Using Dual-Duct, Dual-VAV to Reduce Cooling & Heating Loads

"Using Dual-Duct, Dual-VAV to Reduce Cooling & Heating Loads" by Nabil Nassif, Ph.D., P.E., in the November 2020 *ASHRAE Journal* does not address dehumidification of the heating unit in a dual-duct system, which is part of the reason this type of system went out of favor. There is a reference to the dual-duct strategy being more applicable to heating-dominated climates, but there needs to be a more clear discussion of outdoor air dehumidification since the heating air handler has no capability for dehumidification. Does the heating system shut down or go to full recirculation during periods when dehumidification of outdoor air is required?

Also, I recently considered a dual-duct system for a cGMP project in which the air change rate was much higher than the airflow required for cooling. This is a possible application for a dual-duct system that may still apply. The focus on reducing simultaneous heating and cooling is important for energy efficiency, so striving to break out of the typical VAV reheat system will continue to be both important and challenging.

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The Author Responds

You raise an important point. The paper did not directly address the dehumidification of the heating unit in a dual-duct system because during warm weather when dehumidification may be needed, this heating unit turns off and no fresh air is introduced through the unit. As indicated in Table 5, Case 5, for instance, when the outdoor air temperature (OAT) is 82°F, only the cold AHU (AHU1) operates and provides the required ventilation to the building. In this case, the cold AHU operates exactly as a single-duct VAV system, yielding the same dehumidification challenges of typical VAV systems. The AHU1 unit is equipped with cooling and heating coils that may be used for dehumidification.

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COVID-19 and Beyond: A Brief Introduction to Passenger Aircraft Cabin Air Quality

It is interesting to read "COVID-19 and Beyond: A Brief Introduction to Passenger Aircraft Cabin Air Quality" by Douglas Stuart Walkinshaw, Ph.D., P.Eng., in the October 2020 issue of *ASHRAE Journal*, which reviewed passenger aircraft cabin air quality under this atmosphere of the SARS-CoV-2 virus outbreak. Studies were based on possible disease transmission through solid particulates where virus nucleus can be deposited.

The ventilation designs good for removing solid particulates would give a clean cabin. COVID-19 can then be transmitted[1] through coronavirus-bearing respiratory droplets from carriers. A dry cabin environment[2] would evaporate droplets faster, so that the small SARS-CoV-2 virus of size 50 nm to 200 nm have fewer substrate spaces on which to deposit. This might reduce the transmission rate, explaining why even flights[3] from high risk areas had only 11 passengers infected.

Consequently, evaporation effects on liquid droplets play a key role in virus transmission.[1] The transmission of the virus in a cabin appears not as bad when passengers and the crew are wearing masks all the time.

However, the following should be considered in preventing COVID-19 spread, in addition to what the author reviewed:[2] appropriate cabin crew training to have an adequate safety management scheme and avoid transmission through direct contacts in small airplane toilets.

References

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The Author Responds

Your letter raises some interesting points and your Reference 1 aids in understanding that low indoor relative humidity (RH) reduces droplet travel distance, while low air density increases it. It would be interesting to use your equations to predict what maximum size droplets will become aerosols before plating out on surfaces in the low humidity (10%), low air density (3/4 atmosphere) aircraft environment.

It is true that a cabin designed to remove infectious aerosols without mixing and exposure of noninfected persons (like a laminar flow cleanroom) would give a clean cabin but not prevent transmission by fomites. But aircraft cabins are not cleanrooms, and infectious aerosols emitted by an infected person travel in the air many rows as well as laterally.[1,2] Further, airborne infection risks are not small.[3,4] A recent review consistently found that humans produce pathogens predominately as aerosols or small respirable particles (<5 microns), with PCR studies identifying infectious aerosols in the air of rooms with persons ill with COVID-19, the common cold, influenza A and B, tuberculosis, measles, herpes and chicken pox.[5] Low humidity exacerbates the risk.[6]

Many "authorities" saying high air change rate is the criteria for good air quality as far as airborne aerosol infections are concerned does not make it true. Infectious aerosols originate with infected persons creating and shedding virus—not with visible and hidden building or aircraft cabin materials creating and shedding virus, not with equipment creating and shedding virus and not with the frost and moisture behind the insulation creating and shedding virus. Given that fact, the rate of infectious virion-free air supply to each person, including each ill person and the persons around them, governs virion concentration in the air around the ill persons—not air change rate.

While high air change rates provide some protection, they also result in the virions in the air being inhaled by others being fresher and more virulent, with less settling having occurred and the concentrations higher than in low air change settings. High air change rates can be the antithesis of low infectious aerosol exposure when they are the result of tightly packed together persons in spaces with low ceilings—the situation with aircraft passenger cabins, for example. The total virion-free air being supplied is large, but the amount per person is not. Speaking of low ceilings, spaces with high ceilings are naturally safer, because body heat and warm breath rise to the ceiling, taking with them human-generated aerosols, and stay there if they are not pushed back down by ceiling fans and the like.

Equation 2, then, in my paper predicts the total number of virion aerosols inhaled by persons in the same space but not their dispersion or individual inhalation. It does this prediction by accounting for the per occupant outdoor air supply rate and filtration rate of particles from the recirculation air supply. It will also accommodate an estimation of the filtration benefit of mask wearing on aerosol exposure reduction, which should eliminate viral

TABLE 1 Narrow body and wide body passenger aircraft influenza A virions inhaled and infections per ill person, $I = 9$ L/min·p, $t = 5$ h, $N = 76{,}000$ v/h, $HID_{50} = 900$ v. Narrow body: $OD = 1$ m^3/p, $V = 9.4$ L/s·p, $V_e = 0.65$. Wide body: $OD = 1.6$ m^3/p, $V = 11.8$ L/s·p, $V_e = 1$.

