These two discoveries allowed us to reduce the fan flows for the 3 problem shafts, but overall they were still 30% above the target flow to achieve required flow at the far inlets. We estimate annual energy costs from $1,500 to $2,000 for the higher flow rates.

It may be possible to further reduce duct leaks using the Aeroseal sealing method. This is an aerosol duct sealant that is injected in to the pressurized ducts, where it builds up at leaks to seal ducts from the interior. Aeroseal can seal gaps up to a width of 5/8”. Payback on this investment could range from 7 to 9 years.

ENERGY SAVINGS ANALYSIS

Building	Estimated	Actual
CFM savings	2,473 cfm	2,299 cfm
Gas savings (NG)	5,062 therms	4,706 therms
Fan power savings	22,680 kWh	21,979 kWh
Cooling savings	5,959 kWh	5,539 kWh
Energy cost savings*	$5,868	$5,535

Per unit annual savings	
Gas savings (NG)	58 therms
Electric savings	339 kWh
Cost savings*	$67/unit

*Based upon $0.65/therm and $0.09/kWh

Investment analysis	
Simple payback	6.2 years
Savings to investment ration (SIR)**	1.6
Internal rate of return**	10%

**Based upon motor lifespan of 10 years

The positive outcome extended beyond energy savings The property management was motivated by the energy savings and payback, as well as other performance improvements such as:

- Better ventilation throughout the building
- Reduced odor transfer
- Reduced humidity, resulting in less frequent painting and caulking at turnovers
- Lowered upkeep costs associated with fan belt replacement and unclogging inlets
- Reduced fan noise

Figure 9: Before installation. Air leakage often found around the duct where it meets the sealing is important to seal.

Figure 10: Clogged balance louvers.

Figure 11: Left image - new fixed inlet orifices installed. Right image-register grilles were removed, the old balancing louvers were detached and discarded, the new balancing orifices were installed, and mastic sealant was applied to any leakage around the orifice and at the ceiling connection.

Figure 12: Branch ducts at bath inlets before and after cleaning. Branch duct inlets were cleaned before the new balancing orifices were installed.

The building management’s primary drivers to perform this evaluation were resident comfort and operation costs associated with troubleshooting ventilation. They had received complaints from residents regarding odor issues, and building maintenance staff had recently investigated multiple ventilation issues in the building. The ventilation retrofit resulted in balancing and distribution modifications that improved the system effectiveness. These modifications also yielded difficult-to-quantify operational savings and added value to the apartment units by improving air quality.

MINNESOTA DEPARTMENT OF COMMERCE DIVISION OF ENERGY RESOURCES

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Innovation Exchange
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VENTILATION RETROFIT CASE STUDY REDUCING AND BALANCING EXHAUST VENTILATION FLOW

BUILDING CHARACTERISTICS

- 14 story residential high-rise
- Located in Minneapolis
- Built in 1972
- Natural gas fired steam hydronic boiler heat, 85% efficient
- Central chiller provides cooling
- 81 apartment units
- Mix of one bedroom and two bedroom apartments

VENTILATION SYSTEM

This building has both a central supply and a central exhaust ventilation system.

SUPPLY SYSTEM. Outdoor air is continuously supplied by an air handling unit that is located in the penthouse mechanical room. It draws 100% fresh air (no recirculated air) and distributes it to the corridors on every floor. The outdoor air intake for this air handling unit is a 4 x 6 foot grille located at the penthouse exterior wall. The air handler draws in outdoor air and filters, conditions and distributes it through a common vertical shaft to a single register on each floor. The building is conditioned with hydronic boilers in winter and a chiller in the summer. The air handler has a heat exchange coil for the boilers and the chiller to condition outside air. The supply fan motor has a variable frequency drive, which allows for easy flow adjustment.

The measured supply system flow rate was within +/- 10% of code required rates, so we did not make any energy saving recommendations. However, the bird screen was loaded with debris so we recommended cleaning it to reduce any airflow restriction. After it was cleaned the flow rate was re-measured and the fan speed was adjusted to produce the required flow rate.

EXHAUST SYSTEM. Exhaust air is continuously drawn from apartment unit bathrooms and kitchens. Each bath inlet is ducted into one of six exhaust shafts where a rooftop exhaust fan, or powered roof ventilator (PRV), draws the exhaust air out to the exterior (see Figures 1 & 3). Adjustable balancing louvers are integrated in the inlet register grilles to regulate the bath inlet flow. Each kitchen exhaust inlet is a range hood with a separate switched motor that when turned on boosts the flow into the hood (see Figure 4). The kitchen exhaust hoods do not have flow regulating louvers. There are 4 exhaust shafts serving the kitchen hoods. All of the shafts are made of gypsum board and transition to a horizontal metal duct in the roof cavity that runs to the rooftop PRV. The branch ducts from the inlet to the shaft are 3” round ducts with an elbow to a 22” vertical subduct for a fire/smoke barrier (see Figure 2).

