Increasing Ventilation In 1980s High-Rise Commercial Office Buildings

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The COVID-19 pandemic has driven public interest in building ventilation rates. The ASHRAE Epidemic Task Force's recommendation that buildings "provide and maintain at least the minimum outdoor airflow rates for ventilation as specified by applicable codes and standards"[1] put quantitative ventilation system assessments in high demand. Throughout the pandemic, many building owners conducted assessments of building systems, including ventilation, to reduce risk of COVID-19 transmission. A recent study of assessments at 95 commercial office buildings found that 77% provided minimum ventilation rates or could make minor adjustments to do so.[2] However, 23% of buildings were underventilated and would require significant capital investment to meet current standards. All but one of these buildings were designed between 1981 and 1992, with ventilation rates as low as 9 cfm/person (4 L/s·person) (assuming default occupant density).

The concentration of ventilation deficiencies in 1980s buildings is not surprising, given the history of minimum ventilation rates in ASHRAE Standard 62.1, *Ventilation and Acceptable Indoor Air Quality* (*Figure 1*). The standard's first edition in 1973 required 15 cfm/person (7 L/s·person) of outdoor air (OA) in offices. After the 1970s oil crisis, the 1981 edition prioritized energy efficiency, reducing ventilation rates to 5 cfm/person (2.5 L/s·person) in nonsmoking offices. Sick building syndrome and other IAQ concerns exposed

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the inadequacy of lower rates, so the 1989 edition increased office ventilation rates to 20 cfm/person (10 L/s·person).[3,4] Subsequent editions of 62.1 have required roughly the same rates, albeit calculated somewhat differently.[5,6]

Underventilated Office Buildings

About 164,000 U.S. office buildings in use today were constructed in the 1980s, representing 17% of all office buildings.[7] While many have been renovated over the past 40 years, a significant number still rely on constrained ventilation systems that fall far short of today's standards.

Many ventilation-constrained buildings in the previously referenced study[2] had similar system configurations, with a central OA shaft providing minimum ventilation air to air-handling units (AHUs) on each floor (*Figure 2*). In some buildings, OA is simply induced by the AHUs; in others, fans pressurize the OA shaft.

Increasing Ventilation in Constrained Systems

Increasing the amount of OA in a ventilation-constrained building presents several challenges.* Potential solutions range from equipment replacement to full renovation of the ventilation system. These modifications require significant capital investment and will typically increase ongoing energy use and operating costs. Options generally fall into three categories: upsizing the existing equipment, splitting into high-rise and low-rise systems or an incremental floor-by-floor approach.

Other Capacity Considerations

For many retrofit options, additional OA will require more heating, cooling and exhaust air (EA) capacity. In some cases, the changes to OA may incorporate energy recovery (whether implemented by choice or required by energy codes), which will lower the additional cooling and heating loads imposed by the additional outdoor air. If the existing central plant equipment is sufficiently oversized, then the retrofit evaluation can focus on the ventilation system alone. Otherwise, chillers, cooling towers, boilers and pumps all may need to be upgraded, too.

The additional loads (sensible and latent) from OA may require each AHU to have additional cooling and/or heating capacity. Typically, this would mean the replacement of the AHU cooling coil and/or the addition of heating capacity on the floor, both of which are expensive options. Instead, a dedicated outdoor air system (DOAS) could precondition OA, which would require more floor or roof space and new electrical service but adds flexibility.

More airflow in requires more airflow out, so in addition to increased thermal capacity, the building will need provisions for increased exhaust. Similar approaches to the ventilation air can be used: upsizing equipment, splitting high- and low-rise or incremental floor-by-floor changes.