	NARROW BODY VIRIONS INHALED	NARROW BODY PREDICTED INFECTIONS	WIDE BODY VIRIONS INHALED	WIDE BODY PREDICTED INFECTIONS
No Mask	9,244	≤5	4,794	≤3
Mask 50%	2,311	≤1	1,199	≤1

infection risks from surfaces contaminated with fomites (except for eye touching) and greatly reduce risk from airborne droplets, both emitted and inhaled. Eye exposure might be important only in hospital-related viral transmission during ophthalmic practice.[3] Mask wearing will not reduce the infection risks completely, as a just-completed case study indicates. That study identified a 9.8% to 17.8% COVID-19 attack rate on persons spread throughout the cabin, some wearing masks, during a 17% full, seven-hour international flight to Ireland.[7]

I will assume in the calculations that follow regarding the August 3 flight from Delhi to Hong Kong that masks remove 50% of the virions from both our exhaled and inhaled air. In place of COVID-19 for which there are no shedding and infectiousness criteria, I will use influenza A (virions are similar in size to those of COVID-19),[3] virion (*v*) shedding rate and its lowest infectiousness criteria, which seems appropriate for aircraft due to the very dry conditions being more favorable to airborne infection spread due to impairment of nasal mucociliary clearance, innate antiviral defense and tissue repair function. *Table 1* here shows Equation 2 predictions and all parameters used.

So if influenza A is a valid surrogate and everyone was wearing masks, it is possible that five COVID-19 infections occurred during that flight from exposure to six persons with false-negative preflight tests if they were all shedding.[8] It is also possible that if masks were being worn, no COVID-19 infections occurred during the flight or, if there were infections, that these persons had not yet begun shedding at the time of the post-flight tests. To these predictions must be added any virions inhaled prior to the flight and those of the 24,000 v/h coarse (>5 microns) particles shed by ill persons that were aerosolized and inhaled before settling or exiting the cabin.

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What to Consider When Designing For *N* + 1

I note in Figure 3A of David Sellers' November 2020 column, "What to Consider When Designing for *N*+1," that slowing the fans to reduce airflow has left them operating very close to the peak of the fan curve. Readers should consider an inlet vane damper in similar situations. Partly closing an inlet vane damper reduces flow without dropping the peak static pressure. Put another way, it shifts the fan curve to the left, rather than down and left, resulting in more stable operation, and possibly more energy savings.

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The Author Responds

Your observation is quite valid and was one reason I was a nervous wreck when we headed out to test our theory without really knowing what the fan curves looked like. The inlet vane dampers you reference would have been a real asset for the reasons you describe. (This point is illustrated in the *2020 ASHRAE Handbook—HVAC Systems and Equipment,* Chapter 21, Figure 18, where the devices are called inlet vanes, and in Figure 15.4 of Howden-Buffalo's *Fan Engineering—An Engineer's Handbook on Fans and Their Applications*, where the devices are called inlet vanes, https://tinyurl.com/yyh5j4f7.)

I've also heard them referred to as inlet guide vanes (IGVs), I believe because they function by directing or guiding airflow into the impeller in a way that changes the performance curve rather than by restricting flow, which is what dampers generally do.

In any case, our problem was that we were dealing with an existing system; the fans simply didn't have IGVs. So we worked with what we had: the VFDs. However, I am not sure inlet vanes would have been an option for the application because of the corrosive exhaust. Some acids we used could etch silicon, and the system was fabricated from special acid-resistant materials.

Inlet vanes are mechanical, with much of the mechanism in the airstream. (Photos are here: https://tinyurl.com/2020-11-ASHRAE-02.) Thus, I am not sure they would have been viable in the corrosive exhaust.

I also think, with a "clean sheet of paper," if the design had targeted a two-fan operating mode for normal operation, the operating point would have been at a much better spot on the fan curve. A fan failure could be accommodated several ways:

- Provide a third fan like Nathan Ho's team did ("Performance-Based Approach to Laboratory Exhaust Systems," September 2020 *ASHRAE Journal*).
- Provide two fans, each equipped with a larger motor and a wheel rated for a higher fan class than normal operation would require. If one fan failed, the other could speed up and deliver the design condition on its own.

I just did a quick selection and both options seem theoretically viable. The three vs. two fans decision would likely come down to a first-cost vs. life-cycle cost decision and an *N* + 1 consideration.

Two fans with larger motors and higher wheel classes would probably have a lower first cost compared to three fans when the related duct, electrical and control system infrastructure required to accommodate a third fan were considered.

But the two fans would spend most of their hours operating a low motor load/motor efficiency/low VFD efficiency condition. (The curves in the article illustrate this.) Thus, the operating cost would not be as attractive as what might be achieved with a three-fan approach, especially given 24/7 operation and a system that would likely be in place for a long time.

From an *N* + 1 perspective, the two-fan approach would leave you with no redundancy if the remaining fan failed prior to repairs. In contrast, the failure of two of three fans would not cause a total loss of flow. Safe operation would likely not be possible on only one fan. However, you would have not crashed the fab with the issues associated with that, giving the three-fan approach a potential edge.

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