Terminal Equipment with DOAS: Series vs. Parallel

While there's no disagreement that DOAS systems require some supplemental equipment to handle remaining sensible cooling loads, a couple of schools of thought have evolved regarding the best way to arrange certain terminal equipment within the overall system. Can this be a simple misunderstanding about one option's ideal configuration? Can a 2,700% difference in power consumption really be a part of this discussion? Read on to find out.

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DOAS[1] supply the ventilation air required by ASHRAE Standard 62.1 to the individual occupied spaces, generally cooled and dehumidified to provide a portion of the terminal space sensible cooling and the entire space latent cooling requirements. Consequently, terminal equipment is required to accommodate the sensible cooling loads not met by the DOAS. The variety of terminal equipment includes:

- Fancoil units (FCU);
- Heat pumps;
- Multi-split units;
- Constant or variable volume all-air systems;
- Active chilled beams, i.e., induction devices[2];
- Passive chilled beams;
- Ceiling radiant cooling panels[3].

Presently, there are two views concerning the introduction of the DOAS ventilation air for the first three terminal devices listed above, particularly when that equipment is ceiling plenum mounted.

One view is to supply the DOAS air in series with the terminal equipment cooling coil, while the second view is to supply the DOAS air in parallel with the terminal equipment cooling coil. All-air systems are also subject to the differing opinions, at both the central AHU and the terminals. The last three pieces of terminal equipment, beams and panels, can not be arranged in series with the DOAS air, so they are not subject to the differing views. Finally, the first three pieces of terminal equipment generally cannot be placed in series when floor mounted in the individual zones. This article will focus on FCU terminal equipment located in the ceiling plenum.

TERMINAL EQUIPMENT IN SERIES WITH DOAS

This arrangement is characterized by the requirement that all ventilation air be handled by, or pass through, the terminal devices. A schematic of this arrangement is illustrated in Figure 1.

Those who favor this arrangement operate under the false paradigm that a parallel arrangement requires separate DOAS ductwork and terminal supply air diffusers, as illustrated in Figure 2. Note: The false paradigm does not mean that Figure 2 is wrong; rather, it is not the required parallel arrangement since there is a better alternative to be discussed later.

Consequently, those in this camp[4] identify the following advantages of the series arrangement over the parallel arrangement illustrated in Figure 2:

- Superior thermal comfort;
- Superior IAQ;
- Superior energy efficiency and performance;
- Simpler arrangement;
- Reduced first cost for both labor and materials;
- Ideal for constant volume systems;
- Best choice for low occupancy density spaces;

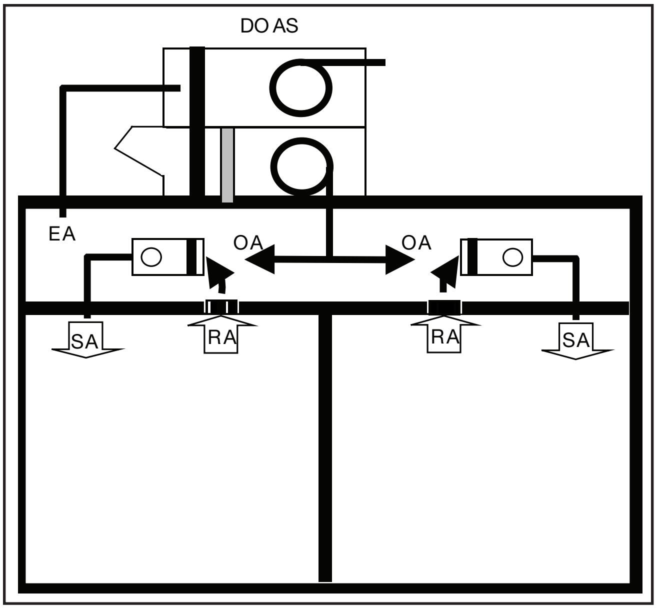

FIGURE 1. Series arrangement of DOAS and terminal equipment.

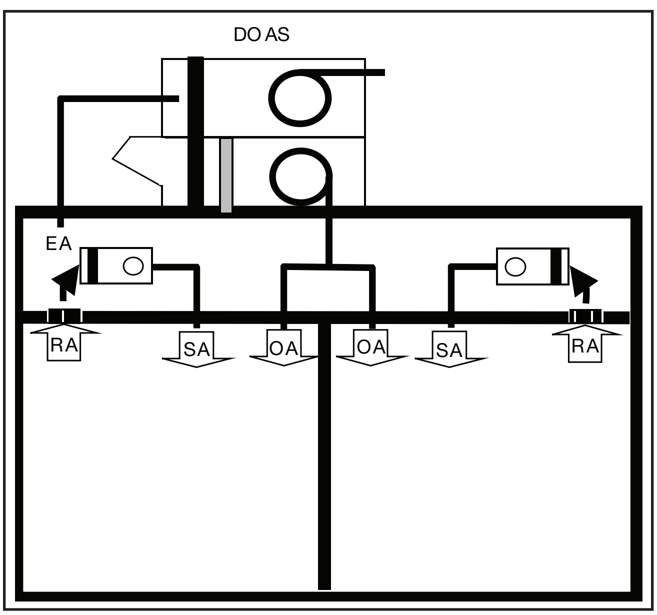

FIGURE 2. Parallel arrangement of DOAS and terminal equipment with individual SA and OA diffusers, a false paradigm.

