IMPROVING VENTILATION
IN EXISTING OR NEW BUILDINGS WITH CENTRAL ROOF EXHAUST

WHY VENTILATE?

Most of us spend the majority of our time in homes or apartments. Making sure the home living environment has enough clean, fresh air will help to improve occupant health. Many multi-family buildings do not consistently provide families with clean, fresh air. While all of our buildings have windows, these windows do not make a complete ventilation system in most U.S. climates. Nearly all buildings require mechanical ventilation and fans to:

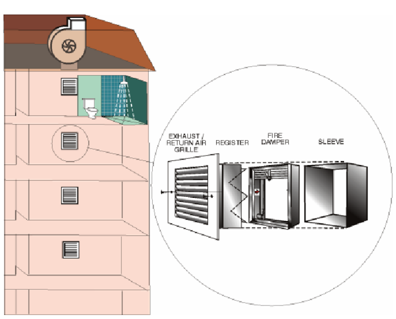
- Exhaust pollutants generated inside the building, such as moisture from bathrooms and cooking, contaminants generated during cooking, and chemicals from building materials and cleaners; and
- Provide enough clean, fresh air by pulling in and filtering outside air before it is heated, cooled, or circulated in the building to help reduce contaminants and allergens in homes.

Buildings that are ventilated well are also less likely to experience unhealthy odor or moisture/mold issues that can trigger tenant complaints. Living in damp or moldy environments has been linked to increased risks of breathing problems, such as asthma.[1]

DO YOU HAVE CENTRAL EXHAUST VENTILATION?

Central ventilation systems are the most common type of ventilation systems used in mid- to high-rise multi-family buildings constructed after the 1960s. You know your building has this system if there is a farm of "mushroom" fans on the roof. These roof exhaust fans are connected to grills in individual apartments via vertical shafts/ducts. (See Figure 1.) Exhaust shafts can be constructed of sheet metal ductwork, gypsum board, or even masonry. Exhaust grills may be located in apartment baths and/or kitchens. In some cases, only a portion of the baths and/or kitchens in a building will be mechanically ventilated and have exhaust grills. Sometimes kitchens and baths with operating windows will not have an exhaust. Common areas and corridors may also have one or more exhaust grills at each floor connected to a central roof fan. Alternatively, they may have one or more

Figure 1 | Central Exhaust Ventilation System



[1]National Academies Press, *Damp Indoor Spaces and Health*, Institute of Medicine of the National Academies, ISBN 0–3–9–09246–9, 2004.

National Center for Healthy Housing

GREEN & HEALTHY HOUSING

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supply grills (from which air flows into the building) at each floor connected to a make-up air unit, which is usually located on the roof and blows fresh outdoor air into the corridors. *Field experience suggests that many central systems do not perform as intended, with significant consequences for indoor air quality and energy.*

IS MY VENTILATION SYSTEM OPERATING POORLY?

Problems associated with central exhaust systems can be linked to poor design, installation, operations and maintenance (O&M), and tenant/resident behavior, or combinations of these issues. However, nearly all of the problems owners and residents experience fall into one of two diagnoses:

- **Case 1:** Inadequate ventilation in all or part of the building, but no opportunity for whole-building energy savings. (See Figure 2.)
- **Case 2:** Inadequate ventilation in part of the building ***and*** an opportunity for whole-building energy savings, based on over-ventilation in another part of the building. (See Figure 3.)

Before discussing solutions, it's helpful to take a closer look at the common problems with these systems *that apply to both existing buildings and new construction*.

Figure 2 | Case #1: Exhaust balancing performance: Inadequate ventilation in most apartments. No whole-building energy savings potential

