FIELD RESULTS

Final Report on the Evaluation of Constant Airflow Regulators (CAR) in Multi-Family Multi-Story Central Ventilation Systems

New York, NY and Caldwell, NJ

October 2008

PATH
PARTNERSHIP FOR ADVANCING TECHNOLOGY IN HOUSING

NAHB RESEARCH CENTER

America's Housing Technology and Information Resource

PATH PROGRAM

The Partnership for Advancing Technology in Housing (PATH) is dedicated to accelerating the development and use of technologies that radically improve the quality, durability, energy efficiency, environmental performance, and affordability of America's housing.
PATH is a voluntary partnership between leaders of the home building, product manufacturing, insurance, and financial industries and representatives of Federal agencies concerned with housing. Working together, PATH partners improve new and existing homes and strengthen the technology infrastructure of the United States.

HUD's Office of Policy Development and Research (PD&R) coordinates all PATH activities. PD&R manages PATH's budget, strategy, and daily operations. Staff in PD&R's Affordable Housing Research and Technology Division have expertise in various construction systems, housing issues, and technology policies.

Because PATH involves many participants from diverse parts of the home building community, PATH seeks guidance from the Industry Committee and other Federal agencies. PATH also works with industry partners to advance housing technology.

DISCLAIMER

ACKNOWLEDGEMENT

Marc Zuluaga of Steven Winter Associates was the principal investigator and author of this report. NAHB Research Center staff provided technical review, editing, document design, and formatting.

NAHB RESEARCH CENTER

PATH
PARTNERSHIP FOR ADVANCING TECHNOLOGY IN HOUSING

Table of Contents

Executive Summary 1
Background 2
Objectives 5
General Construction Information 5
Details 5
  MLK Apartments 5
  Carlyle Towers 8
  Echo Apartments 9
Significant Results 10

List of Tables

Table 1. Exhaust Ventilation Rates 3
Table 2. Building Information 5

List of Figures

Figure 1. Typical Central Exhaust Ventilation System 2
Figure 2. Constant Air Regulator (CAR-I) 4
Figure 3. Constant Air Regulator (CAR-II) 4
Figure 4. Pressure Differences Across the Damper 4
Figure 5. Exhaust Ventilation (CFM) by Floor in Three Lines of Apartments 6
Figure 6. Leakage Area at Connection Between 6
Figure 7. Exhaust Grille Assembly Inserted Into Rough Opening 7
Figure 8. CAR Register Box with “V” gasket 7
Figure 9. Bath Exhaust w/ CAR-II 8
Figure 10. Kitchen Exhaust with CAR-II 8
Figure 11. Carlyle Towers: Exhaust Airflow (CFM) by Floor Prior to CAR Retrofit 8
Figure 12. Carlyle Towers: Exhaust Airflow (CFM) by Floor After Damper Retrofit 9
Figure 13. CAR-I damper installed at Echo Apartments 9
Figure 14. Echo Apartments: Exhaust Ventilation by Floor Before and After CAR Retrofit 10

EXECUTIVE SUMMARY

This evaluation covered a ventilation strategy for multi-story buildings with a central ventilation system serving multiple dwelling units. Because these systems often provide over ventilation at the higher floors and under ventilation at the lower floors of a multi-story building, the goal was to investigate a system for more consistent air exhaust rates from each unit via the central ventilation fan and ductwork.

Ventilation systems in this evaluation required either the refitting of Constant Airflow Regulators (CAR) into each existing housing unit in an older building or the installation of CARs in units of a newly-constructed building. The CAR is a duct boot end and register cover with an integral mechanism that is factory calibrated for a specific air flow. The air restriction mechanism is located within the boot housing and opens or closes with air pressure to regulate air through the duct boot end without the need of a power source or seasonal manual adjustment.