- Simpler controls;
- Eliminates the need for DOAS terminal reheat;
- Simplifies the selection, performance, and placement of the main diffusers;
- Eliminates the distribution of cold DOAS air to perimeter spaces in the winter.

TERMINAL EQUIPMENT IN PARALLEL WITH DOAS

This arrangement is characterized by the ventilation air being introduced downstream of the terminal devices, rather than upstream. A schematic of this arrangement is illustrated in Figure 3.

Consequently, those in this camp identify the following advantages of the parallel arrangement:

- At low sensible cooling load conditions, the terminal equipment may be shut off, saving fan energy.
- The terminal device fans may be downsized since they are not handling any of the ventilation air, reducing first cost.
- The smaller terminal fans result in fan energy savings.
- The cooling coils in the terminal devices are not de-rated since they are handling only warm return air, resulting in smaller coils and further reducing first cost.
- Opportunity for plenum condensation is reduced since the ventilation air is not introduced into the plenum near the terminal equipment, for better IAQ.
- Is not inferior to the series arrangement in any of the 11 categories cited above as advantages by that camp when configured as per Figure 3, the correct parallel paradigm.

ILLUSTRATION OF THE PERFORMANCE DIFFERENCE BETWEEN SERIES AND PARALLEL ARRANGEMENTS

To illustrate the size, energy, and thermal performance differences between the series and parallel arrangements, consider the following 1,000-sq-ft classroom example.

- Default values from ASHRAE Std. 62.1-2007:
  - 35 students, 13 scfm of outside air (OA)/student;
  - or 455 scfm OA;

- Occupant latent load: 7,175 Btuh;
- DOAS supply air (455 scfm) at 45°F and saturated;
- FCU terminal device with DOAS, series or parallel;
- Room drybulb temperature (DBT) maintained at 75° each case;
- Sensible load assumed for each case: 20,000 Btuh;
- Resulting room condition each case: 75° DBT, 56° dewpoint temperature (DPT), 52% rh, 63° wetbulb temperature (WBT), and w=67.53 gr/lbm$_{DA}$ (based upon the DOAS supply air (SA) conditions, flow rate, and latent load).

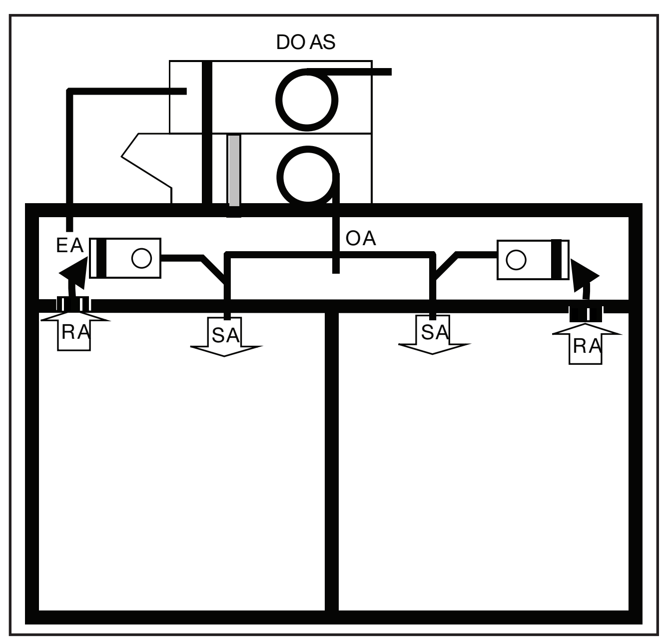

FIGURE 3. Parallel arrangement of DOAS and terminal equipment.

Finned height	12 in.
Finned length	12 in.
Rows deep	3
Fins per inch	10
Tube OD and thickness	5/8 OD, 0.020 wall
Fin material and thickness	Corrugated Al, 0.0060
Face area	1 cu ft
Airflow	420 scfm
Face velocity	420 fpm
Airside pressure drop	0.17 in. w.g.
Entering air DBT	75°F
Entering air WBT	63°
Leaving air DBT	63.2°
Leaving air WBT	63.2°
Entering chilled water temp.	56°
Leaving chilled water temp.	58°
Circuits	4
gpm	5
Waterside pressure drop	1.5 ft H_2O
Liquid velocity	1.4 fps
Total capacity	5,260 Btuh
Sensible capacity	5,260 Btuh-dry coil

TABLE 1. Coil performance for the parallel FCU.

For the parallel case, the 455 scfm of saturated DOAS air at 45° is able to remove the entire latent load and 14,740 Btuh of sensible load, leaving 5,260 Btuh of sensible load for the terminal FCU to handle. The low DOAS SA DPT makes it possible to operate the terminal units dry, avoiding septic amplification in the conditioned zones. To avoid further latent cooling by the terminal units, their cooling surfaces must not operate below the entering air DPT.

