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Authors: Mehdi Jalayerian, PE, Managing Director, Environmental Systems Design, Inc.
Tyler Jensen, PE, Studio Leader, Environmental Systems Design, Inc.
Kenneth Griffin, MBS, Senior Building Analyst, Environmental Systems Design, Inc.

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Post-Pandemic HVAC Systems Strategies For High-Rise Office Buildings

Mehdi Jalayerian

Tyler Jensen

Kenneth Griffin

Authors

Mehdi Jalayerian, PE, Managing Director
Tyler Jensen, PE, Studio Leader
Kenneth Griffin, MBS, Senior Building Analyst
Environmental Systems Design, Inc.
233 South Wacker Drive, Suite 5300
Chicago, Illinois
United States 60606
t: +1 312 456 2268
e: mjalayerian@esdglobal.com
esdglobal.com

Mehdi Jalayerian is Managing Director at ESD. His expertise spans three decades of work on iconic tall, public assembly and institutional buildings that include the world's first positive-energy large-scale building and the world's next tallest building. He is a frequent speaker on integrated building systems design, and is a major contributing author to the *ASHRAE Design Guide for Tall, Supertall and Megatall Building Systems*. He holds a Master's degree in mechanical engineering from the University of Kansas and is a licensed professional engineer in 14 states.

Tyler Jensen is a Studio Leader in ESD's High Performance Buildings group. He has broad experience across a variety of markets, with a focus on new construction, tall buildings, infrastructure, large commercial interiors, and repositioning projects. He holds a Bachelor of Science and Master of Science Mechanical Engineering degrees from Washington University in St. Louis, and is a licensed professional engineer in Illinois.

Kenneth Griffin is an architect and Master of Building Science through his education, with 13 years of professional work experience in building energy performance analysis and building science. He has worked on numerous analytical projects, including envelope optimization, daylighting analysis, parametric analysis, HVAC optimization, thermal comfort analysis, net-zero buildings, existing building retrofits, building integrated renewable technology, climate analysis, code compliance, LEED energy modeling, and urban-scale energy analysis.

Tyler Jensen will present "How Do Air Distribution Methods and Air Exchange Rates Impact Viral Spread in High-Rise Offices?" at the CTBUH 2020 virtual conference, on 17 November.

Abstract

The impact of the COVID-19 pandemic on building design and strategy will be as revolutionary as the rise of the first skyscraper. COVID-19 and potential future pandemics have forever changed the design approach and methodology for high-rise office buildings. Heating, ventilation and air-conditioning (HVAC) operational changes since the onset of the pandemic have been important to improve wellness and increase occupant comfort. These include moves recommended by ASHRAE (such as more outside air, better filters), along with air-cleaning technologies that can readily be added to existing systems, such as Ultraviolet Germicidal Irradiation (UVGI) and Bipolar Ionization (BPI).

But what if future tall buildings were designed to better respond to a pandemic from the start? Moving forward, high-performing buildings should be configured with mechanical systems that minimize or eliminate air mixing between floors. They should optimize ventilation effectiveness within the space. In the increasingly connected world, intelligent sensors can provide air quality data that is useful for both operators and occupants. With forward-thinking transparency, the data can be compiled into meaningful metrics and shared with occupants to give them insight into building operations and performance.

Keywords: COVID-19, HVAC, IAQ, Intelligent Buildings, Pandemics, Ventilation

Introduction

As 2020 dawned, imagining the possibility of a pandemic was not on the radar of developers, engineers, architects, or anyone else in the tall-building community. Today, it's Topic Number One. To respond to the current pandemic, building owners and operators are using the tools available to them and adopting operational changes that go hand-in-hand with the requirements of the pandemic. Stretching the limits of existing HVAC systems, owners and operators are increasing the use of outside air when conditions allow, running the systems for longer periods to flush the building before and after occupancy, and upgrading mechanical filters when possible. In the longer term, however, system configurations and other operations are poised to change drastically in future high-rises.

Though it's too late to change an existing building's HVAC design, now is the time to rethink how future buildings will deal with future pandemics. Though hardly anyone today was alive during the previous pandemic that hit the world in 1918, there is no excuse not to be prepared for the next one, with all we have learned.

HVAC Guidelines

Primary disease mitigation strategies today consist of social distancing, wearing masks, keeping sick people out of buildings, cleaning interior spaces, and maintaining good hygiene. Many proactive building owners and operators are seeking ways to further help mitigate the chance of transmission of the virus, and more and more are turning to their HVAC systems. This is especially important with mounting evidence that airborne transmission of COVID-19 is possible, especially in spaces with poor ventilation and filtration.

The American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE), the predominant HVAC professional association, has published guidelines for the pandemic. HVAC systems can change operation by diluting the indoor air with more fresh ventilation air and cleaning the indoor air via filtration media. More specifically, ASHRAE guidance for office buildings (ASHRAE 2020) includes advice such as:

- When outdoor temperatures allow, increase the overall ventilation by going to partial air-economizer mode to increase outside air delivery and reduce recirculation.
- Disable any demand-control ventilation (DCV) sequences that would otherwise reduce ventilation air for increased energy efficiency.
- Increase hours of operation of systems before and after typical occupancy to flush the space, and to provide additional time for ventilation dilution.
- Upgrade and improve existing filtration media. Minimum Efficiency Reporting Value (MERV) 13 minimum is recommended, and MERV 14 or 15 is even better. High-Efficiency Particulate Air (HEPA) filtration is not feasible in typical commercial air handling systems, and isn't necessary for tall office buildings.

