than about ¾ inch. Aeroseal can reach very convoluted duct runs, including horizontal and vertical sections, but in order for it to work, every register in the system must be sealed very tightly, so access to every apartment is absolutely required. The spray mastic technology is a simpler approach to sealing, but it requires access to vertical sections of shafts to lower equipment. Pulley systems can extend the range to navigate short horizontal runs, but elaborate duct runs complicate matters. Access to apartments is critical with this approach as well, but it is possible that the spray sealing can be carried out without simultaneously accessing an entire line of apartments.

Access considerations aside, the sealing performance of the two technologies differs. Aeroseal does not require the operator to identify leaks by sight, while the spray seal technology does. In addition, there are limits to the reach and coverage of the mastic spray nozzles. For shafts made of more-complicated surfaces, such as firebrick, it's necessary to apply a heavy cover of spray mastic from many angles to seal the numerous small leaks. Essentially, the whole shaft must be coated to ensure that most of the small leaks are covered. Aeroseal by its very nature targets only the leaks in a system. It also has the advantage of measuring and documenting the leakage of the shaft before, during, and after the retrofit.

SWA has worked successfully with both approaches. Rather than pick a winner, we prefer to define a performance-based specification that is technology neutral. One duct leakage target to shoot for, from the recently released Energy Star standard for multifamily high-rise buildings, is 10 CFM leakage at 50 Pa per floor per shaft. This may be tough for some existing buildings, but in most cases, it's entirely achievable.

RETROFIT OPTIONS: BALANCING

Balancing a ventilation system so that it pulls the intended amount of exhaust from each space is another main goal of retrofit, and there are different options for achieving this goal. Fixed-orifice plates take traditional duct design a step further; they exactly define orifice size and pressure drop at each register

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to specify flow. An experienced duct designer is needed to make this work, but it can be the least expensive solution.

Self-balancing devices, such as the American Aldes Constant Airflow Regulator (CAR), alter their free area in response to changes in duct pressure, holding constant the amount of air that passes through. These devices, while they are initially more expensive than fixed devices, make balancing much simpler. They self-adjust to actual operating conditions at installation and continually thereafter, as duct pressures change over time. Because they can be chosen for specific flow rates, they eliminate some of the guesswork and cost of balancing.

RETROFIT COSTS

Costs for retrofits are generally compared between buildings on a per-register basis. Depending on all the above factors, costs for a complete ventilation system retrofit may range from $100 per register—using in-house labor for manual sealing and fixed-orifice balancing—to more than $350 per register for full cleaning and sealing service with CARs. Our recent experience suggests that ease of access to apartments is one of the biggest unknowns for pricing.

With systems already in decent shape, well-trained in-house staff can seal register connections and install regulating devices with perfectly acceptable results. Other more complicated jobs may be best left to a turnkey contractor. There is no one-size-fits-all approach; and above all, we advise owners and auditors to think creatively about getting the work done.

THE ECONOMICS OF VENTILATION RETROFITS

In many cases, fixing a ventilation system cannot be construed as an energy-efficient retrofit. For example, replacing broken fans will increase exhaust rates and energy use. In nearly every case, though, the retrofit can make a poorly balanced system work better, whether it is under- or overventilated. Once you have a rough figure for the total ventilation rate, you will be able to determine whether the retrofit might save energy. Many existing buildings were built under past codes that required significantly higher ventilation rates than current codes, and

Two examples of major gaps at shaft/register connections.

Table 2. Calculating Ventilation Rate

Ventilation Rate	EXISTING		PROPOSED		SAVINGS	
	Per Register	Total	Per Register	Total	Per Register	Total
Measured at apartments	42	2,016	25	1,200	17	816
Duct leakage rate	21	1,008	8	384	13	624
Measured at roof	63	3,024	33	1,584	30	1,440

CFM Savings	Specific Heat Constant	HDD	Hours	Heating Efficiency %	Infiltration Factor	Fuel Cost/Btu
1,440	1.08	4,500	24	0.81	0.7	$0.000013

Table 3. Payback

Cost and Savings	
Cost per register	$350
Total cost	$16,800
Total savings	$1,887
Simple payback	8.9 years

these may be good candidates for retrofit.