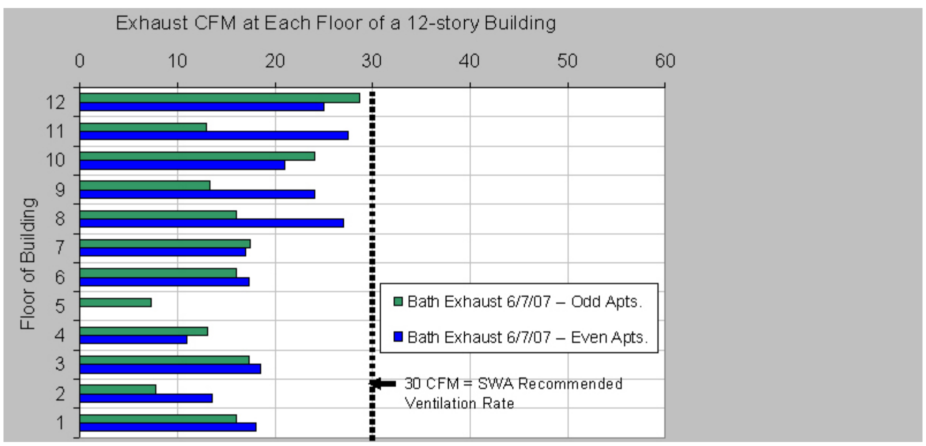
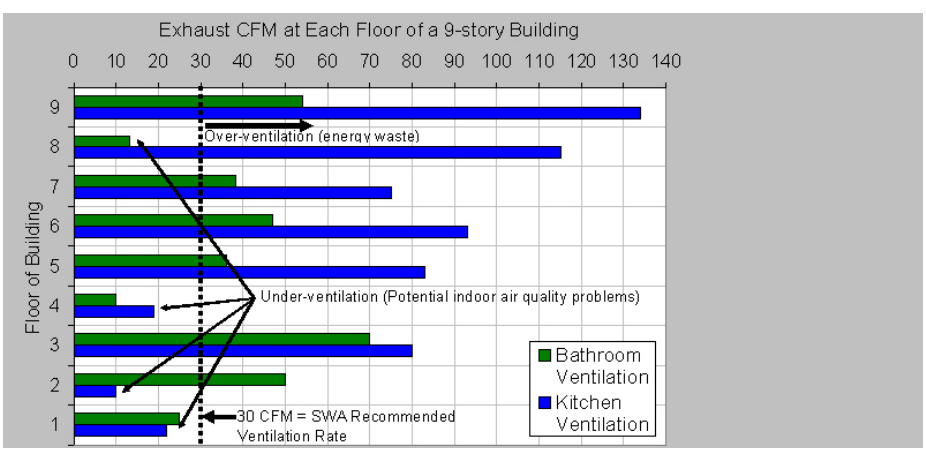


Figure 3 | Case #2: Exhaust balancing performance: Inadequate ventilation in certain apartments and whole-building energy savings potential



DESIGN PROBLEMS

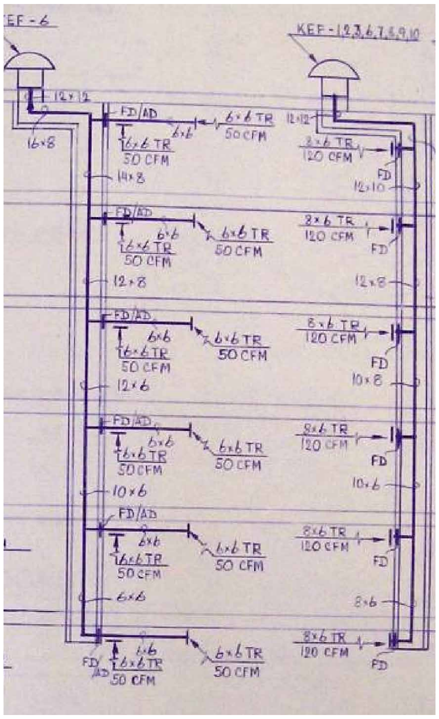
The mechanical designer generally chooses the exhaust ventilation rate for bathrooms and kitchens based on local conventions, code requirements, and green/high-performance building criteria. The International Mechanical Code requires continuous exhaust ventilation rates of 20 cubic feet per minute (CFM) in baths and 25 CFM in kitchens. While design practices vary across the country, it is very common for designers to select exhaust ventilation rates of 100+ CFM per kitchen and 50 CFM per bath. The energy penalty associated with such high ventilation rates is substantial, and even systems designed for these high ventilation rates will not necessarily assure adequate pollutant removal in practice without the proper implementation of critical details discussed below. Typically, the wisdom of targeting very high exhaust ventilation rates is that there is more margin for error and a greater likelihood that apartments on lower floors (furthest from roof fans) will receive at least some ventilation.

Designers are also now asked to achieve enhanced ventilation as part of local codes, green building requirements, or owner instructions. The specified standards most frequently cited are the ASHRAE standards (62.2 for low-rise buildings and 62.1 for high-rise buildings).

A typical mechanical designer's worldview is presented in Figure 4. Carefully-drawn arrows indicate with precision the 50 CFM that is meant to be exhausted from each bathroom served by the riser. Typical problems of mechanical designers' choices are presented below.

For energy efficiency and indoor air quality, it is preferable to target lower (but still code compliant) continuous exhaust ventilation rates while focusing on quality assurance details that will ensure that systems actually perform as designed.

Figure 4 | Typical mechanical designer's worldview



- The total roof fan exhaust flow is equal to the sum of the exhaust flows from each floor, which implies a perfectly sealed duct system. Yet the designer did not provide specific guidance on duct-sealing details or performance specifications in the construction documents.
- The operating pressure at each register that is required to deliver the 50 CFM exhaust for the bath is not specified. Instead, the designer specifies an adjustable register at each point of exhaust that is to be adjusted based on field conditions to achieve the desired exhaust at each floor. This register effectively transfers the responsibility of the system performing as intended from the mechanical designer to the mechanical contractor.
- Finally, roof fans are specified with belt drives that are relatively cumbersome to adjust in the field. Direct-drive fans with speed controllers can be adjusted in the field more easily.