Beyond disease mitigation, many building operators have yet to focus on the challenges of having low occupancy in buildings, especially during the cold winter months, as many office workers continue to work from home.

With low occupancy, there's not as much demand on building systems, and operators accustomed to operating systems in a certain way could face obstacles. Technology equipment and plug loads will be reduced because the majority of the workforce is at home. Toilets will not be flushed as often, and water heaters will be used less, which can prompt stagnant water issues.

Perhaps the most significant risk during heating season: minor problems that linger on unoccupied floors may develop into major problems without a tenant present to notify management. These are all crucial considerations that building operators cannot ignore.

Retrofit Opportunities

In addition to the ASHRAE-recommended operational changes, what else can be done in existing tall office buildings to improve air quality and provide comfort to occupants as they return to the office?

Wholesale HVAC system reconfiguration is not feasible, but upgraded filters and advanced air cleaning systems can readily be retrofitted to existing systems.

MERV Filters

MERV ratings define the effectiveness of air filters, with higher-rated filters able to capture a greater percentage of particles, and able to capture smaller particles. Recent ASHRAE test data confirmed that properly-designed air filters are highly effective at removing airborne viruses. MERV 5 filters, typically used for residential applications, captured approximately 30 percent of airborne particles in the test, while MERV 13 filters captured approximately 90 percent of airborne particles (see Figure 1).

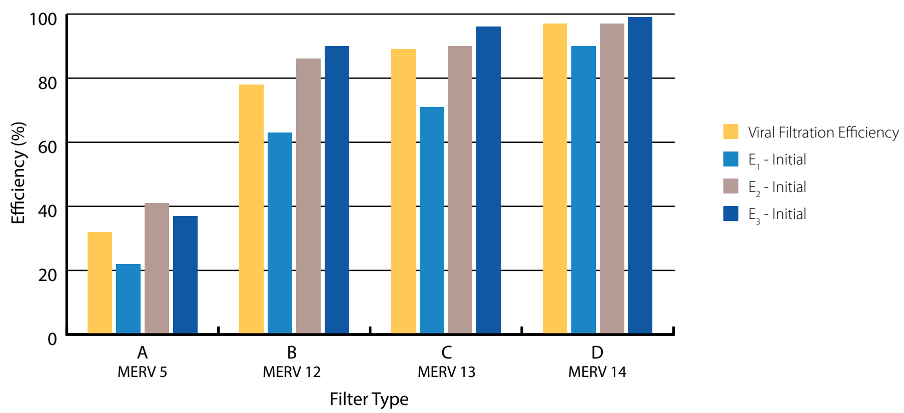

Figure 1. The level of viral filtration efficiency of filters with various Minimum Efficiency Reporting Value (MERV) ratings. Source: ASHRAE, Zhang et al. (2020); redrawn by CTBUH

> “Properly-designed air filters are highly effective at removing airborne viruses. MERV 5 filters, typically used for residential applications, captured approximately 30 percent of airborne particles in the test, while MERV 13 filters captured approximately 90 percent of airborne particles.”

MERV 13 is the minimum suggested for high-performing office space, with the potential for MERV 14 or MERV 15 for even better virus removal (Zhang et al. 2020). But higher performance comes with an additional pressure drop for the supply fans and higher energy consumption. Depending on the existing system capabilities, supply-fan and motor upgrades may be needed.

HEPA filters, typically used for hospital and clean room applications, are deemed impractical for permanent commercial applications due to the high pressure drop that would be required. Typical fan horsepower would need to increase by more than 50 percent just to accommodate HEPA filters. However, portable and packaged HEPA filtration units can be used for high-traffic common spaces and for localized air cleaning after an event.

Advanced air cleaning systems can provide further benefit. Two such air-cleaning technologies that can readily be added to existing systems include Ultraviolet Germicidal Irradiation (UVGI) and Bipolar Ionization (BPI). These can help reduce airborne exposure and may reduce disease transmission, though neither should be considered a "silver bullet" that is 100 percent effective.

Both UVGI and BPI may be appropriate for new construction and retrofit applications to improve indoor air quality and mitigate airborne infectious diseases. Both technologies can be reasonably cost-effectively retrofitted to existing air-handling systems. Careful consideration can help determine which technology is best for the application, evaluated on a case-by-case basis.

UVGI Systems

UVGI is an established technology that is proven effective at reducing pathogens on surfaces and in the airstream. It is specifically recommended by ASHRAE in its COVID-19 response guidance (ASHRAE 2020). It can easily be retrofitted into existing air handling systems, but exposure to ultraviolet rays is harmful to humans, so additional safeties and interlocks are required for safe operation, especially with the high-intensity lamps required for airstream disinfection. UVGI also only disinfects what it "sees" (e.g., surfaces in direct exposure to the light beams), so systems installed in air-handling units only neutralize viruses in the return air stream that have made their way back to the unit. UVGI lamps can also be installed directly in the office space—either at the ceiling level directed above the occupied zone or activated after-hours when the building is in unoccupied mode only—but those solutions are cost-prohibitive and aesthetically challenging for high-rise office buildings.

BPI Systems

BPI systems work by generating and distributing charged ions into the space. The ions attack surface and airborne pathogens and break them down to kill or inactivate them. The charged ions also agglomerate airborne contaminants into larger masses that can either drop out of the airstream or more easily be filtered by the air-handling unit (AHU).