Upsized Equipment

A system that requires a modest increase in OA may be upgraded simply by increasing the existing OA fan's

FIGURE 1 A history of ASHRAE Standard 62.1 minimum ventilation rates for offices, based on default occupant densities, with a significant reduction to 5 cfm/person from 1981 to 1989. While the calculation methods changed in later editions (and expanded to two procedure options in 2019), the effective ventilation rates remain roughly the same since 1989.[3-6]

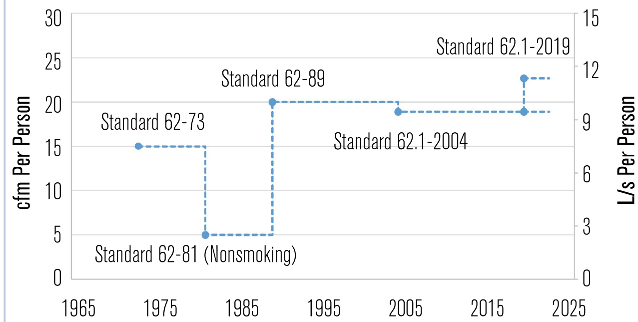
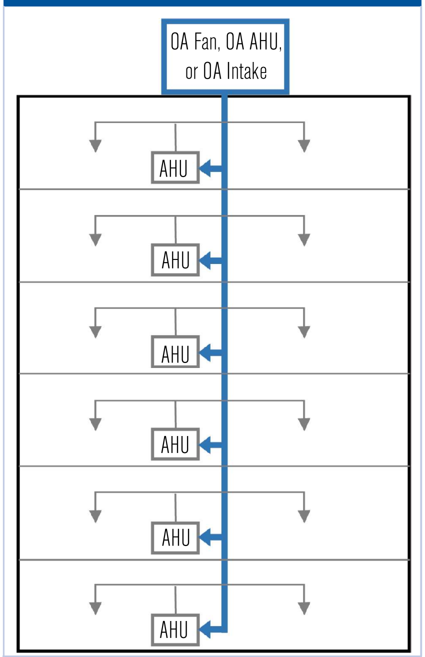


FIGURE 2 Typical constrained ventilation system configuration for 1980s buildings.[2]



*Small adjustments are unlikely to bring systems designed to meet the nonsmoking rate of Standard 62-1981 into compliance with Standard 62.1-2019; the case studies presented here need at least twice their current ventilation rates. However, the rest of the building stock likely has many low-/no-cost options for increasing ventilation if systems fall short of today's standard, such as increasing OA damper positions or changing OA fan setpoints to meet the current ventilation standard, while still meeting most, if not all, cooling and heating loads.

airflow. Evaluating this option requires access to the fan's performance data, and the original submittal data or fan curve should suffice. Two things are at issue here: the fan brake horsepower at existing design conditions and the fan's maximum rpm. The fan laws state that airflow is proportional to fan speed, and fan power draw increases with the cube of the airflow. It doesn't take much of an increase in airflow before the fan motor will need to be upsized. Less obvious is that fans have maximum rpm ratings beyond which they should not operate.[8]

If the existing fan cannot meet the operational requirements to provide the additional ventilation air, the fan and motor could be replaced with larger equipment. This could require more floor area, as well as upgraded electrical service and wiring.

Increasing airflow through existing ductwork also requires scrutiny. Virtually any amount of air can be forced through a given duct size, but the increased airflow means increased air velocity, and with that comes increased noise both from the fan itself and from the increased turbulence in the duct system. Increased flow may also result in exceeding the duct pressure class rating. Many duct design software packages can model noise generation and predict breakout noise from an OA shaft or OA grille. The noise issue should be given full consideration before moving ahead with an upsizing effort.

If noise or excessive fan power requirements are concerns, the OA shaft and OA ductwork may need to be replaced with larger ductwork. This project will likely require construction on every floor, which could be disruptive to tenants, especially if the work on the OA shaft will happen in a building common area or tenant space rather than a mechanical room.

One of the largest challenges associated with upsizing the existing central ventilation system is that any significant changes have to occur at the same time, resulting in larger single-year budget expenditures.

High- and Low-Rise Split

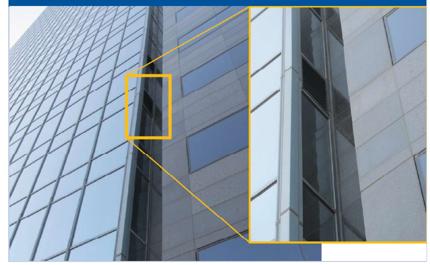
If the existing OA fan system and ductwork are not capable of handling the total increase in OA volume, splitting the existing system into an upper and a lower system may be a solution. Consider a roof-mounted ventilation system that requires a 50% increase in OA flow. Neither the fan nor the duct system would be capable of such a large increase in capacity. But by splitting the system into two sections, a high-rise portion and a low-rise portion, the increase to the existing fan and duct (now limited to the high-rise section) may be feasible. The low-rise section would be an entirely new fan and retrofitted duct system.

