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Contaminant Transport and Filtration Issues with DOAS

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ABSTRACT

Dedicated outdoor air systems (DOAS) are often thought to be inferior to all air systems when contaminant flushing rates from occupied spaces are considered. This is a particularly prevalent attitude when the parallel terminal sensible cooling equipment provides no, or minimal, filtration of terminal air, such as the case with chilled ceilings, beams, and even fan coil units. The central thrust of this paper is to determine if the attitude concerning the perceived inferiority of DOAS's contaminant flushing rate is warranted. The investigation is carried out via an analytical case study involving a multi zone facility served by either a DOAS or a Variable Air Volume (VAV) system.

DOAS BRIEFLY DEFINED

A DOAS delivers 100% outdoor air (OA) to each individual space in the building via its own duct system, at flow rates generally as dictated by ASHRAE Std. 62.1 or higher. Elevated design ventilation flow rates may be necessary for latent load control, building pressurization, or to garner LEED green building points. Based upon the requirements of ASHRAE Std. 90.1, most DOAS applications require the use of total energy recovery. As a general rule a DOAS operates at constant volume during all occupied hours.

Consequently, for most applications, the DOAS is not capable of meeting all of the thermal loads in the space by itself, and requires a parallel system to accommodate any sensible and latent loads the DOAS can't accommodate. The DOAS is not to be confused with what is commonly called a "100% OA system", whose flow rate is selected to meet the entire building sensible and latent loads. In other words, a DOAS generally delivers only about 20% as much air to a space as a "100% OA system".

The thermodynamic state of the delivered air varies[1], but as a minimum it should condition the air to the desired space dew point temperature (DPT), thus decoupling much of the latent load from the parallel system charged with the bulk of the space sensible load control.

From a contaminant transport point of view, the constant volume DOAS leads to predictable pressure differentials (including neutral if desirable) between adjoining spaces or zones, thus minimizing the potential for interzonal transfer of airborne contaminants. Also since it does not use any recirculated air, airborne contaminants that may be present in one zone are not immediately distributed throughout a facility by the mechanical system, as is common with mixing air systems (i.e. VAV).

The selection of the parallel system based upon contaminant transport is important for two main reasons: first the parallel system may or may not recirculate and filter air locally, and second the parallel system may recirculate and filter air centrally, such as an all-air VAV system.

THE FACILITY AND ASSUMPTIONS FOR THE CASE STUDY

Consider a 20,000 ft^2 (1,858 m^2) facility with 10 ft (3 m) high ceilings, Figure 1, consisting of a 2 zone perimeter region; 1,000 ft^2 (93 m^2) zone 1 and 9,000 ft^2 (836 m^2) zone 2 respectively. The facility also has a large interior 10,000 ft^2 (929 m^2) zone 3. For the sake of the study, the following air flow rates will be used in the analysis:

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- **VAV system.** Supply air (SA) flow rate, 16,000 cfm (7,550 l/s), of which 4,000 cfm (1,888 l/s) is OA. Perimeter zones 1 and 2, each receives 1 cfm/ft^2 (5 l/s-m^2) of supply air via a shut off box VAV system, Figure 2 (from here on just referred to as a VAV system). Since the SA is 25% OA, then each perimeter zone is receiving 0.25 cfm/ft^2 (1.3 l/s-m^2) OA. Interior zone 3 receives 0.6 cfm/ft^2 (3 l/s-m^2) of supply air via a VAV system. That translates to 0.15 cfm/ft^2 (0.76 l/s-m^2) OA
- **DOAS.** OA flow for the facility, 4,000 cfm (1,888 l/s) uniformly distributed in each zone, Figure 3, or 0.2 cfm/ft^2 (1 l/s-m^2).

The analysis is based upon the following additional assumptions:

- Well mixed zones, i.e. uniform concentrations.
- No interzonal transfer, i.e. neglect influence of pressure differentials, human activity and or infiltration/exfiltration.
- Contaminants stay suspended, i.e. they do not settle or plate out in the zone.
- VAV system is analyzed while operating in the minimum OA mode (4,000 cfm (1,888 l/s) OA), and at the design supply airflow rate, i.e. 16,000 cfm (7,550 l/s). Contaminate releases during full economizer mode (resulting in very high peak space concentrations when releases occur near the OA inlet) will not be presented.
- The capacitance of the duct system, and its associated influence on the transient response, is neglected.