BPI can provide many of the same benefits as UVGI, with the added benefits of odor control and Volatile Organic Compound (VOC) and particulate matter reduction.

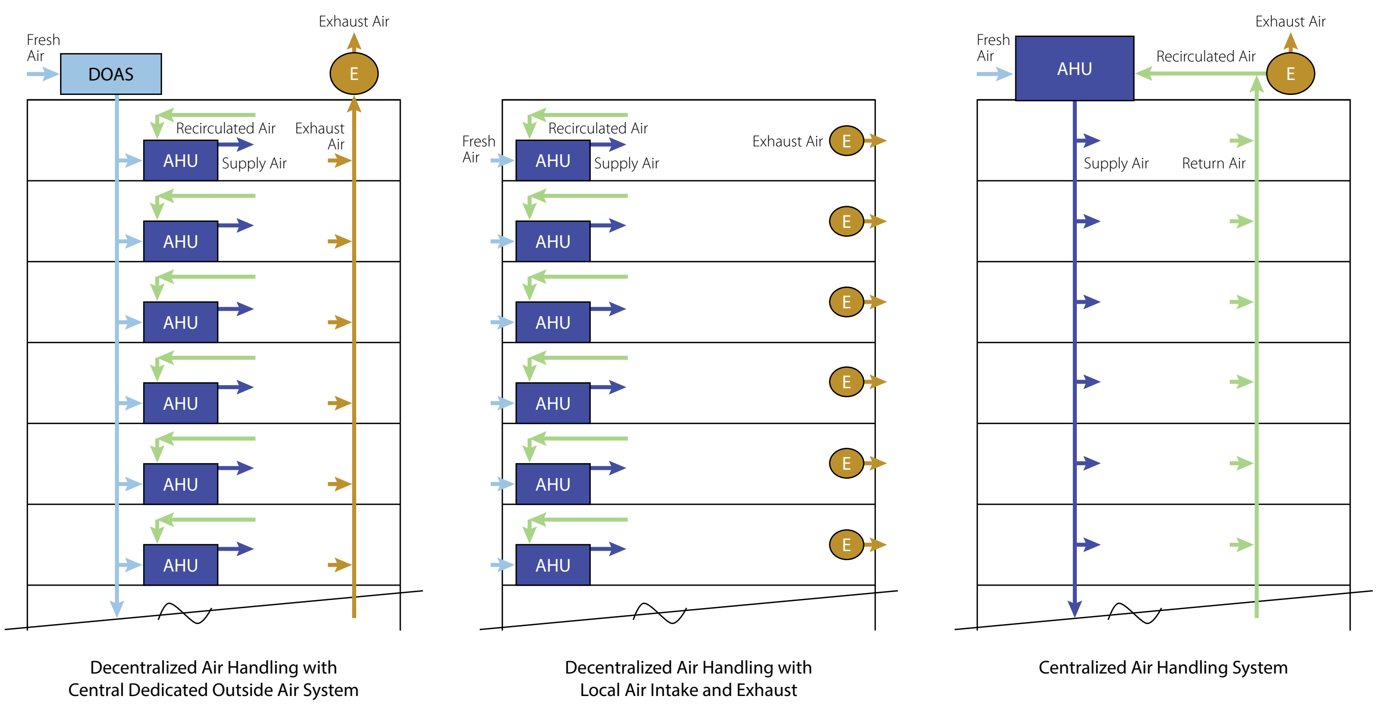

Figure 2. Three typical configurations for air-handling systems in commercial office buildings. © Environmental Systems Design, Inc., redrawn by CTBUH