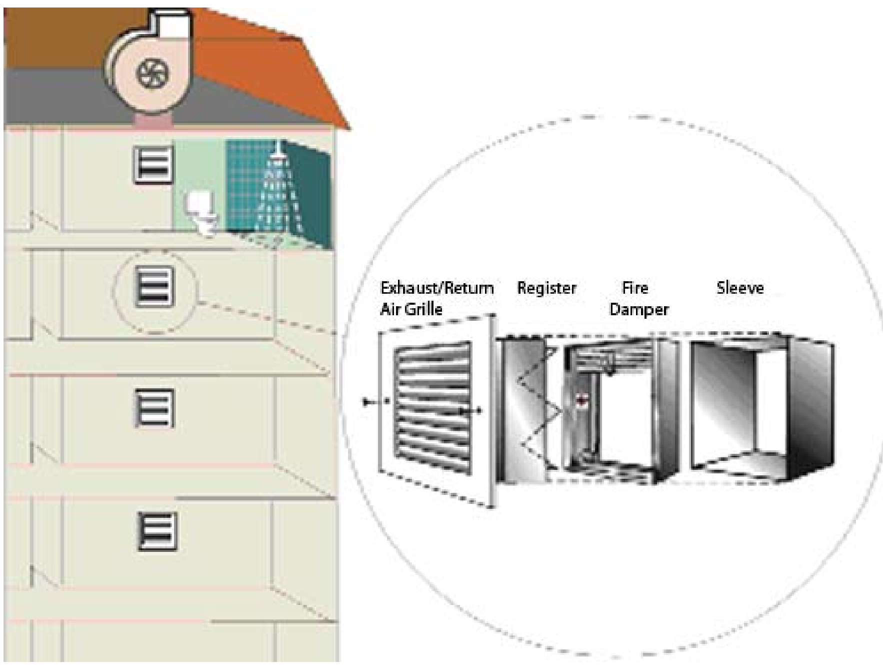
Where the regulators were installed in an existing building, before and after retrofit air flow testing was performed. Retrofits included sealing the central ventilation ducts from the inside of the ducts using an aerosol process. Testing after the retrofit confirmed that the air flow rates to each unit were within specification on all floors of the two buildings.

In these two retrofit cases, the duct systems were operated at a minimum pressure of 0.2 inches water column at the farthest point in the duct system from the fan and the average exhaust airflow measured through the CAR dampers was within 15% of factory set point. It is very important to note that there is a minimum system operating pressure that is required for the CAR dampers to regulate flow. At operating pressures below 0.2 inches water column, CAR dampers cannot regulate airflow. In the new building, leaky ventilation ducts resulted in system operating pressures less than this critical threshold on lower floors which yielded lower flow rates through the CAR dampers at these floors. In this building, leakage between the duct take-off and gypsum board was identified as a detail that could be addressed even after construction in order to reduce leakage and improve system balancing performance from floor to floor.

BACKGROUND

Ventilation system performance has an impact on the energy use and indoor air quality of multi-family, multi-story buildings. In these buildings, mechanical ventilation is often provided via central exhaust systems that consist of a roof fan connected to a vertical shaft with exhaust registers at each floor drawing air from baths or kitchens as detailed in Figure 1.

Figure 1. Typical Central Exhaust Ventilation System



Exhaust ventilation rate designs for kitchens and bathrooms vary throughout the country based on local codes and practices. Kitchens and bathrooms with windows may be allowed to be naturally ventilated with no mechanical ventilation requirements. For those kitchens and baths without windows, the International Mechanical Code requires either continuous exhaust ventilation rates of 20 Cubic Feet per Minute (CFM) for bathrooms and 25 CFM for kitchens, or intermittent exhaust ventilation rates of 50 CFM for bathrooms and 100 CFM for kitchens. Until 2008, the New York City Building Code required exhaust ventilation rates of 50 CFM for bathrooms and 2 CFM per square foot for kitchens (which typically translated to a design in excess of 100 CFM). As of 2008, New York City adopted the lower ventilation rate requirements associated with the International Building and Mechanical Codes.

Whatever the local code requirements, it is important to recognize that exhaust ventilation serves several purposes - among them are pollutant, moisture, and odor removal at their sources in kitchens and baths, and dilution of other pollutants that can build up in a closed area. Exhaust ventilation rates required to achieve an air change rate of 0.35 air changes per hour are presented in Table 1. This threshold was established by the American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) in an ANSI/ASHREA standard for indoor ventilation to promote the quality of indoor air.