The governing equations for the VAV follow:

$$V_1 \cdot \frac{dC_1}{dt} = Q_1 \cdot (C_m - C_1)$$

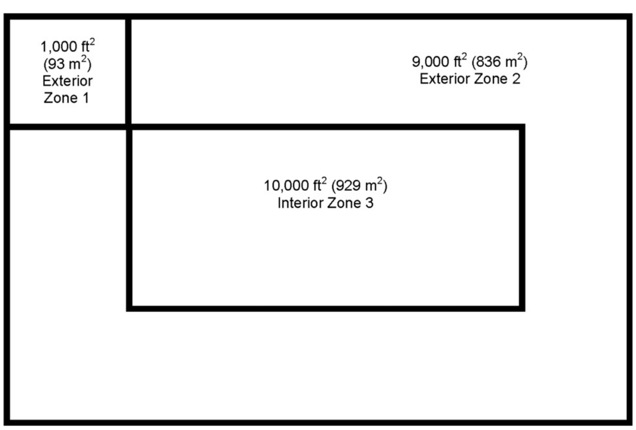

Figure 1 *Floor plan, zone labels, and areas.*

$$V_2 \cdot \frac{dC_2}{dt} = Q_2 \cdot (C_m - C_2)$$

$$V_3 \cdot \frac{dC_3}{dt} = Q_3 \cdot (C_m - C_3)$$

$$C_{exh} = \frac{Q_1 C_1 + Q_2 C_2 + Q_3 C_3}{Q_1 + Q_2 + Q_3}$$

$$C_m = (1 - \eta_f) \cdot \frac{Q_{OA} C_{OA} + Q_{rec} C_{exh}}{Q_1 + Q_2 + Q_3}$$

$$Q_{rec} = (Q_1 + Q_2 + Q_3) - Q_{OA}$$

and DOAS follow:

$$V_1 = \frac{dC_1}{dt} = Q_1 \cdot (C_{in} - C_1)$$

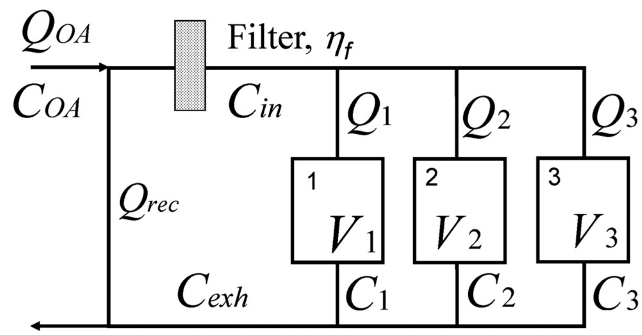

Figure 2 *Schematic for the VAV system.*

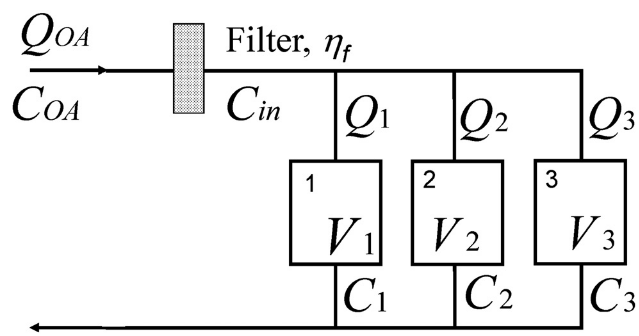

Figure 3 *Schematic for the DOAS.*

$$V_2 = \frac{dC_2}{dt} = Q_2 \cdot (C_{in} - C_2)$$

$$V_3 = \frac{dC_3}{dt} = Q_3 \cdot (C_{in} - C_3)$$

$$C_{in} = (1 - \eta_f) \cdot C_{OA}$$

Where:

C = concentration of contaminant

Q = SA flow rates

V = space volume

η_f = filter efficiency

CONTAMINANT INTRODUCTION NEAR THE OA INTAKE

Only contaminant sources near the OA intake are presented. Contaminant transport from internal sources[2] will not be presented since filtration has no bearing on concentrations for DOAS. The contaminant source is assumed to be near the OA stream and of 5 minute duration.