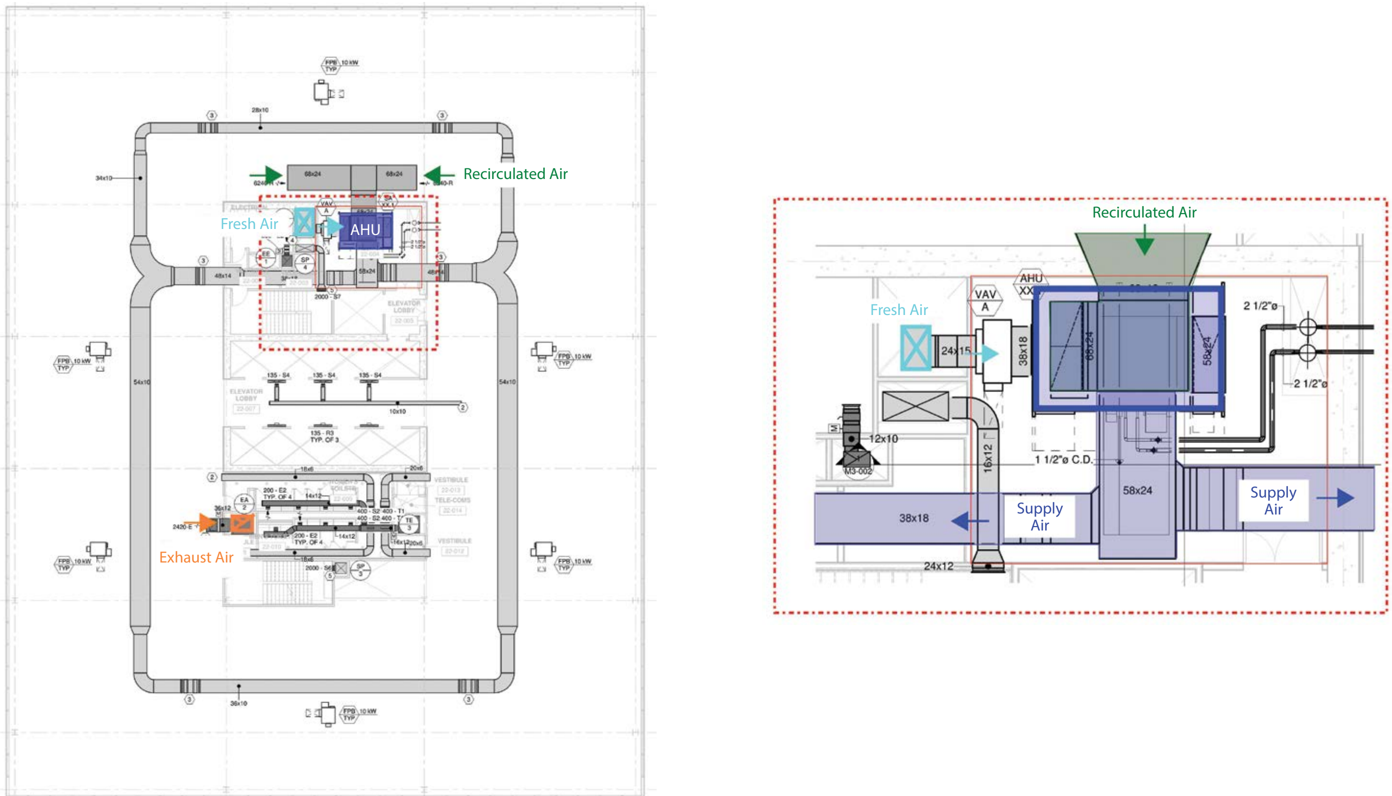

Figure 3. Floor-by-floor air-handling units (AHUs) with central dedicated outside air (DOAS) and central exhaust systems. Left: Full floor-wide system view; Right: Detail at intake.
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Although typically installed in the air handling unit, BPIs can also kill pathogens in the air and on surfaces in the space, not just at the AHU.

However, some BPI products generate harmful ozone, and there is a lack of scientific data and testing protocols with which to evaluate and compare technologies. These risks must be evaluated, but can be mitigated to some extent. If BPI is used, proper specification to ozone-free Underwriters Laboratory (UL) standards is critical. Field performance testing and validation to confirm the efficacy and proper operation of the installed product is also essential.

Changes Ahead for Air-Handling Systems

A high-rise office building typically includes either a centralized or decentralized arrangement of its air handling systems. A centralized system provides ventilation and air conditioning to multiple floors. A decentralized system arrangement will include dedicated or direct outside air, as well as a relief/exhaust air system, and limits the air recirculation to each floor (see Figure 2). At the zone level, these arrangements can be coupled with conventional overhead or underfloor air-distribution systems.

Traditionally, many tall office buildings have utilized central air-handling systems with dedicated mechanical floors incorporating large, built-up systems that serve groups of 20 to 30 floors. This approach reduces the mechanical footprint on tenant floors, centralizes maintenance, and delivers good energy performance with a cost-efficient HVAC system. High-performing buildings of the future should be designed to address shifting demands—with the flexibility to efficiently respond to future pandemics, and with HVAC systems that prioritize occupant health and wellness. (Of course, building codes differ across the world and have limitations, so the following information may not represent "one-size-fits-all" solutions.)

To achieve these goals, high-performing buildings should be configured with mechanical systems that minimize or eliminate air mixing between floors. They should optimize ventilation effectiveness within the space, maximize fresh air volume and provide economizer/purge capability. They should consider air delivery schemes that reduce local air mixing within the space.

Two configurations look to have the best odds of achieving success. The decentralized floor-by-floor AHUs eliminate air recirculation between floors and still enable air economizer/purge capability. They also provide the most rentable square footage compared to other options. Underfloor air distribution increases the number of space air changes per hour (ACH), while enabling air economizer/purge capability during greater number of hours per year; significantly increases space ventilation effectiveness, with a single-pass airflow from floor to ceiling; and minimizes local air mixing compared to the traditional overhead mixing system.

Other options are not as effective, but have their benefits. In the traditional centralized AHU configuration, air is filtered prior to redistribution to the space, but it is recirculated between all floors in the office stack that the air handling unit serves. With dedicated outside air system (DOAS) and floor-by-floor systems, air recirculation is minimized to individual floors only (see Figure 3).

A centralized DOAS can be replaced with a localized (each-floor) fresh-air intake and relief/exhaust that can completely isolate duct distribution between floors (see figures 4 and 5).

Localized fresh-air intakes and relief/exhaust require coordination and louver integration with the exterior façade at each level. Floor-by-floor fan rooms (see Figure 6) can either be located at the perimeter for easy duct connections to the louvers, or within the core, to maximize views and leasable floor area. Core-based floor-by-floor fan rooms will require coordination of large intakes and relief/exhaust duct connections from the core fan rooms to the perimeter louvers.

Flexibility is also increasingly important with so much uncertainty in the world. Floor-by-floor systems provide the best flexibility for single tenants and single floors to operate their systems independently. Ventilation, filtration, and advanced air cleaning enhancements can be implemented flexibly, depending on individual tenant needs. And floor-by-floor systems will be best-positioned to respond and adapt to unknown future requirements.

