Using Dedicated Outdoor Air Systems

Decoupling OA and Space Thermal Control

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Significant indoor air quality benefits can be achieved by decoupling the outdoor ventilation air cooling and dehumidification from the space cooling and dehumidification functions. This has become an important topic in the current literature and emerging engineering design efforts. [1,2,3]

Space relative humidity with current all-air variable air volume (VAV) system designs can fluctuate significantly at part-load conditions leading to poor IAQ. To overcome the space humidity control fluctuations in all-air VAV systems, the case has been made for the use of separate air paths through the air handling unit (AHU), one path to condition the OA and the other path to condition the recirculation air. The two paths are then joined and the cooled and dehumidified air is delivered to the space through a single duct system. This has resulted in the emergence and use of new terminology, i.e., dual-path systems. The literature acknowledges, and then generally dismisses the concept that the two separate paths through the AHU could continue all the way to the conditioned spaces. The literature for the most part is also silent on the use of total energy recovery (TER) even though the following language from ANSI/ASHRAE/IESNA Standard 90.1, *Energy Standard for Buildings Except Low-Rise Residential Buildings,* would require it in many cases:

> **6.3.6.1 Exhaust Air Energy Recovery.** Individual fan systems that have both a design supply air capacity of 5,000 cfm (2400 L/s) or greater and have a minimum outside air supply of 70% or greater of the design supply air quantity shall have an energy recovery system with at least 50% recovery effectiveness. Fifty percent energy recovery effectiveness shall mean a change in the enthalpy of the outdoor air supply equal to 50% of the difference between the outdoor air and return air at design conditions.*

For that reason, in this article the "dual-path" terminology will be limited to those systems that use a dual-path through the AHU and a single supply air delivery system, but do not use

* TER is not required by Standard 90.1 where the design OA load is predominately sensible like Denver; however, sensible energy recovery is required!

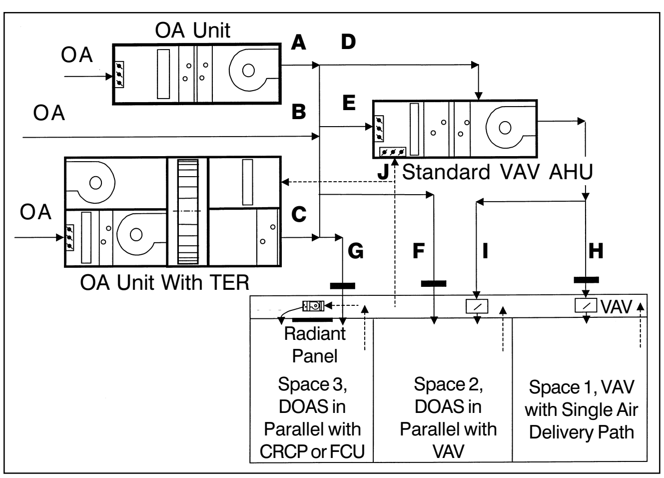

Figure 1: Air delivery combinations.

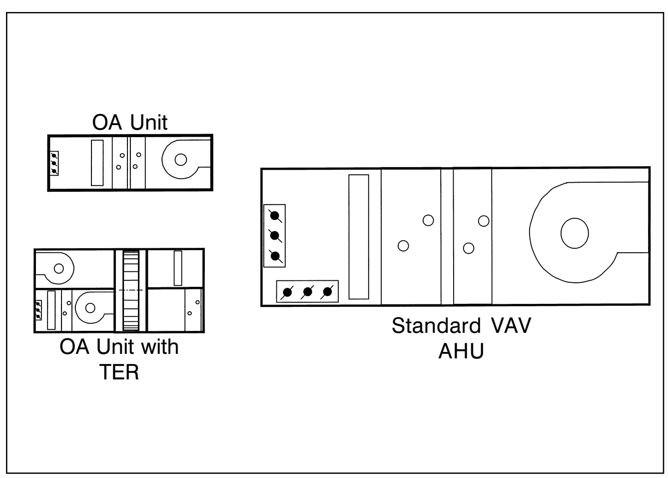

Figure 2: Relative sizes of the equipment.

TER. The literature also acknowledges that achieving 0–100% cooling coil (CC) capacity control in the OA path is a huge challenge for small direct expansion (DX) equipment, especially when humidity control is lost with on-off controls. It can even challenge a chilled water CC with modulating controls.