Filter efficiency can significantly impact the peak concentrations and transient response of the zone concentrations when the contaminant source is near the OA intake.

First consider the case where the filters have no impact on contaminant removal, i.e. zero percent filter efficiency. Figure 4 illustrates such a case with the release near the OA intake. Since the VAV supply air quantity to the exterior zones 1 and 2 is higher than that of the interior zone 3, their peak concentrations are different. For the DOAS system, since the supply airflow rate is a constant 0.2 cfm/ft^2 (1 l/s-m^2) the peak concentration in all zones and the subsequent response is uniform throughout the facility. Note: the zone transient concentrations are presented in dimensionless form, referenced in all cases to the peak concentration experienced by the DOAS system with zero percent filtration efficiency. Since the VAV supply airflow rates differ between the interior and perimeter zones, their peak concentrations differ (with the higher flow/unit floor area perimeter zones OA/ unit floor area exceeds that of a DOAS 20% and the interior zone OA/ unit floor area is 20% lower than DOAS). The higher VAV supply airflow rate to the zones 1 and 2 not only causes their peak concentrations to be higher than that of the interior zone 3, but also causes them to clear faster than the interior zone 3.

Typically it is assumed that the filtration efficiency used with a VAV system and a DOAS system are equal. That need not be true. And if the filtration efficiency for a particular contaminant is 80% for a VAV system, the zone concentrations for both the VAV and DOAS systems are equal, exactly one hour following the release, if the DOAS filter efficiency is 98% as illustrated in Figure 5. The area under the curves represents the exposure that the occupants of the zones would experience. It is significant to note that with the improved efficiency DOAS filtration, the integrated one hour exposure immediately following the release is about 425% more in the facility served by the VAV system than that the a DOAS system. This is true since the 98% filter in the DOAS OA path removes 98% of the material before delivering it to the space.

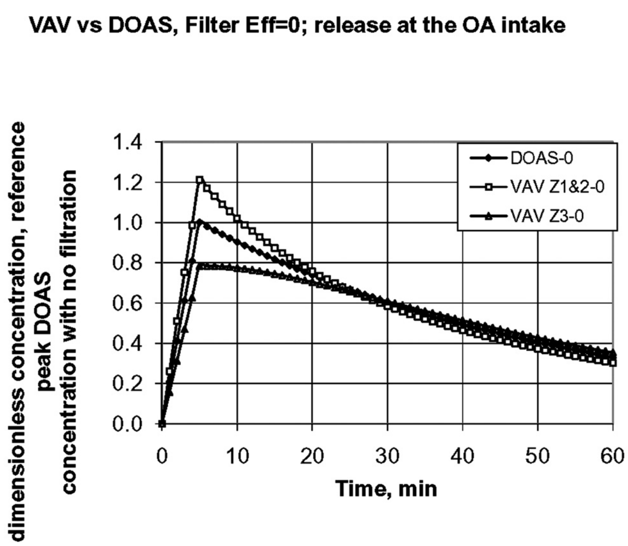

Figure 4 *Transient dimensionless concentration from release near OA inlet with filter efficiencies of 0%.*

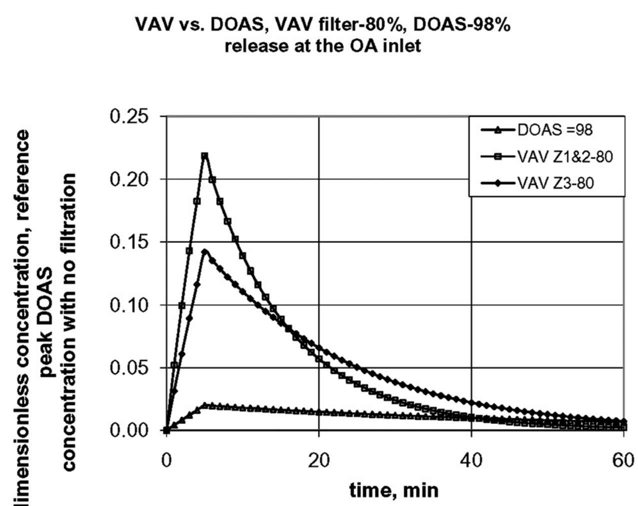

Figure 5 *Transient response to a release nears the OA intake, VAV filters efficiency. 80%, DOAS filter efficiency 98% for same space concentration after 60 min.*

So even though the DOAS spaces clear slower than the VAV system, its peak concentration is only 2% what it experiences without a filter.