INSTALLATION PROBLEMS

Ducts not sealed. The mechanical contractor begins to connect the rectangular sheet metal pieces of ductwork that will make up the vertical shafts in the field. No particular attention is paid to sealing transverse (horizontal) joints at the connections between two pieces of ductwork. Sealing positively pressurized supply ducts helps to ensure the air in the ducts reaches the designated location. If ducts are not sealed, air may flow out before it reaches the spaces where the designer wanted it to go. But with exhaust ducts under suction, the significance of a leak is not as widely understood. In this case, air may be pulled into the ducts from locations other than the units. This may result in well-ventilated chases, ceiling or wall cavities, attics and crawlspaces, but poorly-ventilated units.

Gaps and cracks not sealed. In some cases, vertical shafts are made out of sheetrock instead of sheet metal. At every location where the vertical sheetrock shafts are in contact with the floor or ceiling, there is an unsealed gap. (See Figure 5.) With any shaft construction, when the contractor reaches the top floor and punches through the roof deck, the gap between the rough opening and the ductwork is not sealed. In some cases, the rough opening is fairly tight. In other cases, daylight is visible through this gap. Later, after the roof curb and fan are installed, the gap between the masonry and ductwork can be a major source of leakage. (See Figure 6.) Highest system operating pressures are closest to the roof fan; hence the roof connection is the worst possible location for a leak in the duct system. Often the most significant leakage location in the system can occur at the connection between the ductwork and the sheetrock/plaster. Figure 7 illustrates a gap between the back of the sheetrock and the horizontal take-off duct that connects the vertical shaft to the register assembly. When the register assembly slides into the take-off duct, there will still be a space between the inside of the take-off duct and the outside of the register assembly due to sheet metal tolerances. A perimeter crack of 1/16" (illustrated by the red dotted line) will result in a total leakage area of 1.5 square inches for a 6x6 duct and 2 square inches for an 8x6 duct. Holes this large can result in up to 50% of roof fan exhaust flow being pulled from random building cavities, instead of the kitchens or baths that require ventilation.

Field balancing of exhaust flows not completed. After the fans start up, the design specified by the mechanical designer called for manual balancing of exhaust flows at each bath/kitchen. Sometimes problems occur in the field

Figure 5 | Leakage point at connection between gypsum board shaft and floor slab (red arrow)

Figure 6 | Leakage point at roof deck connection

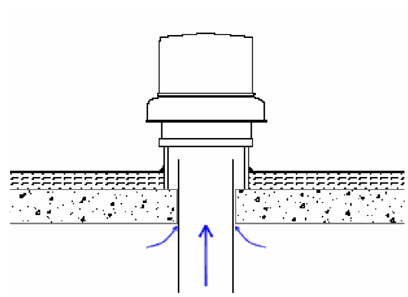


Figure 7 | Leakage between sheetrock and horizontal take-off duct

that make such testing challenging. For example, the mechanical contractor may not own equipment capable of measuring low exhaust flows accurately. Even if the equipment is available, many contractors do not bid the full price of the labor associated with running up and down floors to adjust the exhaust registers for fear of losing the job to a lower bidder. This can create a financial incentive to cut corners on the necessary testing. While the mechanical designer may blame an unbalanced system on the contractor, the designer may also be to blame since the typical designs are only possible to balance with extraordinary effort on the part of the contractor. Adjusting one grill impacts the flow through all other grills, which makes it difficult to achieve the system design in the field. As a result of less than optimal damper adjustment, upper floors closest to the fan tend to be over-ventilated and lower floors tend to be under-ventilated. Leakage in and around ducts exacerbates this problem. Some may question the purpose of sealing the ducts if they are in conditioned spaces. In exhaust systems, leaks toward the top of the shaft pull air from random building cavities, effectively stealing ventilation air from lower floor kitchens and baths. Pulling air from these spaces can result in unventilated or over-ventilated apartments and, in some cases, owners/residents may pay to heat air ventilating uninhabited spaces (e.g., ceiling and wall cavities, shafts, attics, and crawlspaces). Adjusting belts to increase roof fan shaft RPM can help boost ventilation in lower floors somewhat, but creates an extreme energy penalty in over-ventilation of upper floors if the distribution system is leaky and unbalanced. In short, proper balancing is essential for any ventilation system.

O&M AND PROBLEMS OVER TIME

Cold climate issues. Particularly in cold climates, tall multi-family buildings can experience significant pressure field changes due to wind and stack effect. Thus, if a system was perfectly balanced in the summer, it could be significantly out of balance in the winter as a result of different environmental conditions.