A single duct supply air VAV system can experience significant ventilation air distribution problems.[4,5] To overcome the distribution problem, large OA quantities must be introduced and conditioned with the associated large energy use ramifications. Perhaps the most popular emerging method used in an attempt to ensure that Standard 62 has been met with VAV systems in an energy-efficient fashion is to use CO_2-based demand controlled ventilation (DCV). When properly applied, this approach can work well,[6,7] provided the fundamental assumptions made with the approach are met. Those assumptions are:

- That the OA CO_2 concentration is constant;
- The CO_2 generation rate per person is a constant;
- The CO_2 instrumentation is accurate and free of calibration drift;
- There is sufficient CO_2 instrumentation to detect the critical space(s);
- The airflow through the spaces is well mixed;
- The occupancy is quite variable;
- That an OA flow measuring station is present to ensure that:
    - OA flow rate does not drop below 20–50% of design flow so non-occupant contaminant sources do not reach critical levels; and
    - With varying metabolic rates (i.e., CO_2 generation rates) and/or elevated exterior CO_2 levels, the OA flow does not exceed design.
- An injection fan, complete with a variable frequency drive (VFD), is required in most cases to ensure the required ventilation air is delivered under varying AHU supply fan speed and wind conditions.

General Description	Combination Numbers	Path Letters Combinations	Comments
Conventional Single Path VAV	(1) To Space 1	**B-E-H**	**Single path through VAV unit and on to space:** Low first cost but fails to meet requirements for humidity control, prudent energy use, or the ventilation delivery requirements without an excellent DCV system.
Outdoor Air Unit Without TER Combinations	(2) To Space 1	OA Path 1 in or to AHU **A-D**, Recirc. Path 2 in AHU **B-E&J**, Single path to the space **H**	**Dual-path in or to the AHU with single air path to the space:** Can meet humidity control requirements, and Ventilation delivery with DCV, but does not provide prudent energy use and presents part load CC control problems.
	(3) To Space 1	**A&B-E-H**	**OA unit path in series with the AHU then to space:** Not recommended.
	(4) To Space 2	OA Path 1 to space **A-F**, Recirculation Path 2 to space **B-E&J-I**	**DOAS in parallel with VAV:** Can meet humidity control requirements, ventilation delivery with smaller OA quantities; but fails to meet Standard 90.1 requirements for TER, does not provide prudent energy use, presents part load CC control problems, and potential ductwork crossover issues.
	(5) To Space 3	OA Path to Space **A-G**	**DOAS in parallel with FCU or CRCP:** Uses less fan energy, can meet humidity control requirements, ventilation delivery with smaller OA quantities. Fails to meet Standard 90.1 requirements for TER, does not provide prudent energy use and presents part load CC control problems.
Outdoor Air Unit with TER Combinations	(6) To Space 1	OA Path 1 in or to AHU **C-D**, Recirc. Path 2 in AHU **B-E &J**, Single path to the space **H**	**Dual-path in or to the AHU with single air path to the space:** Can meet humidity control requirements, and ventilation delivery with DCV, and provides prudent energy use and minimizes part load CC control problems.
	(7) To Space 1	**C&B-E-H**	**OA unit path in series with the AHU then to space:** Not recommended.
	(8) To Space 2	OA Path 1 to space **C-F**, Recirculation Path 2 to space **B-E&J-I**	**DOAS in Parallel with VAV:** Meets humidity control requirements, ventilation delivery with smaller OA quantities; provides prudent energy use and solves the part load CC control problems, but causes potential ductwork crossover issues.
	(9) To Space 3	OA Path to space **C-G**	**DOAS in parallel with FCU or CRCP:** Uses less fan energy, meets humidity control requirements, ventilation delivery with smaller OA quantities; provides prudent energy use and solves the part load CC control problems.