For the facility used in this analysis, employing the associated assumptions and transient equations, it is easy to compute the DOAS filtration efficiencies necessary to match the lowest 60 minute VAV zone concentration and exposure. Those results are presented in Figure 6. Notice the VAV and DOAS filtration efficiencies match at zero and 100 percent. Otherwise the DOAS filter efficiency must be higher than the VAV for equivalence. Finally, the DOAS filter efficiency necessary to match 60 minute exposure is less than that necessary to match the 60 minute concentration.

OPTIMIZED FILTER SELECTION FOR A DOAS TO PROVIDE EQUIVALENT ONE HOUR EXPOSURE, OR SPACE CONCENTRATION, RELATIVE TO AN OPTIMIZED VAV FILTER EFFICIENCY SELECTION

Figures 5 and 6 illustrated that selecting a more efficient filter for a DOAS, when compared to a lower efficiency VAV, leads to similar exposures or interior concentrations when dealing with contaminant sources in the OA stream. That could lead one to theorize that the higher first cost per unit area and pressure drop of the DOAS filter would make such a selection economically impractical. In an effort to test that hypothesis for the facility used in the case study, assuming that the average contaminant particle size is 2 micron, cost and operating data for various efficiency filters was undertaken and used in an optimization set of equations. The data presented in this paper is limited to the filter efficiency combinations presented in Table 1. Images of the filters used for the simulations are in Figure 7.

Detailed performance data for commercially available 2 micron efficiency filters were obtained from the manufacturers[3], including clean and loaded pressure drop at a given face velocity, pressure drop as a function of loading, pressure drop as a function of face velocity, and recommended filter change frequency. These data were curve fit for use in the optimization solutions.

For the base case optimizations, the following assumptions were made:

1. VAV SA flow: 16,000 cfm (7,550 l/s); and DOAS SA flow: 4,000 cfm (1,888 l/s).
2. Assume that the filter loading profile is exponential, causing the average pressure drop over the life of the filter to be: $[(\Delta p_{loaded\ opt} - \Delta p_{clean\ opt})/2] \cdot Fill_{ratio}$. Use 0.87 as the $Fill_{ratio}$.
3. Reference replacement frequency is 3 months for VAV and 6 months for DOAS
4. fan/motor combined efficiency: 60%.
5. Electrical cost: \$0.10/kWh.
6. Term of analysis: 5 years.
7. Fan operating hours per year: 4160 hours.
8. Neglect the time value of money and inflation.

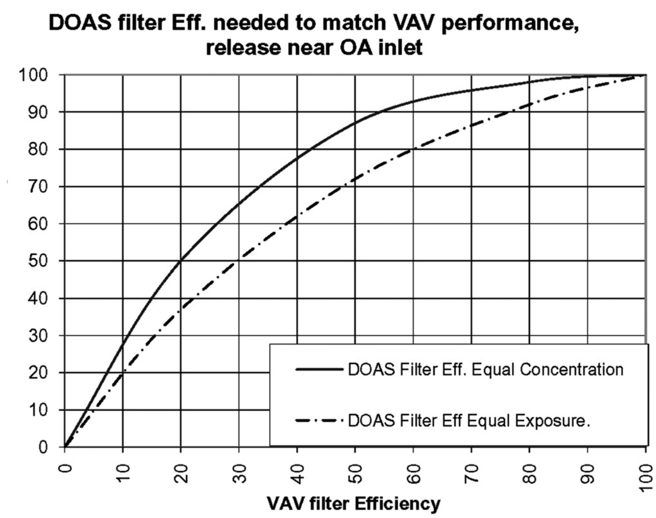

Figure 6 *DOAS filter efficiencies necessary to match the space concentration or exposure after 60 min compared to the VAV filter efficiency, for occurrences near the OA intake.*

Table 1. VAV/DOAS Filter Efficiencies for Equivalent Performance

Nominal VAV Filter Efficiency, Merv Rating	Nominal DOAS Filter Efficiency, Merv Rating	Filter Efficiency for Equivalent 1 h Concentration/Exposure Performance (Figure 6)
75, merv 11	94	97/89
94, merv 13	98	99/98
98, merv 14	99.7, merv 16	99.7/99.3

9. Filter cost data was obtained from an online University Business Services purchasing contract[4]. Labor costs for filter replacement was not considered.
10. Op cost for parallel equipment (I.e. FCU's, Chilled Ceilings etc.) used with the DOAS have not been included in the analysis.