An array of potential systems and configurations for tall office building HVAC is provided in Table 1.

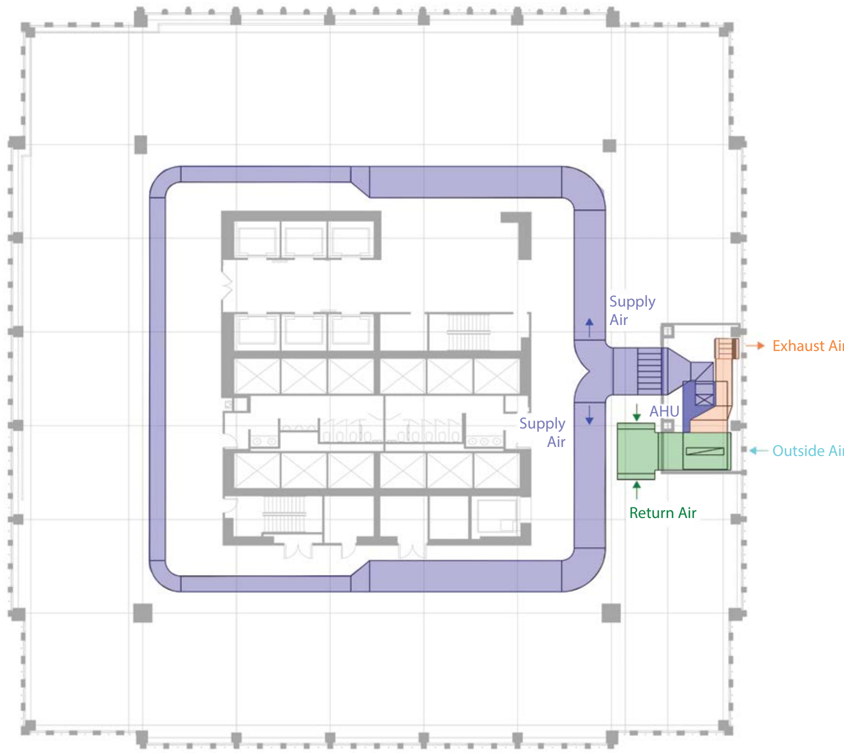

Figure 4. Decentralized floor-by-floor AHUs, with local outside air and exhaust with perimeter fan room.
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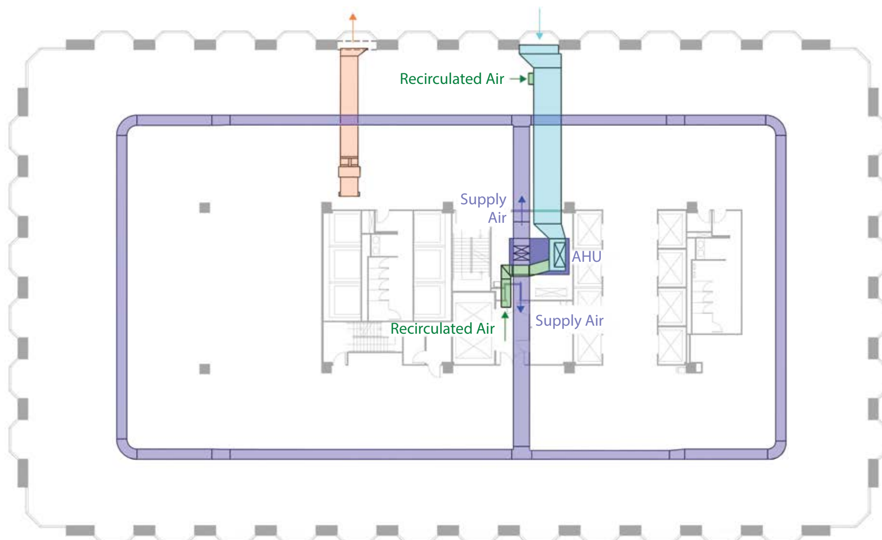

Figure 5. Decentralized floor-by-floor AHUs with local outside air and exhaust, paired with core-based fan room.
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Improved Space Airflow

Most tall office buildings rely on overhead air distribution to supply conditioned air to the occupied space for ventilation and cooling. There are many different system types and variations, but all overhead supply systems use air diffusion and air mixing to perform properly. Primary cooling supply air is around 55°F (12.7°C), which would be too cold and drafty to blow directly on occupants, so ceiling diffusers are designed to maximize air mixing. The cold jet of primary air from the diffuser induces room air to move towards the diffuser, mix, and transfer heat from the space.

Tall office buildings with overhead supply air create a fully mixed space, which is effective for evenly distributing cooling and ventilation air (see Figure 7). However, another air distribution method can provide improved indoor air quality (IAQ) and pathogen removal, without fully-mixed room air.

Underfloor air distribution (UFAD) minimizes supply air ductwork and instead utilizes a pressurized raised floor air plenum and low-velocity swirl diffusers to supply cool air at the floor level, typically 65–68°F (18–20°C) (see figures 8 and 9). The system works best with a separate dedicated perimeter system for envelope heating and cooling, so that the UFAD system operates at a consistent, stable pressure to accommodate the interior cooling and ventilation only.
A combined system may work in milder

Figure 6. View of a typical floor-by-floor AHU. © Environmental Systems Design, Inc.