This approach effectively cuts the project in half. The upper high-rise section may require only minor modifications to achieve the increased ventilation air. The bulk of the retrofit would be in the building's lower half. The new fan would require floor space near the bottom of the OA riser. Tenant construction disruption would be limited to lower floors for the installation of the new ductwork in the existing OA shaft.

Incremental

Rather than attacking the entire ventilation system at one time, a phased solution can offer the flexibility of upgrading spaces on a floor-by-floor basis. Work can be isolated to a single new tenant build-out, with no disruption to tenants on other floors.

FIGURE 3 A building façade with features that camouflage additional OA louvers.



Since the incremental solution does not access the existing OA system, OA from another source must be found. One possibility is through the building façade. Changes to the building's architecture may be met with skepticism or worse, disallowed, but certain building types can almost hide OA intake grilles, especially small ones. This would not be feasible for a smooth curtainwall façade but may work quite well for façades that alternate glass and other spandrel materials or that have architectural nooks (*Figure 3*).

A single floor retrofit uses a small supply fan to bring OA into the mechanical equipment room and a small exhaust fan to relieve the additional makeup air. Both can be mounted above a drop ceiling and ducted to the equipment room. In colder climates, the supply fan would need onboard heat to preheat the OA before delivering it to the AHU. The new fans and any necessary electric heat would require electric service that may not currently exist. As with the previous approaches, AHU cooling capacity must be sufficient to absorb the additional OA load, both sensible and latent, and adding energy recovery can mitigate the load increase.

Blended Options

Each building has unique qualities and design features that set it apart from its peers. Unusual façades, complicated HVAC systems or tenant needs may require a blended or hybrid solution to bring more OA into the building.

Here, we present two case studies of retrofit options for 1980s office buildings with deficient ventilation systems that are located in the southeastern U.S. These case studies may be useful to those who own, operate or consult on buildings from the 1980s, so that they can prepare to make the changes necessary to meet or exceed today's ventilation standards.

FIGURE 4 Schematics of Building A retrofit options.

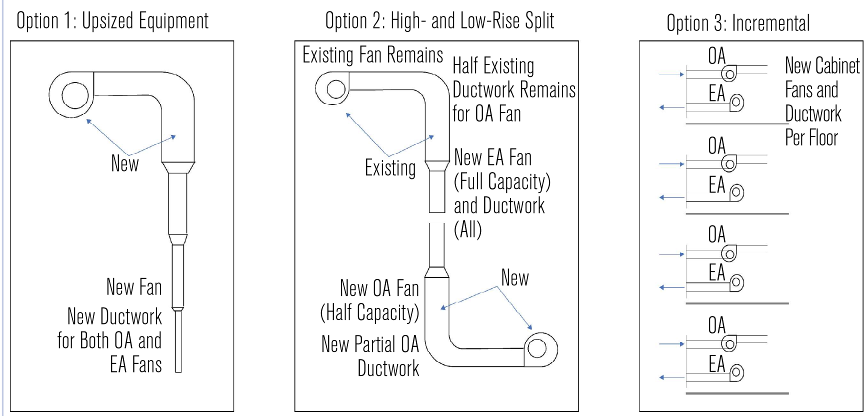


TABLE 1 Building A retrofit options.