Table 1. Exhaust Ventilation Rates

Apartment Size	Ventilation Rate Required to Ensure 0.35 Air Changes per Hour
500 ft^2	23 CFM
1,000 ft^2	47 CFM
1,500 ft^2	70 CFM

Designed for a rate of continuous ventilation of 20-30 CFM per kitchen and bath, a small one bedroom, one bath apartment (500 – 1000+ ft^2) will have an air change rate greater than 0.35 air changes per hour, because 0.35 air changes equate to approximately 1 CFM for every 20 square feet of living area. Meeting the code design rate of 20 and 25 CFM of continuous exhaust ventilation per bath and kitchen, respectively, provides adequate air flow for a unit up to approximately 1,000 square feet.

THE CHALLENGE

Properly balancing central ventilation systems so that upper floors receive the same ventilation as lower floors is difficult. Where the exhaust fan is roof-mounted, typically, upper floor apartments are over-ventilated (resulting in energy waste due to the cost of conditioning the exhausted air), and lower floor apartments are under-ventilated (resulting in potential indoor air quality issues). One-time, manual balancing of traditional volume diffusers or adjustable register grilles is inherently difficult because adjusting one register in a system impacts the airflow through other registers. Moreover, pressures throughout tall multi-family buildings can fluctuate significantly over the course of the year due to “stack” effect (cold air entering near the bottom of a building and warm air exiting near the top) and wind effects. As a result, even a system that is well balanced in one season may become significantly out of balance in another season. The old New York City code ventilation rate requirements (50 CFM for bathrooms and 100+ CFM for kitchens), had the effect of over-ventilating the building as a whole but resulting in a greater probability that at least some airflow was exhausted from lower floor apartments. With the lower ventilation rates allowed by the International Codes, balancing flow rates in each unit requires more precision.

ONE IDENTIFIED SOLUTION

The Constant Airflow Regulator (CAR), manufactured by American ALDES, can be used to automatically regulate airflow at each exhaust grille location of a central ventilation system in either new construction or retrofit applications. The device automatically controls air flow that passes through it by increasing or decreasing the free area available for airflow in response to pressure.

Figure 2. Constant Air Regulator (CAR-I)

The original CAR-I design incorporated a silicon bladder mechanism that would expand as the pressure drop across the regulator increased. (See Figure 2). The design results in a relatively constant airflow rate over a wide range of pressure differences across the device (0.2 to 0.8 Inches of Water Column). The regulators are factory calibrated for a given airflow rate (i.e., 50 CFM) and require no manual balancing during installation.

In 2007, American ALDES introduced a CAR-II damper product that utilizes a shutter mechanism to regulate airflow over the same range of pressure differences across the device as the first generation model. (See Figure 3.) Both regulators are supplied by the manufacturer with a variety of options for mounting plates or sleeves to allow for installation flexibility.

Figure 3. Constant Air Regulator (CAR-II)

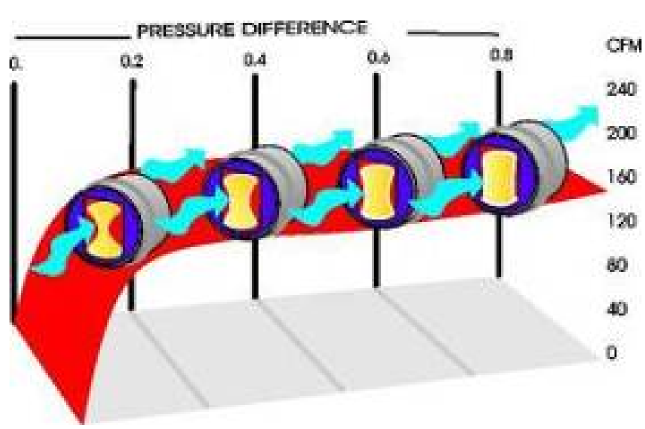


Figure 4. Pressure Differences Across the Damper

OBJECTIVES

Assess the field performance of CARs at regulating airflows in central exhaust ventilation systems.