Tall building issues. The taller the building, the more significant the pressure changes due to wind and stack effect. The lower the operating pressure of the duct system, the more sensitive the duct system balancing is to changes in "background " pressure changes due to wind or stack effect. Typical average shaft operating pressures in these buildings are very low, making performance very sensitive to wind or stack effect. Leaky ducts and exhaust registers specified with large free areas contribute to such low operating pressures. (The net free area of a grill is the area that remains after subtracting the areas of the vanes, louvers, and screens that the air has to flow around to exhaust.) If the system operating pressure is low enough and stack pressure is high enough, stack effect can actually overwhelm the exhaust fan and cause flow direction to reverse in upper floors. In this case, instead of removing pollutants from upper apartments, the system draws polluted air from lower units and supplies it to the upper floors. This effect is just one of the ways the system designed to improve Indoor Air Quality (IAQ) can actively result in IAQ problems.

Roof fan issues. Roof fans are often not operating, sometimes unintentionally as a result of broken belts and sometimes

Figure 8 | Dirt and dust build-up in exhisting shafts

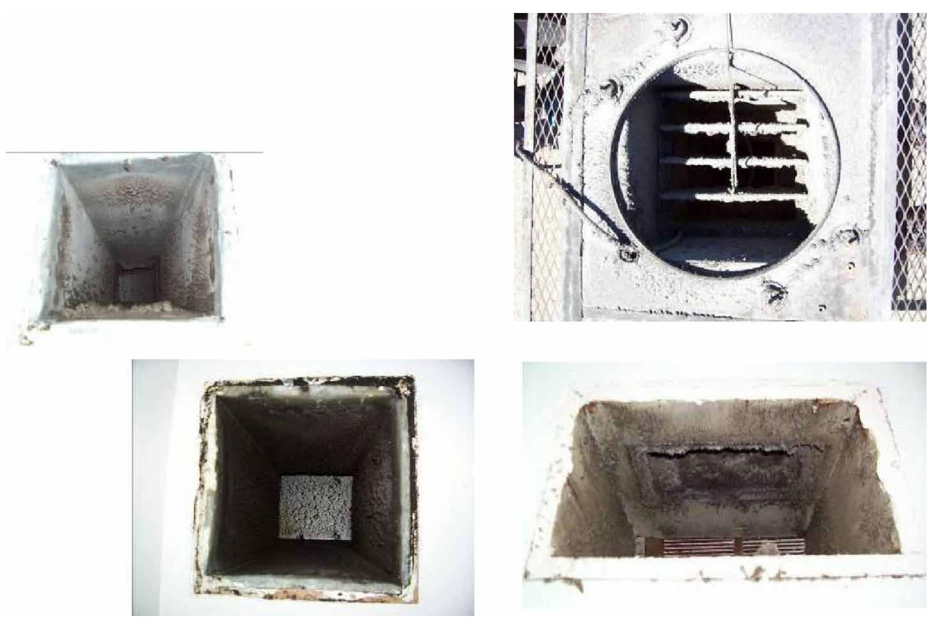


Figure 9 | Dirt and dust clogging grills/registers and restricting airflow

Figure 10 | Occupants blocking registers due to noise, drafts, or dirt

intentionally when they are put on timers to conserve energy by only operating a certain number of hours during the day. Once a fan is off, a shaft becomes a passive plenum (i.e., cavity) for transferring pollutants between units in response to the smallest pressure differences due to wind or stack effect. A common practice to save energy is to turn the roof fans off at night, which can result in IAQ problems, because nights are when most units are typically occupied.

Dirt issues. Systems in existing buildings may not been cleaned during the life of the building. (See Figure 8.) Dirt, dust, and grease can clog exhaust registers. (See Figure 9.) Occupants may cover up the registers themselves (see Figure 10) on upper floor apartments due to roof fan noise or drafts (air coming out of register). Residents may also have covered kitchen grills to keep the dust and dirt trapped in the ventilation system from affecting their asthma.

SOLUTION FOR EXISTING BUILDINGS

A solution to any system with any combination of the problems discussed above must include the four steps described below.

Step 1: Seal all the holes in the duct system that can be sealed. Two of the three possible typical locations for duct leakage (roof curb connection and behind exhaust grill) are easily identifiable and accessible in every building. The roof curb connection can be sealed with expanding foam. The least time-consuming method for sealing leakage at the sheetrock/plaster connection is to use a sheet metal sleeve inserted into the take-off duct with a V-gasket. The sheet metal sleeve effectively extends the duct to the inside of the sheetrock and the V-gasket seals the gap between the sleeve and the take-off duct that is located behind the exhaust grill. (See Figure 11.) Some owners have successfully used an American ALDES product that has incorporated this V-gasket feature as an option with their Constant Airflow Regulator assembly, which will be discussed in Step 3. In many cases, this common leaky roof curb connection and sheetrock/plaster connection leakage area is significant and can represent 50% of total system leakage area.