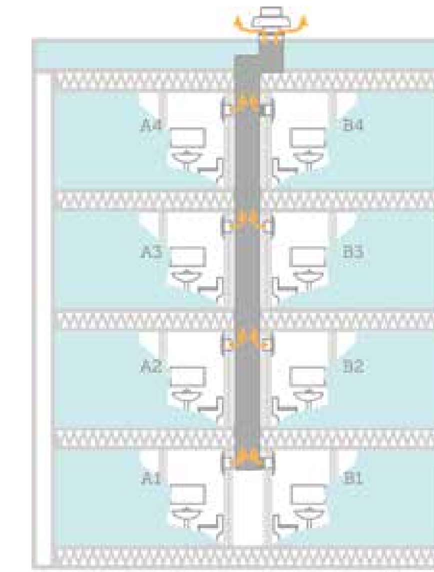

Figure 1: Exhaust system configuration. 10 PRV fans serve the building, 6 shafts for bathrooms and 4 shafts for kitchens.

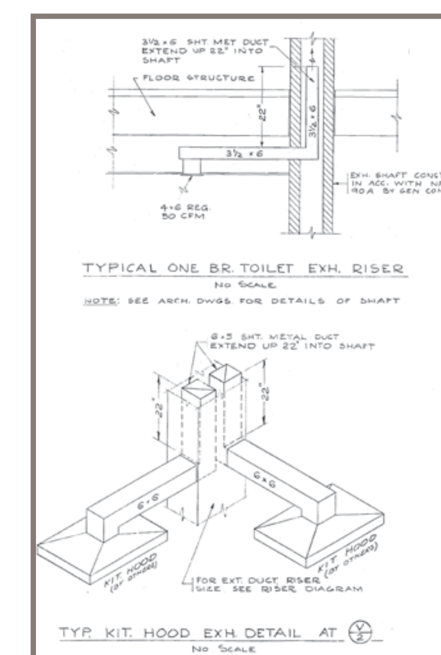

Figure 2: Blue prints showing exhaust inlets and subducts into shaft.

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MEASUREMENT AND FINDINGS

Significant energy savings opportunity for reducing exhaust ventilation. We measured the total exhaust airflow of each PRV to determine the energy savings potential of the exhaust system. We used a collapsible capture cube (Figure 5) set over each PRV. The cube was fitted with Duct Blaster fans that measured flow when the fan speeds were adjusted to match the pressure in the PRV shaft during normal operation. We found a potential for reducing and balancing exhaust flow rates by 50%, which would achieve significant energy savings with total project paybacks less than 6.5 years.

Significant ventilation improvement opportunity for balancing ventilation distribution. We measured all exhaust inlet flows and compared them to the intended flow for each apartment. We used the FlowBlaster adapter for the Duct Blaster fan (Figures 6 & 7), which accurately measures inlet flow on a multi-inlet system by using the Duct Blaster fan to compensate for the capture hood adapter flow restriction. Once we obtained all inlet measurements we compared the total PRV outlet flow to the measured inlet flow to compute the amount of air leakage in the duct boots, branch ducts and shafts.

Three bathroom shafts had significant duct leakage, accounting for at least 65% of the total flow. The average leakage for the other shafts was approximately 20%. Due to the high duct leakage in three shafts, we added a 25% correction factor to our savings estimates. This was based on an assumption that ventilation could be reduced by approximately 25% above code required rates before the flow for far apartments would drop below the required rate.

There were some units that were under-ventilated and others that were over-ventilated, with measured flow rates ranging from no flow to 6 times the required flow. The kitchen shafts had the greatest opportunity for energy savings with 70% of kitchen inlets over-ventilating. In addition, 13% of the inlets had no flow, most often because some of the exhaust hoods had an integrated back draft damper that was stuck shut. This was less of an issue with bath inlets, of which 10% had no flow and 4% were over-ventilating. In some cases the balancing louvers directly behind the bath inlet grilles were either clogged with dust or had been altered at some point to change the flow (louver adjustability permits tampering, and slight alterations can affect the entire shaft).

The property management regularly responded to odor complaints due to either clogged inlets or broken drive belts on aging rooftop fans. A total of 30 inlets were clogged or otherwise non-operable. In other units, high ventilation airflow contributed to a feeling of draftiness.

Figure 3.1 & 3.2: Exhaust PRVs on rooftop. Large PRVs on the roof provide exhaust flows ranging from 850 to 1,850 cfm. One PRV had an unusual termination cap that required modifications to our flow capture boxes.

Figure 4: Kitchen exhaust inlets. The exhaust hood over the stove is connected to a continuous PRV fan. It can also be switched on at the exhaust hood to boost already high flows to double or triple their rates.