GENERAL CONSTRUCTION INFORMATION

The installation and performance of CAR regulators in three multi-family, multi-story buildings was investigated. Table 2 shows the year that the three buildings in this study were constructed, the number of stories and dwelling units, and the approximate size of units in the buildings. The MLK Apartments were newly constructed when this study was performed, whereas, both the Echo Apartments and Carlyle Towers involved retrofitting the regulators into existing units with an existing central exhaust ventilation system.

Table 2: Building Information

Building Name	Building Owner	Year Built	# of Stories	# of Units	Approx. ft^2 of Units
MLK Apts.	Dunn Development	2006	6	54	400 – 1000
Echo Apts.	Phipps Houses	1991	9	99	400 – 700
Carlyle Towers	Legow Management	1960	9	106	600 – 1,100

DETAILS

MLK Apartments

MLK Apartments was completed in June 2006, and it was fully occupied by September 2006. CAR-I dampers calibrated for 50 CFM were installed behind all bathroom exhaust grilles. Prior to occupancy, exhaust airflow was measured in several lines of apartments. Results are shown in Figure 5 for each floor of the 6-story building. The exhaust airflow at top floor apartments was approximately 50 CFM, while the exhaust airflow at bottom floor apartments was approximately 35 CFM.

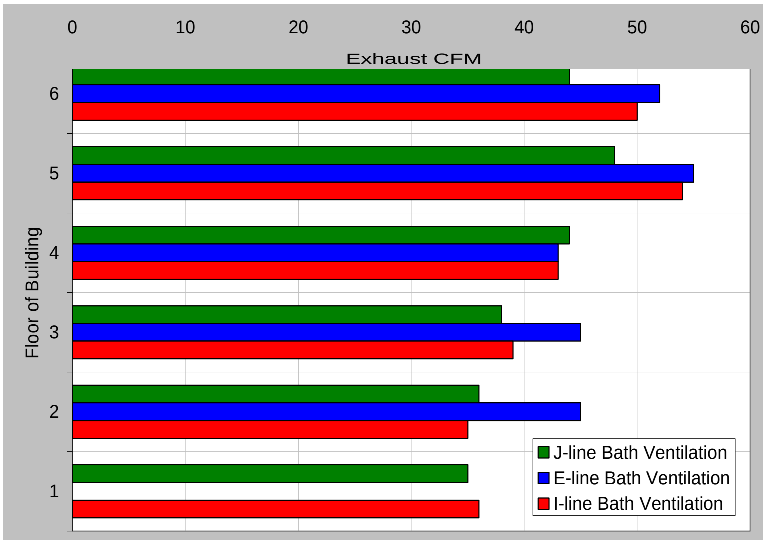


Figure 5. Exhaust Ventilation (CFM) by Floor in Three Lines of Apartments

An investigation indicated that the main duct shaft pressure at lower floor apartments was less than 0.2 inches of Water Column (W.C.I.) – an air pressure too low to trigger the regulators' control mechanisms (bladders in the CAR-1 model) to inflate and regulate airflow. CAR regulators are designed to limit airflow but cannot increase airflow if there is insufficient pressure. Because the central exhaust ventilation system at the MLK Apartments did not perform to the design specifications, the CAR regulators were not subjected to their minimum operating environment of 0.2 W.C.I. at all floors. Duct leakage was the primary reason for the difference between the expected and actual performance of the central system in the building. Leaks in the ductwork at upper floors effectively stole ventilation air from lower floors. The end result was unplanned exhaust ventilation of random building cavities connected to the duct leaks instead of the bathrooms and kitchens at the lower floor levels. While it is possible to increase the capacity of the roof fan to compensate for this extra leakage, it is preferable to seal the ducts.

One of the most significant leakage locations in this building was relatively easy to correct. As is illustrated by the duct displayed in Figure 6 (with grille removed), there was a significant gap behind the grille at the connection between gypsum board and take-off duct to the main

Figure 6. Leakage Area at Connection Between Take-off Duct and Gypsum Board

exhaust trunkline. The area can be sealed against air leakage to improve system flow rates.