Owners have also found the Carrier AEROSEAL system or a spray seal system to be a viable alternative for any further sealing of leakage area associated with non-accessible duct joints in existing buildings. Both of these systems effectively

Figure 11 | American ALDES "V-gasket" on airflow regulator sleeve

seal holes from the inside. Central exhaust ventilation systems are a relatively new application for AEROSEAL, which has been used to seal heating and cooling ducts effectively in 30,000 homes and 400 commercial buildings. An AEROSEAL set-up in a central exhaust application that illustrates the main components of the system is presented in Figure 12. The AEROSEAL equipment is easily connected to the exhaust ductwork by temporarily removing a roof fan. As with a duct blaster test, all intentional openings are temporarily closed with foam blocks and the only place for the sealant to escape the system is through the leaks which gradually plug up over time. Since these access points for injecting the sealant are concentrated on the roof, the AEROSEAL equipment can be set up in one location and the long plastic duct that disperses the sealant can be adjusted to move easily from shaft to shaft.

According to Steven Winter Associates (SWA), AEROSEAL has been used to seal 85%–90% of shaft leakage in a wide range of building and shaft types. The spray seal approach utilizes a system that pumps water-based mastic sealant to a nozzle and video camera assembly. The nozzle and camera assembly is lowered down the shaft and sealant for inspecting and sealing leaks. This system has been proven to be effective at sealing joints in vertical shafts, but not in any horizontal take-off ducts connecting to vertical shafts. These take-off duct joints must be sealed manually by accessing the exhaust grills. With any advanced duct-sealing system (AEROSEAL or spray seal), it is important for owners to require performance-based specifications in contracts with vendors. SWA suggests that owners require a post-retrofit duct tightness of 5 CFM per floor at a test pressure of 50 Pascal. The AEROSEAL system automatically measures and generates a report documenting pre- and post-sealing duct tightness. With the spray seal system, third-party testing for tightness is recommended in a sample of 20% of shafts.

While it is technically possible to use AEROSEAL or spray seal on a duct system of any size, it can be more challenging in high-rise buildings, as the system requires simultaneous access to all the apartments served by a particular roof fan. Setbacks in high-rise buildings can result in vertical shafts with elbows and horizontal sections at certain floors that make identifying exactly which bathrooms or kitchens are associated with a particular fan challenging.

Often the mechanical drawings are not accurate, causing surprises. *Despite these challenges, the taller the building, the more important it is to have a very tight duct system, since taller shafts must be operated at a higher pressure in order to minimize fluctuations due to wind and stack effect.*

Step 2: Determine the appropriate design exhaust ventilation flow rate for individual kitchens and baths to ensure adequate pollutant removal and an effective overall level of air change in the apartment based on occupancy. For apartments with kitchen and bathroom exhaust, follow the code minimum continuous exhaust requirements, plus a safety factor. For example, to meet the ICC code minimum ventilation rate for continuous bathroom and kitchen exhaust in an 800 square foot two-bedroom apartment with one bath and a kitchen, would require 45 CFM. The rate is the larger rate of 15 CFM per person (45 CFM for two bedrooms) or 0.35 Air Changes per Hour (38 CFM for an 800 square foot apartment with an eight-foot ceiling).

Figure 12 | AEROSEAL set-up for a central exhaust ventilation application

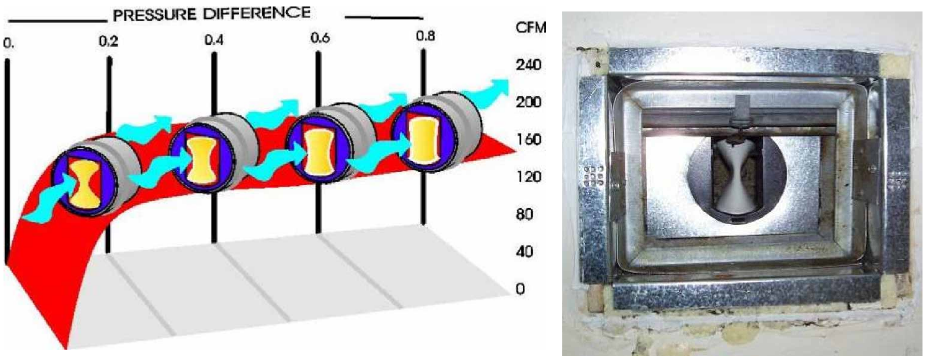
If continuous exhaust ventilation is used in the kitchen and bathroom, the ICC requires:

- 20 CFM continuous exhaust for the bathroom plus 25 CFM continuous exhaust in the kitchen = 45 CFM continuous exhaust flow.
- By meeting the minimum exhaust rate for continuous bathroom and kitchen exhaust, we also meet the minimum requirement of 45 CFM.
- Adding another 15 CFM (around 20%) and increasing the flow from 45 to 60 CFM, which provides a buffer to account for uncertainty in the test and balance and allows for changes in ventilation rates caused by varying weather conditions.