REQUIREMENT	OPTION 1. UPSIZED EQUIPMENT	OPTION 2. HIGH- AND LOW-RISE SPLIT	OPTION 3. INCREMENTAL
OA Duct Enlargement	Yes	Yes (Half as Much)	No
EA Duct Enlargement	Yes	Yes	No
New Ductwork Above Ceiling Per Floor	No	No	Yes
New Mechanical Space Required	No	Yes	No
Work Required in Tenant Space	No	No	Yes
Change to Building Façade	No	No	Yes
Equipment Required	OA Fan and EA Fan With Electrical Service	OA Fan (Half Size) and EA Fan With Electrical Service	Small OA and EA Fan Per Floor, With Electrical Service
CHW Piping Required	No	No	No
AHU Coil Upgrade Required	No	No	No
Crane Required	Yes	Yes	No
Scheduling	One Large Project	One Large Project	One Small Project Per Floor
ESTIMATED COST	$1.2 million	$825,000	$30,000 Per Floor

Building A

Building Configuration

Building A is a 33-story 690,000 ft^2 (64,000 m^2) office tower designed in 1985. A 1,400 ton (4,900 kW) chilled water plant serves variable air volume (VAV) AHUs on each floor. Heating is provided by electric resistance heat in perimeter fan-powered VAV boxes. The ventilation system has a design capacity of 31,400 cfm (15,000 L/s), which equates to less than 9 cfm/person (4 L/s·person).

A single OA fan supplies a vertical shaft with takeoffs into each floor's mechanical room. The OA fan is controlled with a variable frequency drive (VFD) to maintain constant static pressure in the shaft, and the ventilation air is neither heated nor cooled. Air is exhausted through a single constant volume toilet exhaust fan. Both fans are in the mechanical penthouse.

To meet Standard 62.1-2019, Building A needs 72,100 cfm (34,000 L/s) of OA, an increase of 130%. Exhaust air will also need to be increased. A floor-by-floor load analysis showed the overall system load, including that imposed by the additional OA, could be met by the existing chiller plant. The existing AHU cooling coils and VAV electric reheat coils were also verified as capable of handling additional OA.

Retrofit Options

Option 1: Upsized Equipment

Replace the existing OA fan and EA fan with larger fans and motors and increase the cross-sectional area of the OA duct and the EA duct for the full height of the building. The new fans would require a crane to get to the roof. The existing OA and EA ductwork runs through a chase from the penthouse to the lowest floor. To remove the existing duct and to install the larger duct, the chase must be accessed on every floor.

This alternative requires larger

electrical service and new VFDs for both OA and EA fans to accommodate larger fan motors. This project must be done for the whole building at once.

Option 2: High- and Low-Rise Split

Split the OA system, feeding the upper floors from the top and the lower floors from the bottom. This project keeps the existing OA fan and half the OA ductwork. The existing fan and duct system would run at the capacity required for the top half of the building. The existing OA duct would be cut around the halfway point, with OA duct removed below. A new OA fan would be installed at the bottom, with a new OA duct coming up to the halfway point, to deliver the requisite ventilation air to the bottom half of the building. The existing EA fan in the penthouse would be replaced with a larger unit, which would require a crane to get to the roof.

While the existing OA ductwork inside the chase is removed only from the bottom floors, EA ductwork would have to be accessed on each floor to remove the existing duct and to install the larger duct. This alternative requires a new electrical service and new VFD for the new OA fan on the lower level and a larger electrical service for the new EA fan in the penthouse.

Option 3: Incremental

Duct additional OA to each floor's AHU from an outside wall using new cabinet fans for OA and EA. On each floor, a piece of spandrel glass would be removed and an OA louver put in its place. Ductwork no larger than 12 in. × 20 in. (305 mm × 508 mm) (to fit inside the ceiling plenum) would connect the new OA cabinet fan to both the louver and the return air duct that extends from the mechanical equipment room. The exhaust fan would be ducted similarly on the opposite side of the building. This solution would require 120- or 208-volt electrical service be brought to the cabinet fans, as well as control wiring back to the building automation system.

Recommendations

Option 1, Upsized Equipment, is the most expensive; a very large undertaking, this project would cause a fair amount of disruption on the tenant floors. Option 2, High- and Low-Rise Split, would cost less and offer less disruption to the tenants, but only because half as many floors are impacted. Option 3, Incremental, offers the most flexibility of timing and installation. Budget considerations can dictate how many floors are done per year. The work would need to be done in the tenant space, unlike the other options, but that could be done during a tenant build-out. Option 3 is the recommended option, as it offers the best value with the least amount of disruption. *Figure 4* and *Table 1* summarize Building A retrofit options.