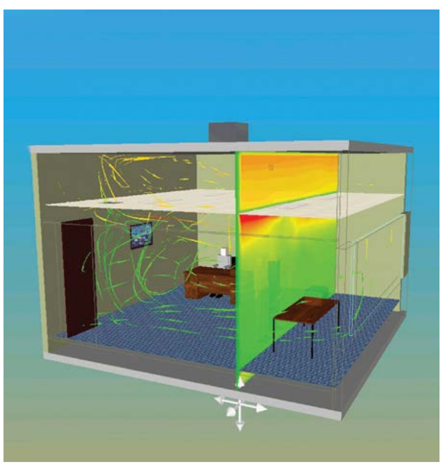

Figure 7. Three-dimensional view of an overhead supply air system, showing air flow and temperature performance in a compartmented office space. © Environmental Systems Design, Inc.

climates, but is especially problematic in harsh climates with high envelope heating and cooling requirements.

Office heat sources such as occupants and computers generate a heat plume that is naturally buoyant and rises towards the ceiling, drawing the low-velocity supply air in its wake and creating a stratified zone near the ceiling. Heat as well as airborne

		Centralized AHUs	DOAS + Floor-by-floor AHUs	Decentralized Floor-by-floor AHUs	UFAD
Indoor Air Quality	Air Mixing Between Floors	Air recirculates between floors	No recirculation between floors Air recirculation limited to individual floors only.	No recirculation between floors Air recirculation limited to individual floors only	Depends on system configuration Typically some recirculation, but less than centralized AHU system.
	Air Mixing Within Space	Typical overhead system uses fully-mixed occupied space	Typical overhead system uses fully mixed occupied space	Typical overhead system uses fully mixed occupied space	Single air pass through occupied zone Heat and pathogens accumulate in stratified zone
	Ventilation Effectiveness (Ev)	Typical overhead system has Ev of 1.0 per ASHRAE 62.1	Typical overhead system has Ev of 1.0 per ASHRAE 62.1	Typical overhead system has Ev of 1.0 per ASHRAE 62.1	Ev of 1.2 per ASHRAE 62.1 (20% better than overhead)
	Economizer Fresh Air Purge Capability	100% fresh air purge capability	Reduced fresh air purge capability	100% fresh air purge capability	100% fresh air purge capability Extended economizer operation
	Space Air Changes per Hour (ACH)	4-6 ACH at design	4-6 ACH at design	4-6 ACH at design	6-8 ACH at design
Cost	First Cost	Cost-efficient Large centralized equipment	Higher first cost Distributed equipment	Higher first cost Distributed equipment	Overall building cost efficient Higher core and shell first cost Lower tenant buildout cost
	Energy Performance	Good energy performance Full economizer capability	Good energy performance Reasonable economizer capability Reduced fan energy	Great energy performance Full economizer capability Reduced fan energy	Excellent energy performance Full economizer capability Reduced fan energy Efficient zone distribution
Operation	Operation Flexibility	Low performing system turndown Need to operate multiple floors to serve a single floor afterhours	Good system turndown Simple, efficient, cost effective afterhours operation Need to run central DOAS to serve a single floor afterhours	Great system turndown Simple, efficient, cost effective afterhours operation Fully independent from other floors	Adequate system turndown Depends on system configuration
	Renovation Flexibility	Overhead system requires rework of FPBs, ductwork, and diffusers.	Enables individual floor filtration and air cleaning enhancements Overhead system requires rework of FPBs, ductwork, and diffusers	Enables individual floor filtration and air cleaning enhancements Overhead system requires rework of FPBs, ductwork, and diffusers	Plug-and-play floor supply diffusers can easily be relocated
	Maintenance	Centralized equipment simplifies maintenance and access Large fans can be difficult to maintain and replace	Distributed maintenance on all office floors Smaller AHUs can be simpler to maintain	Distributed maintenance on all office floors Smaller AHUs can be simpler to maintain	Depends on system configuration
Occupant Comfort	Acoustics	Noise generating equipment centralized on mechanical floor	AHUs are located on occupied office floors close to occupants Smaller fan equipment generates less noise	AHUs are located on occupied office floors close to occupants Smaller fan equipment generates less noise	Main noise-generating equipment typically centralized on mechanical floor Minimal noise-generating equipment required within the office space
	Thermal Comfort	Series flow FPBs provide good thermal comfort	Series flow FPBs provide good thermal comfort	Series flow FPBs provide good thermal comfort	Excellent thermal comfort and local control
Architectural Impact	Floor Space Requirement	Large AHU space required at mechanical floors No AHU space required at typical office floors Large vertical duct shafts required Overall space requirement roughly equivalent	Reduced AHU space required at mechanical floors AHU room required at each typical office floor Reduced vertical duct shafts required Overall space requirement roughly equivalent	No AHU space required at mechanical floors AHU room required at each typical office floor No vertical duct shafts required Overall space requirement roughly equivalent	Reduced AHU space required at mechanical floors Small air column unit closets required at typical office floor Reduced vertical duct shafts required Overall space requirement roughly equivalent
	Louver Locations	Centralized at mechanical floors only	Centralized at mechanical floors only	At each office floor	Centralized at mechanical floors only

Key Terms:

ACH - Air changes per hour
ASHRAE - American Society of Heating, Refrigeration and Air-Conditioning Engineers
AHU - Air-handling unit
DOAS - Dedicated outdoor air system
FPB - Fan-powered box
UFAD - Underfloor air distribution

Table 1. Air Handling Systems Comparison. © Environmental Systems Design, Inc.