ASHRAE 62.2 requirements: Some high-performance and green building programs state that ventilation systems must meet the American Society of Heating, Refrigeration, and Air Conditioning Engineers' (ASHRAE) 62.2 Standard Ventilation and Acceptable Indoor Air Quality for Low-Rise Residential Buildings. Standard 62.2 requires a minimum ventilation rate of 7.5 CFM per person plus 0.01 CFM per square foot of floor space and has prescriptive requirements for bath and kitchen exhaust. For the 800 square foot apartment example noted above, 62.2 would require 30.5 CFM total (22.5 CFM for the two bedrooms plus 8 CFM for the floor space).

Standard 62.2 also requires fan power to either occupant-controlled or continuous exhaust for bathrooms and kitchens. If continuous exhaust is used in the bathroom and kitchen, 62.2 requires 20 CFM per bathroom and 5 ACH for the kitchen. Assuming the kitchen is 59 square feet and eight feet high, ASHRAE 62.2 would require:

Figure 13 | Constant Airflow Regulator: Principle of performance and field installation (grill removed)



- 59 CFM for the apartment minus 20 CFM for the bathroom plus 39 CFM (5 ACH x 472 ft^3/60 minutes per hour) for the kitchen.
- 59 CFM, which exceeds the minimum ventilation rate required by ASHRAE 62.2 and the minimum required by the ICC and meets the high-performance program requirement.

Compliance with ICC standards for ventilation does not necessarily ensure compliance with ASHRAE 62.2. Often additional ventilation is needed above and beyond the code to satisfy 62.2.

Step 3: Specify and install a balancing device at each exhaust point that (in combination with a sufficiently high system operating pressure) can ensure an appropriate and relatively constant continuous exhaust airflow that meets the design target over a wide range of conditions. A number of manufacturers offer self-balancing dampers. These dampers allow a specified airflow through them regardless of how much suction is put on them. For example, Constant Airflow Regulator (CAR) dampers, manufactured by American ALDES, incorporate an inflatable bulb or "airplane wing" mechanism that restricts free area for airflow at higher pressures, resulting in a relatively constant exhaust CFM for duct operating pressures between 0.2 and 0.9 inches water column (inches WC). (See Figure 13.) CAR dampers are essentially devices that choke down airflow to ensure that there is no over-ventilation, particularly in grills closest to the fan. If we prevent over-ventilation in any particular bath or kitchen, there is less likely to be under-ventilation in other baths or kitchens further from the fan. However, it is important to note that CAR dampers require a minimum operating pressure of 0.2 inches water column in order to regulate airflow. If there is insufficient pressure at a particular location in a shaft, exhaust airflow will be lower than the rated airflow. Maintaining a sufficiently high pressure in shafts for CAR dampers to function properly requires (1) tight ducts and (2) adjustment of the roof fan.

Step 4: Adjust the roof fan shaft speed to ensure that pressure at the bottom of the shaft is sufficiently high (but not too high, as this wastes fan electricity). The bottom of the shaft pressure must be at least 0.2 inches water column to ensure sufficient airflow through the CAR dampers. Taller buildings in colder climates require even more suction at the bottom of the shaft in order to ensure that system performance is not significantly impacted by stack effect. Direct-drive fans are very easy to adjust if they are equipped with motor speed controllers, which can be added on as part of a retrofit. Belt-drive fans are adjustable with more effort. Sealing leaks and dialing into a lower exhaust CFM per kitchen/bath with CAR dampers will raise operating pressure. In some cases, the resulting operating pressure at the bottom of the shaft after Steps 1 and 2 will be higher than optimal, resulting in an opportunity for reducing fan RPM and saving some electricity. In other cases, bottom of shaft system operating pressure after Steps 1 and 2 will still not be high enough, resulting in the need to increase fan RPM and increase fan electricity use. But in either case, adjusting roof fan RPM to meet optimal bottom-of-shaft pressure requirements effectively minimizes the electricity required by a particular fan to deliver acceptable ventilation performance. When an existing fan results in extreme over-ventilation building-wide, it may be cost-effective to replace oversized roof fans with smaller direct-drive fans with speed controllers. In the case of the building described in Figure 2, a three-year payback was realized for this retrofit, because the smallest possible motor that could be optimally tuned to field conditions was selected.

PUTTING IT ALL TOGETHER IN EXISTING BUILDINGS

As with any potential building upgrade, simple screening techniques are required to identify problems and inform solutions. If the system in a particular building is not working optimally, measuring exhaust CFM and static pressure at a representative sample of kitchens/baths provides an indication of the severity of the problem. With this information, it is possible to classify the system energy/IAQ improvement potential qualitatively in terms of Cases 1 and 2 described on Page 1. If the building owner approaches this problem like a standard operations and maintenance item to repair a critical system, no further screening information is required and you can proceed with implementing the solution.