The simple optimization equations solved[5] are:

1. $\Delta p_{clean\ opt} = c_1 \cdot FV_{opt} + c_2 \cdot FV_{opt}^2$

2. $\Delta p_{loaded\ opt} = c_3 \cdot FV_{opt} + c_4 \cdot FV_{opt}^2$

3. $FV_{opt} = SA / FA_{opt}$

4. $Fill_{ratio} = 0.87$

5. $\Delta p_{avg\ opt} = [(\Delta p_{loaded\ opt} - \Delta p_{clean\ opt})/2] \cdot Fill_{ratio}$

6. $Fan_{eff} = 0.6$

7. $Fan_{HP\ opt} = SA \cdot (\Delta p_{avg\ opt})/(Fan_{eff})$

8. $Fan_{kW\ opt} = Fan_{HP\ opt} \cdot 0.75$

9. $$\Delta p_{ratio} = \frac{(\Delta p_{loaded\ opt} - \Delta p_{clean\ opt})}{(\Delta p_{loaded\ @\ Manf\ ref\ FV} - \Delta p_{clean\ @\ Manf\ ref\ FV}}$$

10. $Months_{between\ filter\ changes\ opt} = Month(s_{between\ filter\ changes\ opt\ @\ ref\ FV} \cdot \Delta p_{ratio})$

11. $Filter_{1st\ cost\ opt} = FA_{opt} \cdot Filter\ \$_{per\ unit\ area} \cdot (12/Months_{between\ filter\ changes\ opt}) \cdot \text{term of analysis}$

12. $Op_{cost\ opt} = Fan_{kW\ opt} \cdot Op_{hours/yr} \cdot Period_{years} \cdot elec\ \$_{per\ kWh}$

13. $Minimize = Filter_{1st\ cost\ opt} + Op_{cost\ opt}$

Where:

- $\Delta p_{clean\ opt}$: Filter pressure drop when clean at optimal face velocity, in-wg (Pa)
- $\Delta p_{loaded\ opt}$: Filter pressure drop when loaded at optimal face velocity, in-wg (Pa)
- FV_{opt}: Optimal face velocity, ft/min (m/s)
- FA_{opt}: optimized filter size, ft^2 (m^2)
- $Fill_{ratio}$: accounts for the non-linear exponential filter loading characteristics
- $\Delta p_{avg\ opt}$: the average pressure drop over the life of the filter at the optimum conditions, in-wg (Pa)
- Fan_{eff}: assumed combined fan/motor efficiency, fraction
- $Fan_{HP\ opt}$: Fan horsepower at the optimum conditions using the average filter pressure differential, HP
- $Fan_{kW\ opt}$: Fan energy demand, kW
- Δp_{ratio}: ratio of filter pressure drop increase from clean to loaded at optimum FV vs. filter pressure drop increase from clean to loaded at 500 fpm (2.5 m/s) ref FV. NOTE, this is used to alter the normal filter replacement period based on filter size (if $FV > 500$ fpm (2.5 m/s) replacement is more frequent, and if $FV \leq 500$ fpm (2.5 m/s), replacement is less frequent)
- $Months_{between\ filter\ changes\ opt}$: months between filter changes with optimized filter selection.
- $Filter_{1st\ cost\ opt}$: first cost of the filter at optimized conditions.
- $Op_{cost\ opt}$: fan operating cost as a result of the filter alone
- $Op_{hours/yr}$: operating hours per year
- $Period_{years}$: years in the economic analysis
- $elec\$_{per\ kWh}$: utility cost, \$/kWh
- $Minimize$: value of the objective equation, \$

The results of the base case optimizations are presented in Table 2.

Perturbations to the base case were made including: cutting the electric rates or hours of operation by 50%, changing the DOAS filters every month, reducing the fan motor efficiency, and filter average pressure drop with a fill factor of 1.0. These perturbations did not change the trends presented in Table 2. One sizable perturbation was to force a DOAS filter change each month, greatly increasing the first cost of the filter driving its size down at the expense of operating cost. Those optimization results are presented in Table 3.