Building B

Building Configuration

Building B is a 20-story 170,000 ft^2 (16,000 m^2) office tower designed in 1988. Approximately 300 water-source heat pumps (WSHPs), totaling 375 tons (1,300 kW), provide heating and cooling to the spaces. The ventilation system has a design capacity of 9,000 cfm (4,000 L/s); like Building A, this equates to 9 cfm/person (4 L/s·person).

OA is supplied through two vertical shafts by two DOAS units with condensing units on the roof and fan coil units inside the mechanical penthouse. OA is not ducted to WSHPs but supplied to the ceiling return plenum near each shaft. This configuration can result in uneven distribution of OA to the WSHPs, as units far from the OA shafts can have even lower effective ventilation rates; this additional challenge is important, but not discussed here.

To meet Standard 62.1-2019, Building B needs 18,000 cfm (8,000 L/s), an 100% increase. Exhaust air will also need to be increased. The existing condenser water system will likely need to be augmented to accommodate any additional water-cooled loads from increased OA.

Retrofit Options

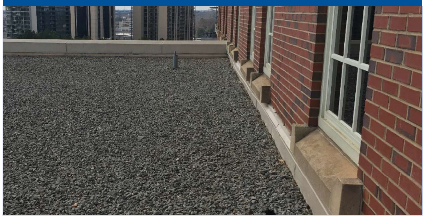
Option 1: Upsized Equipment

Replace OA units with larger capacity units using the existing OA shafts to distribute air. The larger units will not fit inside the mechanical space and will have to be placed outside of the penthouse.

Noise from the OA shafts may be problematic, as air speeds will increase from approximately 1,500 fpm to 3,000 fpm (7.5 m/s to 15 m/s), and external static pressure requirements will increase from 2 in. w.c. to 4 in. w.c. (0.5 kPa to 1 kPa). A T- or Y-cap between the OA ducts and the space may mitigate some noise. Toilet exhaust fans will be replaced with larger fans, pending review of potential noise issues and the duct pressure class rating.

The two OA risers can be upgraded independently. A crane will be needed.

FIGURE 5 A roof setback halfway up the building can provide space for supplemental mechanical equipment.



Option 2: High- and Low-Rise Split

Split the OA shafts so the existing units only serve the top floors. A setback roof on the 10th floor has sufficient space for mechanical equipment (*Figure 5*); provide OA to the lower floors with new OA units installed here. Run the OA duct through two windows and the ceiling plenum to serve the lower half of the existing OA shaft.

This option will focus construction on the 10th floor, which limits the disruption to just one tenant. This tenant will lose some window area, but these windows can be selected at the building rear with limited view.

An alternative location for the lower OA units is the basement parking level, but this would require enlarging the lower-level OA ducts and disrupting additional tenants.

Option 3: Blended: High- and Low-Rise Split with Incremental

Duct additional OA through a window on each of the lower floors and install new WSHPs to condition the OA. Because this approach will increase the building's cooling demand by 5% when complete, additional heat rejection capacity may be needed. Estimated costs include upgrading the cooling tower.

This project can be spread over time because the new WSHPs and OA ducts will not disrupt the existing OA system. Removing a section of the windows on each of the 10 lower floors to provide OA will have a significant effect on the building façade.

FIGURE 6 Schematics of Building B retrofit options.

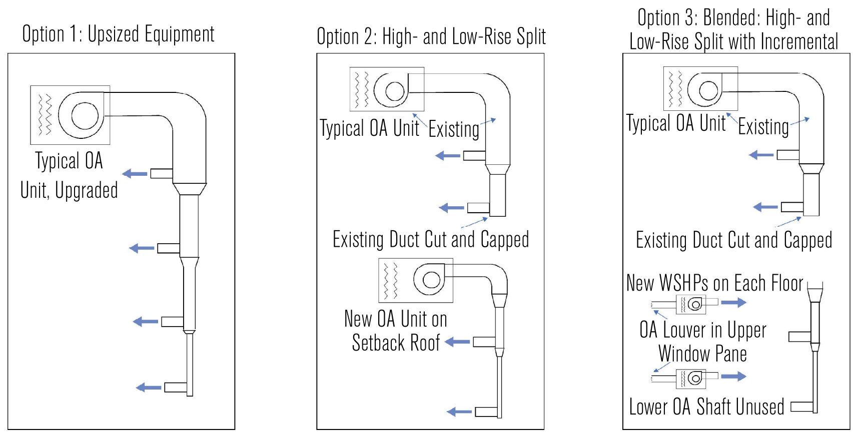


TABLE 2 Building B retrofit options.