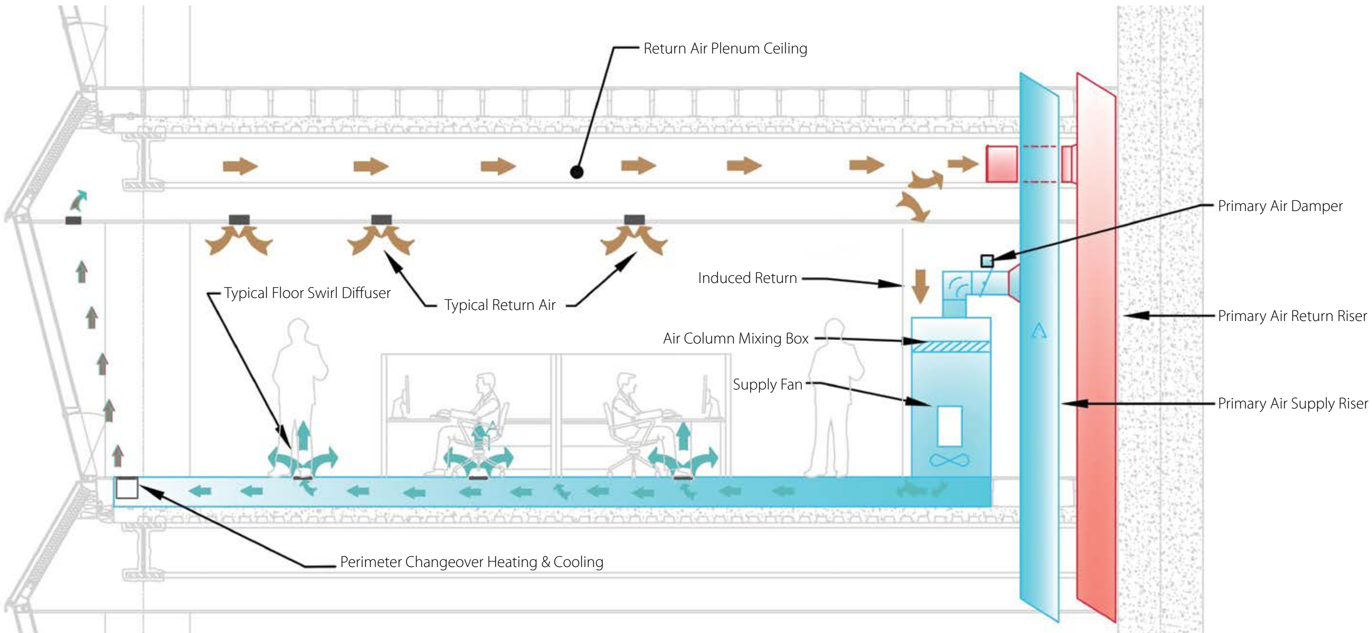

Figure 8. Diagram of an underfloor air-distribution (UFAD) system with a ceiling-based return air plenum. © Environmental Systems Design, Inc., redrawn by CTBUH

> "Rethinking the tenant improvement allowance allocation could make UFAD systems feasible even in tall core-and-shell office buildings, and the IAQ benefits are clear."

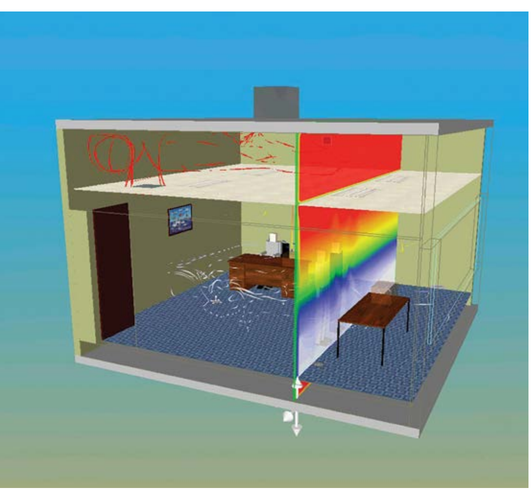

Figure 9. Three-dimensional view of an underfloor air distribution (UFAD) system, showing air flow and temperature performance in a compartmented office space. © Environmental Systems Design, Inc.

contaminants and pathogens accumulate above the occupants, limiting potential exposure duration.

With UFAD systems, particulates and pathogens travel much more directly out of the space compared to traditional overhead systems, where the air swirls and mixes as it leaves the space. CFD analysis shows the air path of potential pathogens exhaled by an occupant for both systems, with clear performance improvements for the UFAD system (see figures 10 and 11).

Raised-floor air distribution systems have been used since the 1950s in computer rooms to accommodate wiring distribution as well as cooling. The system has also been employed in office buildings, but predominantly for owner-occupied buildings. While overall installation cost is typically equal or even less than traditional approaches, UFAD systems push much of the first cost to the base building rather than the tenant buildout, which can be challenging from a leasing standpoint.

Rethinking the tenant improvement allowance allocation could make UFAD systems feasible even in tall core-and-shell office buildings, and the IAQ benefits are clear.

Intelligent IAQ Monitoring

The COVID-19 pandemic has highlighted the importance of HVAC systems and indoor air quality as something that is front-of-mind for all occupants in tall office buildings. The way people live and work may forever be changed as a result of the pandemic, and office buildings will need to adapt in order to prioritize the health, safety, and wellness of tenants.