Figure 5: A collapsible capture cube fitted with 3 Duct Blaster fans was set over exhaust fans on the roof, measuring flow when the pressure in the cube matched the shaft pressure. A comparison of the total flow of all inlets on a shaft to the outlet flow for that shaft gave an indication of the amount of duct system leakage.

Figure 6: Bath inlet measurement. The FlowBlaster adapter for the DuctBlaster fan, measures inlet flow accurately on central exhaust systems by utilizing the calibrated DuctBlaster to compensate for pressure drop from the capture hood.

Figure 7: Kitchen inlet measurement. A triangular capture box was constructed so that the FlowBlaster could measure the kitchen range hood flow.

WORK SCOPE

There are typically two options for reducing PRV flows: replacing the existing fans with properly sized fans that have speed control or re-sheaving the existing fan by adjusting or replacing the drive pulleys. In our experience re-sheaving an existing fan is an effective solution for fans that are new or recently modified, or when the owner is not motivated to replace the entire fan. In most cases there are greater benefits to replacing belt-driven* fans instead of re-sheaving.

Bath exhaust inlets. Each bath had a 4"x6" inlet with a balancing damper behind the grille to control exhaust flow. The building had a mix of one and two bathroom apartments.

Partially clogged bath inlet fan.

Mastic applied to curb below PRV fan to provide an airtight connection between ventilation shaft and fan.

Figure 8: Upgraded PRV fans are much smaller. We are preparing to measure the post-retrofit PRV flow ensure its within +/-10% of the flow requirement.

Reasons to replace a PRV rather than re-sheave:

1) Speed limits on PRVs: Many existing PRVs are oversized for their purpose. Further, most have minimum motor speed (revolutions per minute, or RPM) limits below which the fan will stall out. The RPM reduction needed for the building may be below this limit and therefore not achievable.
2) Improved efficiency: Belt-driven motors are much less efficient and the electricity savings from a new fan with an electronically commutated (ECM) motor will pay for itself over its lifespan.
3) End of life: The average lifespan of a PRV fan is 10 years. Fans that are not operating efficiently may be near the end of their life and may not be worth the investment in maintenance costs.
4) Less upkeep: ECM motors do not have belts that require periodic replacement.
5) Less noise: Residents on the top floor of buildings with old belt-driven fans often complain about the noise; ECM motors are quieter.

*Belt-driven fans are general less efficient than direct-drive fans, which do not have belts that need replacing and simply adding speed controls can be a cost-effective solution.

For the above reasons, the building management chose to replace the existing fans with ones that have properly sized ECM motors and speed controls. The electricity savings for the fan upgrades reduced the fan power use by 2/3, yielding a 7 year payback. Our work scope included sealing air leakage at the transition between the fan and the shaft at the roof curb, which is often a leaky connection. It was a minimal issue for this project, but is a concern worth addressing on any project where the curb is accessible.

Balancing distribution. A fixed, non-adjustable balancing plate with a properly sized orifice was added behind both the kitchen and bath inlets to help provide the desired inlet flow rate for a specified shaft pressure, barring any excessive duct leakage. A round orifice is easier to clean and less prone to clogging (Figure 10) than other commonly specified balancing devices, such as a balancing louver or constant air regulator. In addition, they are only 25% of the cost of the other devices. Based on the existing shaft pressure and the measured amount of shaft air leakage, we designed for a fan inlet pressure of 0.25 in wc (62.5 Pa) with bathroom and kitchen orifice diameters of 2.0" and 2.1" to produce exhaust flow rates of 25cfm for the bathrooms and 30cfm for the kitchens. In order to access the kitchen duct, the contractor removed and reinstalled the range hood motor and fan. This increased the labor costs, but allowed the work to be completed without disturbing the asbestos duct wrap.

RETROFIT COMMISSIONING

After all of the orifices were installed and the fans replaced (Figures 8, 9, 10 & 11), we adjusted the fan speeds to achieve the specified shaft pressures, measured the PRV flows, and measured the flow rate for a sample of inlets to make sure both inlet and outlet flows were within +/-20% of the code requirement.

The kitchen exhaust system retrofit was successful. The fan speeds were reduced to yield a flow reduction of 2,100 cfm, which is within 3% of amount expected. Of the remaining 6 bathroom shafts, the 3 shafts with excessive duct leakage had inadequate inlet flows at the bottom of the shafts when the fan was turned down to the target flow rate and shaft pressure. The fan was pulling air through the duct leaks instead of the inlets in the tower floor apartments.

There were access panels in the top floor ceiling where each shaft elbowed to a horizontal run towards its respective fan on the roof. These access panels allowed for additional investigation into duct leakage issues in the ceiling cavity. The contractor discovered an uncovered duct access panel, resolving the issues in one shaft. Also, for all shafts the contractor sealed a leaky joint at the transition from the vertical gypsum shaft to the horizontal duct.