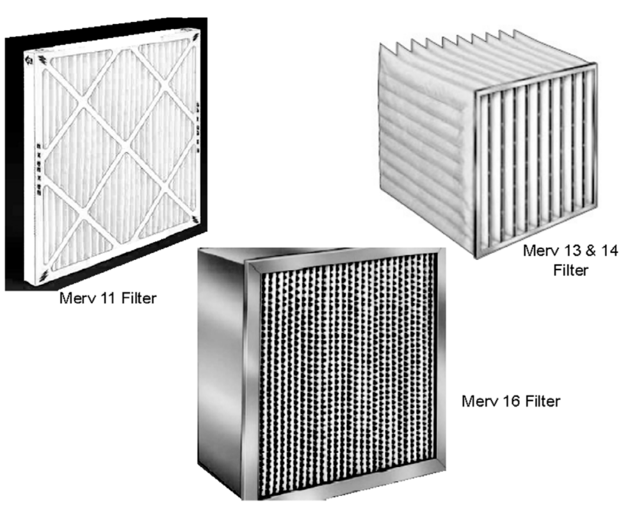

Figure 7 *Images of the filter types used.*

DISCUSSION OF RESULTS

For the 20,000 ft^2 (1,858 m^2) facility with filter efficiency equal to zero for a particular contaminant, the transient concentration rises rapidly in each zone per Figure 4, then dissipates slowly. The interior VAV zone 3, supplied with 0.6 cfm/ft^2 (3 l/s-m^2) of mixed air containing 25% OA (4,000 cfm [1,888 l/s] OA/16,000 cfm [7,550 l/s] SA), or 0.15 cfm/ft^2 (0.76 l/s-m^2) of OA does not reach as high a dose or concentration as the exterior zones 1 and 2. The exterior zones, receiving 1 cfm/ft^2 (5 l/s-m^2) of 25% OA, i.e. 0.25 cfm/ft^2 (1.3 l/s-m^2) are hit harder initially by the contaminant, resulting in a higher concentration. By contrast, the DOAS, supplying 0.2 cfm/ft^2 (1 l/s-m^2) exhibits a peak concentration between that of the interior and exterior zones served by the VAV system.

With the addition of filters that remove a fraction of the contaminant, as illustrated in Figure 5, the peak concentrations in all zones served by either system are much lower than the case above where the filters had no contaminant removal ability. But the peak concentrations are not uniform. The exterior VAV zones 1 and 2 experience higher concentrations than the interior zone 3, but since the exterior zone flow is higher, it clears faster than the interior zone. The higher efficiency DOAS filters significantly lower the peak concentration when compared with the VAV system (with DOAS the peak and transient decay are the same for each zone), but the DOAS clears the zones very slowly. Since the initial DOAS peak concentration is so low, in spite of its slow clearing response, it is as low as the VAV system after one hour after initial exposure to the contaminant. If human exposure were considered to be the area under the concentration-time curves, the occupants of the building served by the VAV system would have received a dose 425% greater that the occupants in a building served by a DOAS.

Figure 6 provides guidance in selecting a DOAS filter efficiency that will give comparable concentration or exposure performance, after one hour, to that of a VAV system. The heavy upper curve illustrates that much better DOAS filters are required between the 2 limiting conditions, zero filter efficiency and a perfect filter, for the DOAS concentrations after an hour to equal that of the VAV system. For example, when a VAV system filter efficiency is 50%, the comparable DOAS filter efficiency is 88%. Clearly a 50% efficient DOAS filter would fail to provide equivalent space concentrations after one hour. The dashed curve in Figure 6 provides guidance on DOAS filter selection for comparable exposure. As with equivalent concentration, a better, but slightly less demanding filter efficiency is required for a DOAS. For a 50% efficient VAV filter, the DOAS filter efficiency for equivalent one hour exposure is 72%.