Even after the pandemic subsides, occupants will be more finely attuned to a building's IAQ, and will demand higher-performing systems as well as insights into their environment. Intelligent air quality sensors can continuously measure, verify, and provide visibility into a tall building's air quality status.

In the increasingly connected world, intelligent sensors can provide air quality data that is useful for both operators and occupants. With forward-thinking transparency, the data can be compiled into meaningful metrics and shared with occupants to give them insight into building operations and performance. By continuously optimizing IAQ and providing full transparency to the occupants, this approach will raise the standard for commercial office buildings and push tall building design to a higher level that can meet and exceed the demands of a post-pandemic workforce.

Tall Office Buildings of the Future

Lessons learned from the current pandemic can help guide design for tall buildings of the future. Buildings that prioritize health, wellness, and IAQ without overlooking sustainability will be well-positioned to attract and retain premier office tenants. Those designed with flexibility integrated into the base systems will best respond to future pandemics and unknown needs. And those that harness data and provide transparency into the occupied environment will provide comfort and confidence for tenants to return to, and remain in the office space.

Decentralized floor-by-floor AHUs eliminate air mixing between office floors and provide flexibility for individual tenant operations and air-quality enhancements. UFAD improves pathogen removal and air quality in the office space. Both system approaches are primed for use in the next generation of high-performing tall office buildings.

The current pandemic will eventually subside, but some impacts will be longstanding. Tall office building tenants will forever be more finely attuned to IAQ and their environment. Forward-thinking tall office building HVAC systems will be rethought and reconfigured to best respond.

No one in the tall building community foresaw the pandemic. The good news is, all of us can play a role in our long-term response: the improved buildings of tomorrow. ■

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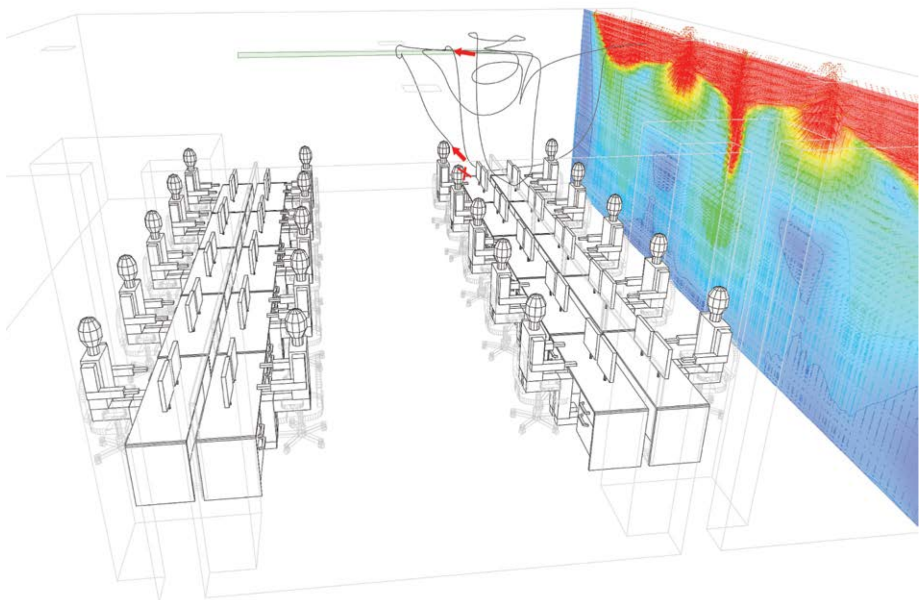

Figure 10. Airborne particle travel paths, using an overhead system. © Environmental Systems Design, Inc.

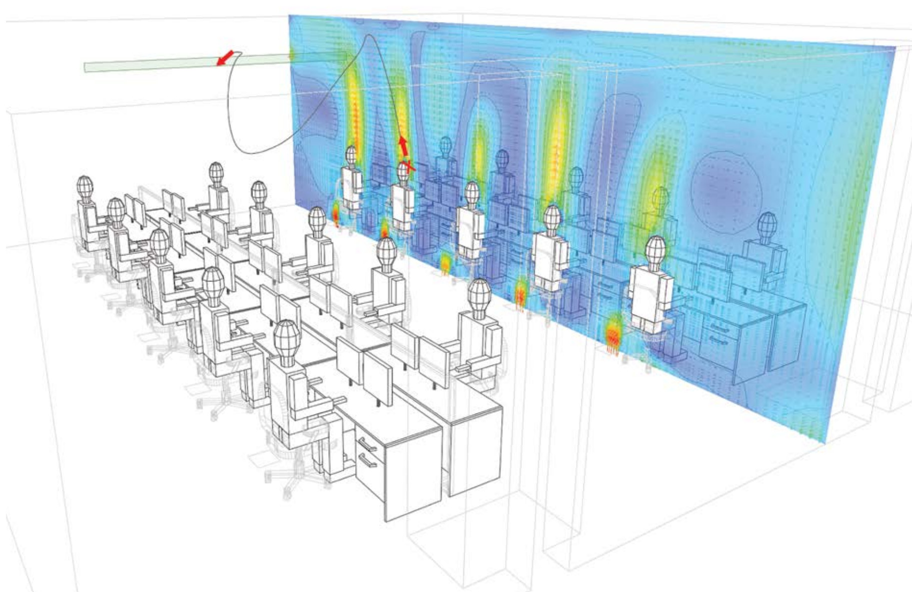

Figure 11. Airborne particle travel paths, using a UFAD system. © Environmental Systems Design, Inc.