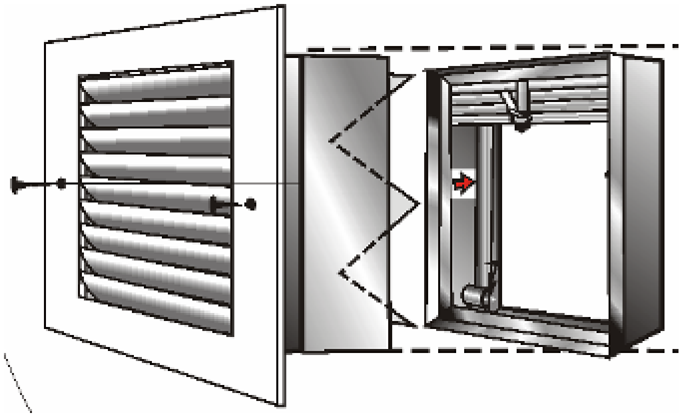


Figure 7. Exhaust Grille Assembly Inserted Into Rough Opening

An exhaust grille assembly inserted into the rough opening may span this gap, but due to sheet metal construction tolerances there may still be a 1/16” gap between the take-off duct and the grille cover along the entire perimeter of the rough opening (red dotted line in Figure 7).

A one-sixteenth of an inch gap around the perimeter of an eight-inch by eight-inch duct is equal to a two square inch hole. For comparison, the free area of a CAR damper calibrated for 50 CFM is only several square inches. If the connection between the take-off duct and gypsum board is not sealed, this gap could result in unintentional exhaust (leakage) equal to design exhaust ventilation from kitchens and baths.

While the gap behind grille covers at duct take-offs should be sealed by mechanical contractors as best practice, this is an often overlooked detail. In recognition of this reality, American ALDES is now offering a CAR damper sleeve assembly equipped with a V-gasket which can be used to minimize leakage area at this location. Other sealing methods (mastic, etc.) could also be used. The advantage of the V-gasket sleeve is that extra labor is minimized.

Figure 8. CAR Register Box with “V” gasket

Carlyle Towers

In 2008, Legow Management retrofitted CAR regulators calibrated for 30 CFM behind all kitchen and exhaust grilles at Carlyle Towers.

Figure 9– Bath Exhaust w/ CAR-II (grille removed)

Figure 10– Kitchen Exhaust with CAR-II (grille removed)

Measurements taken prior to the installation of CAR regulators indicated over-ventilation in upper floor apartments with under-ventilation in some lower floor apartments. Figure 11 details both the kitchen and bath ventilation rates as they were field tested before the CAR retrofit.