For the first pairing (least efficient VAV filters) of VAV and DOAS filter optimization results presented in Table 2, the

Table 2. Optimal Solutions for VAV and DOAS Filters Giving Equal Performance

System	Filter Efficiency	Optimal Face Area, ft^2/m^2	Months Between Filter Change	Filter 5 yr First Cost, $	Fan 5 yr Operating Cost Based on Filter Average DP, $	Total 5 yr Cost, $
VAV	75	61.5/5.7	4.2	$753	$3246	$3999
DOAS	94	9.3/0.86	6.5	$519	$870	$1389
VAV	94	33.4/3.1	3	$3959	$3611	$7570
DOAS	98	8.8/0.82	6.4	$717	$1350	$2067
VAV	98	30.5/2.8	2.9	$5368	$5650	$11,018
DOAS	99.7	8.9/0.83	6.5	$1052	$1392	$2444

Table 3. DOAS Filter Optimization Based on Monthly Replacement

System	Filter Efficiency	Optimal Face Area, ft^2/m^2	Months Between Filter Change	Filter 5 yr First Cost, $	Fan 5 yr Operating Cost Based on Filter Average DP, $	Total 5 yr Cost, $
DOAS	94	4.5/0.42	1	$1635	$1401	$3036
DOAS	98	3.5/0.33	1	$1823	$2130	$3953
DOAS	99.7	3.9/0.36	1	$2981	$2137	$5118

DOAS filter area was only 15% as large as the VAV filter area. The 4,000 cfm (1,888 l/s) DOAS air flow is 25% of the 16,000 cfm (7,550 l/s) VAV air flow, consequently the DOAS filter has a higher face velocity, and pressure drop than the VAV filters. The result is not surprising, however, since the DOAS filter per unit face area cost is over 7 times that of the VAV filter. In both systems, the optimum filter sizes were large enough that the loading time was extended beyond the specified 3 months for VAV and 6 months for DOAS. The optimum sizing resulted in a total 5 year cost of $3,999 for the VAV, almost 3 times the $1,389 for the DOAS.

For the second pairing of filters presented in Table 2, where the two filter efficiencies were closer than the first pairing, the DOAS filter is only 26% the size of the VAV filters, more nearly reflecting the flow rate difference for the two systems. This is not surprising since the DOAS filter is only 43% more expensive than the VAV. The optimum sizing resulted in a total 5 year cost of $7,570 for the VAV, almost 3.7 times the $2,067 for DOAS.

For the third filter pairing in Table 2, the highly efficient VAV filter requires an even more efficient DOAS filter. Comparing the per unit area cost ratio for the two filters reveals that the DOAS filter costs 1.5 times more than the VAV filter. The filter cost differential caused the optimum DOAS filter area to be 29% that of the VAV, again close to the DOAS to VAV filter flow ratios. At the optimum solution, the total 5 year VAV cost of $11,018 is 4.5 times the $2,444 for DOAS.

Recognizing that the filter replacement period can significantly impact the optimum, the DOAS filters were forced into a 1 month replacement schedule. Those results, presented in Table 3, illustrates the significant impact that increasing the frequency of DOAS filter replacement has on the optimum. The DOAS filter face areas dropped by more than 50%. In spite of that, the frequent filter replacement nearly tripled the optimum filter 5 year 1st cost compared to the optimum cases presented in Table 2 with longer periods between replacements. Additionally, the smaller filter areas caused the fan operating costs to jump substantially. Ultimately the total 5 year costs doubled compared to the optimum values of Table 2. In spite of these sharp increases, the optimum DOAS 5 year cost results with monthly filter replacement remained below that of the Optimum VAV 5 year total costs presented in Table 2.

CONCLUSIONS

A common attitude that contaminant flushing is a big problem with DOASs is not warranted when the proper DOAS filter is selected, i.e. one better than the filter used in a comparably performing VAV system as illustrated in Figure 6. This conclusion is limited to contaminants introduced into or near the OA system. The paper does not address contaminant releases inside occupied spaces.

Guidance is offered, at least for one set of conditions, on DOAS filter efficiencies. And a method is provided for use on other sets of conditions.

Finally, contrary to conventional wisdom, the selection of better and more expensive DOAS filters resulted in optimized performance costing less—far less—than VAV systems.