REQUIREMENT	OPTION 1. UPSIZED EQUIPMENT	OPTION 2. HIGH- AND LOW-RISE SPLIT	OPTION 3. BLENDED: HIGH- AND LOW-RISE SPLIT WITH INCREMENTAL
OA Duct Enlargement	No	Yes (2 Shafts on 4 Floors)	No
EA Duct Enlargement	No	No	No
Additional OA Equipment Required	–	2 Split Systems in Basement Parking	10 WSHPs in Tenant Spaces
Replace EA Fans and Motors	Yes	Yes	Yes
New Ductwork Above Ceiling in Tenant Spaces	No	No	Yes (Lower Floors)
Change to Building Façade	No	No	Yes (Lower Floors)
Additional Condenser Water Load Created	No	No	Yes (5% Increase)
Crane Required	Yes	Yes	Yes
Scheduling	Two Medium Projects	Two Medium Projects	10 Small Projects and One Medium Project
ESTIMATED COST	$410,000	$280,000	$340,000

Recommendations

Option 1, Upsized Equipment, is the most expensive, with the potential for significant noise in the OA shafts. Option 2, High- and Low-Rise Split, has the lowest cost and a small impact on the building façade, but with significant construction on one tenant floor. Option 3, Blended, could be less expensive, but will likely require a costly upgrade to the cooling tower, as cooling will be addressed by WSHPs instead of air-cooled direct-expansion (DX) equipment. Option 3 will also remove some windows on each floor, which will change the look of the façade and tenant views. *Figure 6* and *Table 2* summarize Building B retrofit options.

Option 2 is recommended to minimize construction costs and disruptions to tenants and the building façade. The major construction on the 10th floor can take place after standard business hours in stages.

Summary

Two case studies evaluated possible retrofits for 1980s buildings originally designed for low ventilation rates. Each building required a substantial increase in ventilation airflow: 130% and 100% more than design airflow, respectively, along with the requisite increase in exhaust air and cooling/heating capacity. The capital costs of all options evaluated ranged from \$0.80/ft^2 to \$2.40/ft^2 (\$9/m^2 to \$26/m^2).

The solutions balanced budgetary needs, tenant disruption and building aesthetics. Building A's owners, concerned with a single, large budget expense, chose an incremental approach with smaller retrofit projects on each floor through discrete openings in the building façade. Building B's owners, concerned with overall budget cost and changes to the building façade, favored a high-low split with a supplementary OA unit on the 10th floor setback roof.

Design Decisions Last a Generation

After implementing the retrofits, these buildings will gain the benefits of increased ventilation: better COVID-19 risk mitigation, improved indoor air quality and the resulting improvement in occupant health and wellness.[9] However, these increased rates are only the minimum ventilation requirement, and combinations of additional air cleaning strategies, such as MERV 13 central filtration, in-room filtration and ultraviolet germicidal irradiation (UVGI), may be necessary to provide desired disease transmission risk reduction. The U.S. likely has tens of thousands of buildings with similar ventilation deficiencies with different constraints of climate, system configuration and budget, demanding thoughtful engineering to identify creative solutions.

Here, we evaluated retrofit options for 1980s buildings constrained by outdated ventilation standards, which limited their ability to respond to the COVID-19 pandemic. By demonstrating the assessment process, design considerations and cost estimates, we hope to motivate owners to invest in critical ventilation upgrades and to inspire design professionals to apply lessons from this pandemic,[10] creating buildings that reduce respiratory infection risk and that can adapt to the challenges ahead.

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