In the case of the parallel arrangement, that is the space DPT or 56°— using commercial coil selection software[5] — the parallel performance parameters shown in Table 1 were obtained.

For the series case, the 455 scfm of saturated DOAS air at 45° also removes the entire latent load, and 14,740 Btuh of sensible load, leaving 5,260 Btuh of sensible load for the terminal FCU to handle.

In the case of the series arrangement, mixing the DOAS air and the return air ahead of the FCU reduces both the DBT and DPT seen by the cooling coil. The reduced DBT causes the cooling coil performance to be de-rated, while the lower entering air DPT allows the entering cooling water to be reduced while avoiding condensation and further latent load removal. Employing the identical cooling coil for the series arrangement as illustrated above for the parallel arrangement, the airflow rate must be adjusted to ensure that the FCU SA removes the entire 20,000 Btuh of space sensible load. As the supply airflow rate is adjusted, the fraction of DOAS air (%OA) changes. A few examples are illustrated in Table 2.

When the airflow rate is properly adjusted to meet the 20,000 Btuh sensible cooling load, i.e. 33% DOAS air (OA), the series performance parameters shown in Table 3 are obtained.

DISCUSSION OF THE ILLUSTRATION RESULTS

A coil well-suited for the parallel arrangement was selected and the results presented in Table 1. It may be noted that 420 scfm of warm recirculated room air was handled by the FCU where 5,260 Btuh of sensible cooling was done. The balance of the sensible cooling was accomplished with the parallel DOAS air. For the coil selected, the face velocity was a modest 420 fpm and the airside pressure drop was less than 0.2 in. w.g.

When that same coil was applied to the series arrangement where the FCU was required to handle all of the air — i.e., DOAS plus recirculated air — the outcome was bleak. Admittedly, a much larger FCU should have been picked, but to hyperbolize the situation, the parallel unit coil was applied. In contrast to the 420 scfm handled by the parallel arrangement FCU, the series FCU arrangement was forced to handle 1,380 scfm of air at the mixed condition resulting from 33% DOAS air and 67% room air. That represents an increase of 330% in airflow resulting in a face velocity of 1,380 fpm. The increased flow caused the airside pressure drop to increase from 0.17 in. w.g. for the parallel arrangement to 1.4 in. w.g., or an 823% increase in pressure drop. The power increase is 2,700%, something unacceptable.

Of course, one would not allow this to occur, but it dramatically illustrates the impact of using a series arrangement in terms of energy cost. If the FCU for the series arrangement had been increased in size by 330% over the parallel arrangement, the energy issue would be replaced with a first cost issue. In either case, it is desirable to use the parallel arrangement. Finally, under normal part load operating sensible cooling load conditions, the parallel arrangement FCU fan can by cycled as necessary to meet the cooling load, saving fan energy.

CONCLUSIONS

For the conditions explored, it is evident that the parallel arrangement is the best choice for DOAS-FCU combinations. While not explicitly discussed in this article, the same can generally be said for DOAS with heat pumps and multi-split units.

Some DOAS systems deliver air with a low DPT but DBTs in the 50° to 60°[6] range. While an example was not presented above, it can be said

%OA	SA (scfm)	DBT mix (°F)	WBT mix (°F)	DPT mix (°F)	SA DBT (°F)	Q_{coil} (Btuh)	Q_s SA (Btuh)
60	758	57	53	50	54	2,534	17,191
40	1,138	63	56.6	52.2	59.3	4,648	19,287
20	2,275	69	60	54.3	65.8	7,861	22,600
33	1,380	65.1	57.8	52.9	61.4	5,260	20,000

TABLE 2. Mixing conditions for the series arrangement with various percentages.

Finned height	12 in.
Finned length	12 in.
Rows deep	3
Fins per inch	10
Tube OD and thickness	5/8 OD, 0.020 wall
Fin material and thickness	Corrugated Al, 0.0060
Face area	1 cu ft
Airflow	1,380 scfm
Face velocity	1,380 fpm
Airside pressure drop	1.4 in. w.g.
Entering air DBT	65.1°F
Entering air WBT	57.8°
Leaving air DBT	61.4°
Leaving air WBT	58.5°
Entering chilled water temp.	53°
Leaving chilled water temp.	55.2°
Circuits	4
gpm	5
Waterside pressure drop	1.5 ft H_2O
Liquid velocity	1.4 fps
Total capacity	5,260 Btuh
Sensible capacity	5,260 Btuh-dry coil

TABLE 3. Coil performance for the series FCU.

that elevated DBTs tend to de-rate the terminal equipment less than the low temperatures used in the example above. In any event, the required FCU size is still smaller with parallel than series arrangements, saving fan energy and first cost.

In spite of the conclusions presented, no one solution is best for all situations. Nonetheless, the author recommends exhausting every effort to use the parallel approach before considering the series approach.

Note: The series and parallel terminology used in this article does not apply to fan-powered boxes. **ES**

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