If quantified energy savings are required to justify a decision to fix the ventilation system, then some calculations should be performed. For example, in one NYC building, a one CFM reduction in the

Combining balancing damper installation with duct sealing can minimize both labor costs and tenant disruptions.

ventilation/infiltration load on a building will result in approximately $1–$2/year reduction in heating operating costs. Annual operating cost savings can then be estimated by calculating the difference between the existing ventilation load (sum of bath/kitchen exhausts plus estimate of leakage at existing operating conditions) and the potential post-retrofit ventilation load (sum of dialed-in bath/kitchen exists plus estimate of leakage at new operating conditions). Finally, as with any load reduction measure, operating cost savings will only be realized if the boiler or other system is controlled so that it doesn't have to work as hard.

With the green light to move forward from the owner, you must determine if the implementation work will include advanced duct sealing (e.g., AEROSEAL or spray seal) or manual sealing only. This decision should be made based on an understanding of the complexity of the duct system and a frank conversation with the owner explaining that the AEROSEAL or spray seal will be a complete failure without assured simultaneous access to all the apartments in a line. For technical and human reasons, there is a certain subset of buildings out there that are not good candidates for any approach that requires simultaneous access to all the apartments in a line.

Combining balancing damper installation with duct sealing can minimize both labor costs and tenant disruptions. The above-described V-gasket around the balancing damper sleeve can seal the connection of the ductwork to the sheetrock/plaster. Note that AEROSEAL can't be used to seal this gap since it only "sees" leaks between the point of injection and the foam blocks at the end of each take-off duct. The spray seal system is also ineffective at sealing this gap or any joints in the horizontal ductwork connecting to the vertical shafts.
Since the systems generally have never been cleaned, it can make sense to combine damper installation with duct cleaning. Duct cleaners typically (1) drop a roto-brush down from the roof curb to clean the top of the shaft; (2) remove the exhaust register from the top floor apartment and fish the roto-brush further down the shaft; and (3) proceed down the line. Therefore, it isn't much extra effort for the cleaners to install the dampers before they finish. Depending on labor costs, it may make sense to provide new grills instead of paying for the cleaner's time to wipe down the filthy 20-year-old existing ones manually. Note that the grill is the only part of the system that the tenant sees. Optimally tuning all the inaccessible parts of the system and leaving the old rusty grills is like a new car rolling off the assembly line without a final vacuum cleaning. Duct cleaners can also help to install the foam blocks at each exhaust location required for AEROSEAL preparation. If the duct cleaning is thought of as a sunk cost associated with basic building O&M, then this means that you are getting damper installation and AEROSEAL preparation work almost for free. Roof connection sealing with spray foam can be done by duct cleaners, building maintenance staff, or the AEROSEAL crew when they are taking fans off the curbs to hook up their equipment. While the AEROSEAL sealant itself will eventually seal any roof connection gap, sealing this accessible location manually minimizes overall sealing time.

SOLUTION FOR NEW BUILDINGS

Step-by-step design guide for new buildings. The steps required to ensure a best practice central exhaust ventilation system in a new construction application are outlined below. The common mistakes that plague new construction are identical to those described above for existing buildings. With new construction, however, leakage in ductwork connections can be easily addressed with the application of mastic duct sealants prior to sheetrock installation.

Step 1: Determine the appropriate design exhaust ventilation flow rate for individual kitchens and baths to ensure adequate pollutant removal and an effective overall level of air change in the apartment based on occupancy. (This is similar to Step 3 for existing buildings.) For apartments with both a kitchen and bathroom exhaust, follow the code minimum continuous exhaust requirements, plus a safety factor. For example, to meet the ICC code minimum ventilation rate for continuous bathroom and kitchen exhaust, an 800 square foot, two-bedroom apartment with one bathroom and a kitchen would require 45 CFM. The rate is the larger rate of 15 CFM per person (45 CFM for two bedrooms) or 0.35 Air Changes per Hour (38 CFM for an 800 square foot apartment with an eight-foot ceiling).

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- 20 CFM continuous exhaust for the bathroom plus 25 CFM continuous exhaust in the kitchen = 45 CFM continuous exhaust flow.
- Meeting the minimum exhaust rate for continuous bathroom and kitchen Exhaust, which will also meet the minimum requirement of 45 CFM.
- Adding another 15 CFM (around 20%) and increasing the flow from 45 CFM to 60 CFM, which provides a buffer to account for uncertainty in the test and balance and for changes in ventilation rates caused by varying weather conditions.

ASHRAE 62.2 requirements: Some high-performance and green building programs-mandated ventilation systems meet the ASHRAE 62.2 Standard Ventilation and Acceptable Indoor Air Quality for Low-Rise Residential Buildings. ASHRAE 62.2 requires a minimum ventilation rate of 7.5 CFM per person plus 0.01 CFM per square foot of floor space and has prescriptive requirements for bath and kitchen exhaust. For the 800 square foot apartment example noted above, 62.2 would require, 30.5 CFM total (22.5 CFM for the two bedrooms plus 8 CFM for the floor space).