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DISCUSSION

Paul Tseng, Principal, Advanced Building Performance, Potomac, MD: a) Many designs pursuing LEED use IMC (7/1000 occupancy density) instead of the LEED default of 4/1000 occupancy. 7/1000 vs. 4/1000 is a 75% oversized OA CFM. Most DOAS are Dx cooled with a very limited stage of unloading, often only two-stages of unloading. With 223% oversize OA and either on-off of two-stage unloading in hot-humid climates, it is doubtful that DOAS can deliver the space RH without problems. Comment or solution? b) Most government operational requirements stipulate that OA be totally shutdown in an outdoor release of airborne contaminant. Most commissioning protocol verify a "kill-all" button can immediately shutdown the DOAS. Your suggested MERV-13- or 14-rated filter will not effectively remove biochemical agents (bacteria or virus). Would not a bulk-type filter (MERV 8) be most practical and cost-effective for normal operation?

Stanley Mumma: a) I would recommend using the correct airflow for the design, plus some surplus capacity to accommodate unexpected latent loads. In your example, you suggest a 75% oversized system and later a 223% oversized system. It can't be both ways. In any event, with the use of total energy recovered (TER), as required for most situations by ASHRAE Standard 90.1, the wide variability in OA conditions are shrunk into a small bull's-eye, as seen by the cooling coil/plant. As a result, the huge load variability you warn about is essentially eliminated. Thus, the supply air dew-point temperature can be held quite steady with only slight capacity modulation. If that supply air needs some tempering, it should be done with recovered energy. As for holding the space RH steady without problems, ASHRAE RP-1254 confirms that a DOAS with TER offered superior space humidity control.

b) That may or may not be a good idea from my perspective. For the most part, instrumentation does not exist to immediately detect the release. If it is detected once the building is full of the contaminant and the system is shut down, beneficial dilution by the system is lost. I am not sure what this comment means in terms of the paper. The point of the paper was not to specify a filter for any particular airborne contaminant. The point was to identify the DOAS filter efficiency necessary to match either the space concentration or exposure after an hour, when compared to that of a VAV system of specified filter efficiency. This is illustrated in Figure 6 of the paper. The paper did not address, nor did it intend to address, the filter efficiencies necessary to effectively remove biochemical agents or normal operation situations. You might conclude that from Figure 6, which has an efficiency range from 0% to 100%.

David Dinse, Project Manager, Tennessee Valley Authority, Chattanooga, TN: In regard to the table that compared fan energy, it didn't include conventional air distribution (i.e., 16,000 cfm VAV vs. 4000 cfm DOAS). The author was not comparing apples to apples. Additional energy will be needed for conventional heating and cooling for space. That fact was not included in the assumptions.

Stanley Mumma: You have observed correctly. The point of the paper was not to compare the operating costs of DOAS vs VAV, since I have done so in prior papers. Here, the point was to compare the first and operating costs associated with just the filters. Consequently, only the fan energy necessary to move air through filters was included. Fan energy necessary to move supply and return air through other parts of the system was not germane to the intent of this work and is not impacted by filter changes.

Kelley Cramm, Mechanical Engineer, Henderson Engineers, Lenexa, KS: Why does the fan cost increase when the DOAS filters are changed monthly?

Stanley Mumma: You correctly observe, for example, that the fan operating costs increased for each of the DOAS filter efficiencies (94%, 98%, and 99.7%) when the values of Table 3 are compared to those of Table 2. When the filter replacement was forced to be monthly, Table 3, their size was reduced compared to Table 2 to minimize the total 5 year life-cycle cost. This is the consequence of the significant first cost of the filters. For example, consider the 94% efficient filters, the optimized Table 2 replacement frequency was 6.5 months and the face area was 9.3 ft^2. In Table 3, where the replacement frequency was reduced to one month, the filter face area dropped nearly in half to 4.5 ft^2. As expected, the fan energy operating cost responded accordingly.

Dennis Landsberg, President, L&S Energy Services Inc., Clifton Park, NY: Most buildings with DOAS feed secondary areas that heat and cool buildings. Then you need filters on both systems unless the space cooling system is radiant?

Stanley Mumma: The paper addresses systems where DOAS is the only source of OA. In such cases, the space sensible loads are most often handled by parallel terminal equipment such as FCUs, chilled ceilings, chilled beams, induction units, water source heat pumps, etc. To be sure, filtration in the terminal equipment would reduce the concentration/exposure an hour after a release into the OA stream. You correctly note that such filtration was not considered in the paper; rather the full burden of concentration/exposure was placed on the DOAS filters. Perhaps you were thinking about DOAS with all air systems, such as VAV. But surely not, since very few buildings with DOAS are configured that way.