If you are sizing fans, you should also consider the inevitable contribution of duct leakage to the total flow rate, as explained above. Most widely used commercial building standards have yet to include duct leakage as an element of ventilation design, or to set acceptable limits for it. Again, 10 CFM leakage at 50 Pa per floor per shaft may be a good starting point for setting maximum leakage limits.

Combining duct leakage flow with code level ventilation gives the approximate total airflow required at the roof fan. Combining duct leakage flow with 2009 International Mechanical Code (IMC)-level ventilation, for example, gives total airflows of 25–35 CFM per kitchen register (or 25 CFM plus 0–10 CFM_{50} leakage), and 20–30 CFM per bathroom register (20 CFM plus 0–10 CFM_{50} leakage). (While CFM_{50} leakage doesn't translate directly to airflow, it works as an approximation, since 50 Pa is a fair estimate of the operating pressure of multifamily exhaust systems.) With the total target airflow in mind, the following equation can be used to calculate the approximate cost of ventilation:

$$Cost = CFM \times 1.08 \times HDD \times 24\,hr \times \frac{1}{heating\ system\ eff.} \times infiltration\ factor \times \frac{cost}{Btu}$$

Where 1.08 = factor for the mass of air x 60. HDD = heating degree-days. Heating system efficiency = total seasonal efficiency.

Infiltration factor = the effect of ventilation on the building's natural air change rate. Some air that normally escapes a building through natural exfiltration ends up leaving through an exhaust fan, so we can't count all that airflow as ventilation induced. Modeling the interaction of ventilation and infiltration is extremely complex, but for the sake of this exercise, we'll assume that for a four- to six-story building, this factor can be estimated at 70%. That is, 30% of the air leaving the exhaust fan would be leaving the building anyway if the fan were not there.

In the following hypothetical example, we have tested a 48-unit, six-story building and found its kitchens to be overventilated. We can calculate the energy savings to be achieved by reducing ventilation to current IMC levels. A total of 3,024 CFM was measured at the eight kitchen shaft fans on the roof, for an average of 63 CFM per register. In the apartments, we measured the average ventilation rate at each register to be 42 CFM. We can surmise that the missing 21 CFM per register is duct leakage, lost somewhere between the roof fan and the kitchen. If these kitchen shafts are retrofitted so that duct leakage is reduced to 8 CFM per register, and the ventilation rate is reduced to 25 CFM per register, the total ventilation rate falls to 1,584 CFM (see Table 2).

Using the equation above, the savings of 1,440 CFM translates to about $2,000. A retrofit costing $350 per register would have a payback of about nine years (see Table 3).

Choosing more-efficient fans and sizing them to the reduced flows and increased static pressure can reduce electric consumption as well. For smaller fans, we often recommend direct-drive models, since they have no belts to maintain and are now available with very efficient electrically commutated motors with integrated speed controls. Field adjusting to the intended static pressure is also much easier with this technology. With the resized smaller and more efficient fans, ventilation electricity costs may be cut in half.

Sean Maxwell *has been with Steven Winter Associates, Inc. for more than four years in their multifamily division. He has extensive experience testing small and large residential buildings as a HERS rater and Certified Energy Manager. His recent work has focused on cost-effective retrofits for multifamily buildings.*

>> learn more

You can find helpful information on multifamily ventilation at the following web sites:

DOE's Building Technology Program, www1.eere.energy.gov/buildings (click on "Publications" at bottom of the page).

National Center for Healthy Housing, www.nchh.org/Portals/0/Contents/Green_ventilation2.pdf.

New York State Energy and Research Development Agency, www.nyserda.ny.gov/Publications/Research-and-Development.aspx (click on "Other Technical Reports").