If continuous exhaust is used in the bathroom and kitchen, 62.2 requires 20 CFM per bathroom and 5 ACH for the kitchen. Assuming the kitchen is 59 square feet ASHRAE 62.2 would require 59 CFM for the apartment—20 CFM for the bathroom plus 39 CFM (5 ACH x 472 ft^2/60 minutes per hour) for the kitchen; 59 CFM exceeds the minimum required by ASHRAE 62.2 and the minimum required by the ICC and meets the high-performance program requirement.

Compliance with ICC standards for ventilation does not necessarily ensure compliance with ASHRAE 62.2. Often additional ventilation is needed above and beyond the code to satisfy 62.2.

Step 2: Integrate performance-based specifications in the construction documents for duct air tightness and balancing. The following notes on the mechanical plans are critical:

- **Note 1:** All transverse joint in ducts shall be sealed with mastic.
- **Note 2:** Total exhaust shaft leakage shall not exceed 5 CFM per floor at a pressure of 0.2 inch WC.
- **Note 3:** All connections between gypsum board and ductwork must be sealed.
- **Note 4:** Contractor shall adjust roof fan base to provide a pressure of 0.2–0.3 inch WC at the grill from the fan.
- **Note 5:** All fans less than 2,000 CFM shall be direct-drive with speed controllers for ease of adjustment.
- **Note 6:** Contractor shall provide a balancing report for each shaft with operating pressures at the grill furthest from the fan and with airflow (CFM) measurements at 20% of grills. Airflow shall be measured with a capture hood that fully encloses the exhaust grills and is able to measure as low as 20 CFM ± 5 CFM.

Step 3: Meet with mechanical contractor on site prior to installation of ductwork in order to clarify expectations regarding duct sealing.

Step 4: Visually inspect and conduct air tightness testing of 20% of the shafts prior to the installation of sheetrock. Duct air tightness testing must be conducted after all horizontal take-offs are installed and should be used to verify that the systems meet the performance specifications of less than 5 CFM leakage per floor at a pressure of 0.2 inch WC. Duct air tightness testing can be performed by a certified home energy rater or other qualified independent contractor. After the installation of sheetrock, an owner's representative or other third party should visually inspect the connection between sheetrock and ductwork to verify an airtight seal in this location.

Step 5: The owner or owner's representative should coordinate with the mechanical contractor to be present during the system balancing. The contractor should first adjust roof fan RPM to meet the performance specifications for pressure at the furthest exhaust grill from the fan. With direct-drive fans, the optimal position on the speed control dial should be marked with a permanent marker. Once roof fans are adjusted, a good rule of thumb is to verify exhaust airflow for all exhaust grills in 20% of the units, or at least five units, whichever is greater. With the installation of CAR dampers, it is not necessary for the contractor to manually balance and then measure CFM at every exhaust grill in the building. Instead, the final system balancing measurements are intended to confirm performance in a representative sample of the exhaust grills. Since CFM should be measured in only 20% of units, these measurements must be made accurately, with the appropriate equipment, and with the owner or owner's representative present. The pressure drop across the shaft must be measured at the top and bottom of the shaft. Owners should take care to review the balancing reports as these data are critical to ensure the system is operating as intended.

Step 6: The owner should implement a preventive maintenance program to inspect exhaust grills in all apartments once a year. Exhaust grills should be removed and CAR dampers inspected for blockages. CAR dampers and grills should be cleaned.

RESOURCES

"Constant Airflow Regulators (CAR) in Multi-Family Multi-Story Central Ventilation Systems: New York, NY & Caldwell, NJ"—National Association of Homebuilders Research Center. *www.toolbase.org/Building-Systems/HVAC/constant-airflow-regulators*. This website documents a case study that uses central exhaust systems and flow-limiting dampers to provide exhaust-only ventilation for an apartment building. A link to the final report for the project is included.

Energy-Efficient Ventilation for Apartment Buildings—Rebuild America Program, prepared by Lawrence Berkeley Laboratories. *epb.lbl.gov/publications/energy_eff_ventilation.pdf*. This is a large overview of ventilation systems in multi-family buildings.

"HVAC in Multifamily Buildings"—Joe Lstiburek, Building Science Corporation. *www.buildingscience.com/documents/digests/bsd-110-hvac-in-multifamily-buildings/?topic=/doctypes/digest*. This article covers important and often overlooked ventilation fundamentals and includes a case study that uses air handlers in each unit to provide ventilation.

"Reduction of Environmental Tobacco Smoke Transfer in Minnesota Multifamily Buildings Using Air Sealing and Ventilation Treatments"—The Center for Energy and Environment *www.mncee.org/research/environmental_tobacco/multifamily_bldgs/index.php*. This report covers efforts made to stop tobacco smoke migration from one unit to another. It highlights the importance of controlling airflow between units, regardless of whether it is a smoking or non-smoking building.

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