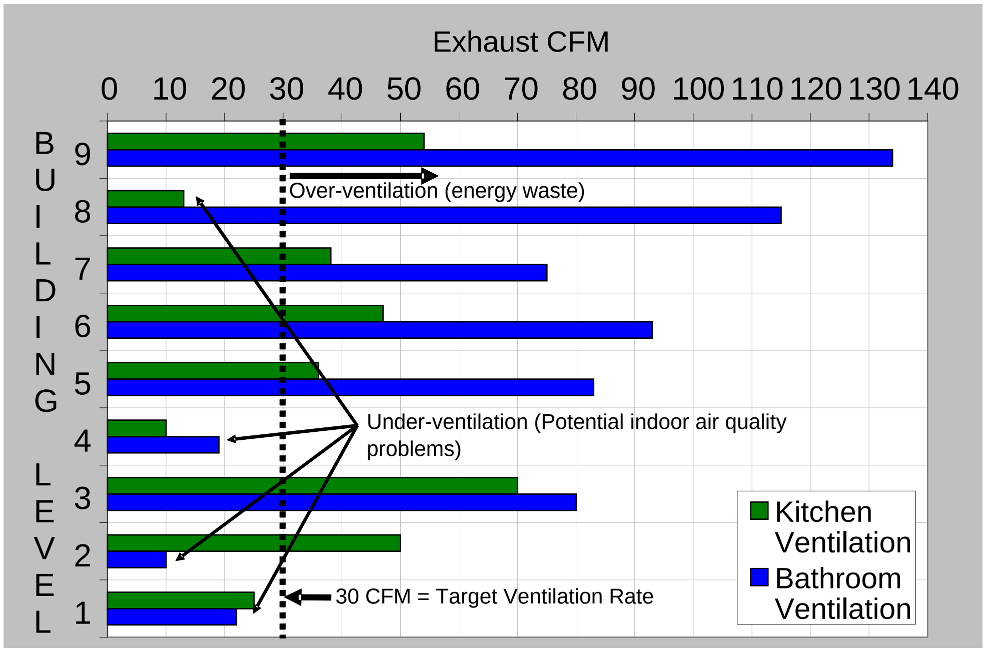


Figure 11. Carlyle Towers: Exhaust Airflow (CFM) by Floor Prior to CAR Retrofit

After the installation of CAR regulators, field results indicated that kitchen and bathroom ventilation rates were within 15% of the desired 30 CFM design exhaust ventilation rate at all floors. Figure 12 shows the ventilation rates tested in the building after the regulators were installed.

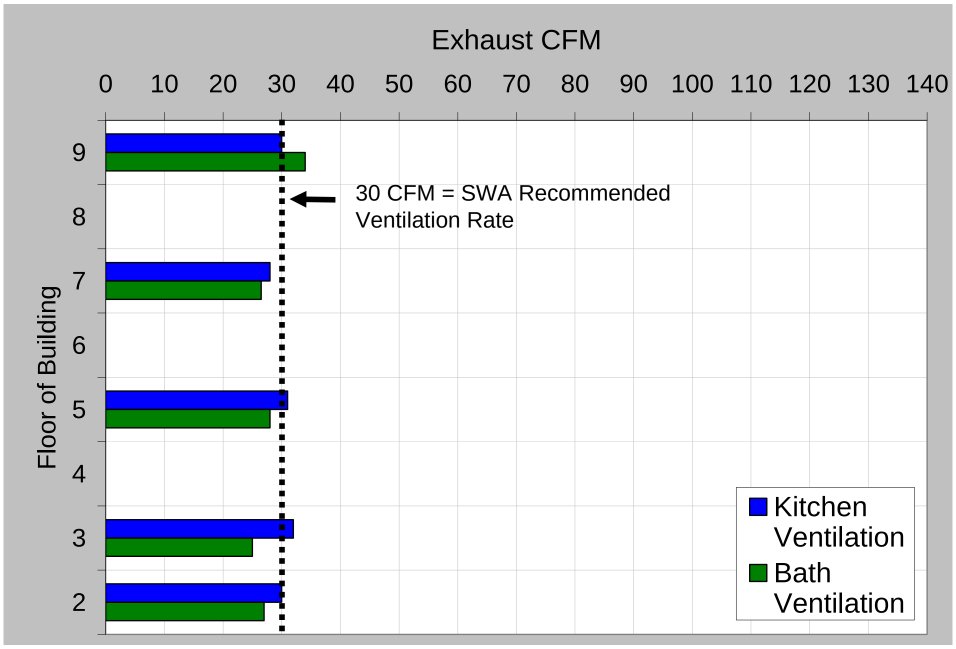


Figure 12. Carlyle Towers: Exhaust Airflow (CFM) by Floor After Damper Retrofit

Echo Apartments

At the Echo Apartments, CAR-I regulators calibrated for 35 CFM were installed behind kitchen exhaust grilles after main ventilation duct leaks had been sealed with AEROSEAL®[1]. Figure 13 depicts the typical installation.

Figure 13. CAR-I damper installed at Echo Apartments(exhaust grille removed)

[1] See Aerosol Duct Sealing at http://toolbase.org/Technology-Inventory/HVAC/aerosol-duct-sealing

Figure 14 shows the before and after field measurements of ventilation rates. The blue bars indicate that ventilation balancing came within 15% of the benchmark rate of 35 CFM after the damper retrofit.

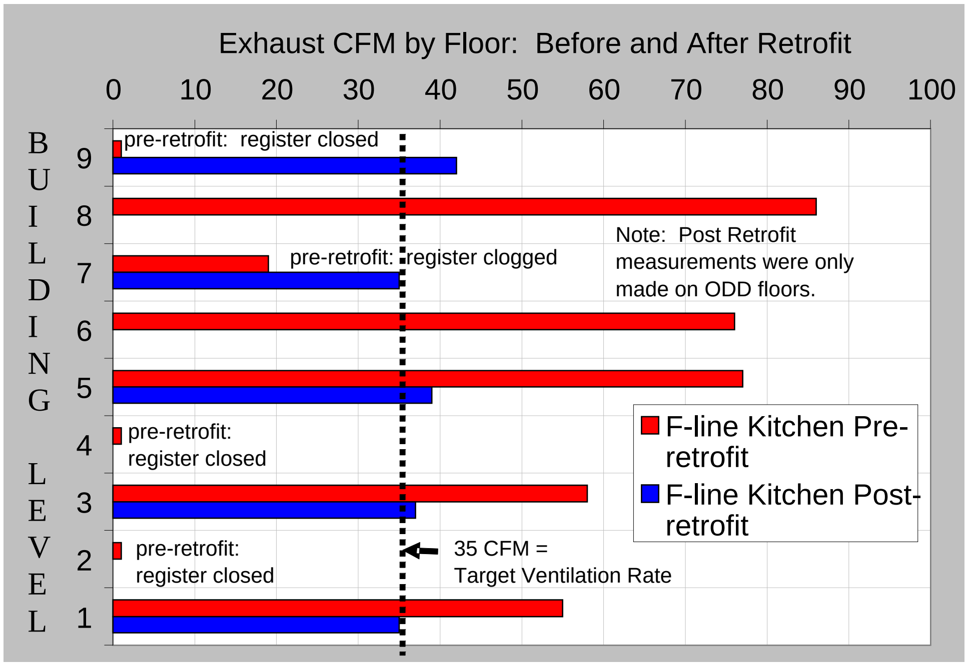


Figure 14: Echo Apartments: Exhaust Ventilation by Floor Before and After CAR Retrofit

Significant Results

The results indicate that the installation of CAR regulators can improve the dwelling unit air flow balance in multi-story buildings designed with central exhaust ventilation systems. The regulators can be used to normalize exhaust air flow in both new construction and remodeling applications. With the ability to control localized flow rates via pressure sensing, the regulators can create balance in a central system by controlling air flow from each unit regardless of the unit's location in proximity to the central fan. The setup allows more consistent air flow to the lower stories in the building and guards against the upper units, which are closer to the exhaust fan, being over-ventilated, without seasonal maintenance or electrical supply to the CAR regulator.

Duct leakage affects the performance of any ventilation system, with or without CAR regulators. One of the most significant sources of leakage found in these buildings was the gap behind the grilles at the duct take-offs in each dwelling unit. In both new and existing buildings, the installation of CAR regulators provides the added opportunity of remediating gaps in this area which will enhance the overall effectiveness of the central system.

In some cases, there is a potential for a CAR damper retrofit to yield operating cost savings. In cases where a kitchen ventilation system was originally designed for continuous exhaust of 100 CFM at each kitchen in a multi-story building, regulators can be used at a lower and more energy-efficient ventilation rate (i.e., 30 CFM). In such a case, a reduction in the overall mechanical ventilation rate of a building can result in a heating or cooling load reduction. In addition, lowering the mechanical ventilation rate of a building with CAR regulators may, in some cases, allow for a reduction in roof fan electricity use if fan belts are adjusted to reduce the motor load. The potential for energy savings with CAR regulators depends significantly on the “baseline” performance of the building and in place operation and maintenance guidelines. Based on the experience of energy auditors of many multi-family buildings in the Northeast, it is not uncommon for roof fans to be put on timers and only operated for fractions of the day. Broken fan belts can result in no ventilation to some main ducts. CAR regulators can always be used to balance a system. However, if the building is under-ventilated from the outset (whether by design or due to operation and maintenance practices), there may be no benefit to either energy savings or indoor air quality from a regulator retrofit.