Table 1: Path combinations possible in *Figure 1.*

Dedicated OA systems (DOAS) using TER, delivering the ventilation air directly to the spaces and working in parallel with space conditioning systems (the parallel systems could be all-air, air-water, or all water) has been compared with single air delivery VAV systems using DCV.[8] Those comparisons conclude that the DOAS offers superior control and operating simplicity, first cost savings, operating cost savings and demand savings. Some of the reasons for the superiority of the DOAS are:

- Standard 90.1 requires TER, thus reducing both design cooling plant capacity, peak demand, energy use, and the need for preheating the OA;
- The volumetric flow rate of OA to be treated is reduced from 20–70% over single path delivery systems since the multiple spaces approach of Standard 62 in an effort to ensure proper distribution in single supply air duct systems does not

apply to DOAS, where all of the 100% outdoor ventilation air is delivered to each individual space, reducing the size and energy consumption of the OA unit;

• Constant volume OA system, therefore no need for VFD's and associated controls;

• The function of space conditioning can be met with an alternative to VAV such as fan coil units (FCU) or ceiling radiant cooling panels (CRCP).

Decoupling Space Latent Cooling and Ventilation Air Delivery From the HVAC System

The configurations that will be presented and briefly discussed are the combinations that result from the use of the following major pieces of equipment:

• An OA unit,
• An OA unit with TER,
• A Standard VAV AHU with terminal VAV boxes,
• FCUs,
• CRCPs.

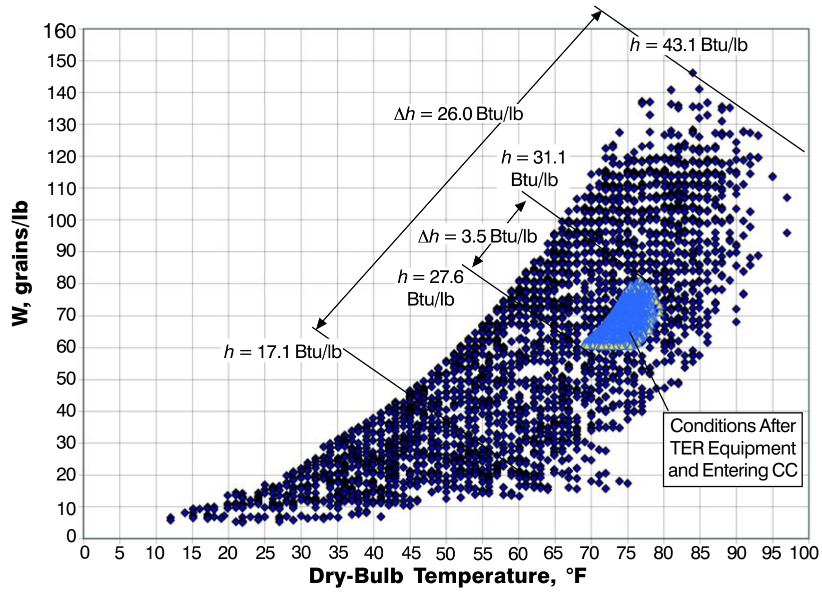

Figure 3: Hourly Atlanta TMY weather data (12 hours per day, six days per week), and the conditions after 80% effective TER equipment.

For ease and clarity of presentation, the OA units are illustrated independent of the VAV AHU. However, when they are used together in new construction, the OA unit functions could be physically integrated into the AHU.

The major pieces of equipment illustrating the possible combinations are presented in *Figure 1*, with the nine different combinations summarized in *Table 1*. Each air path is given a letter designation from **A-J** in both *Figure 1* and *Table 1*. In *Table 1*, as an example, a path designated **A-D** represents a flow of air from **A** to **D**. **B-E&J-I** represent airflow from **B** to **E** where **E&J** mix and the mixture continues through **I**. The supply from any of the combinations terminates in one of the three different spaces illustrated in *Figure 1*:

• VAV with single air delivery path;
• DOAS in parallel with VAV; and
• DOAS in parallel with either FCUs or CRCPs.

The equipment illustrated in *Figure 1* are not to scale, and could give the impression that the outdoor air units are about the same size as the standard VAV AHU. *Figure 2* presents a more realistic perspective on the relative sizes of the equipment, assuming that the outdoor air equipment is supplying about 20% as much air as the VAV AHU.

OA Units with TER

The four major benefits of using TER are:

• A major reduction in the variability of the thermodynamic state of the OA entering the CC—simplifying equipment sizing and controls;

• A significant reduction in the design OA load, hence a reduction in both the chiller size and the peak demand;

• A reduction in the annual energy consumed to cool and dehumidify the OA;

• Heating of the OA is not required to achieve temperatures of 55°F (13°C) or lower until the OA temperature drops below –25°F (–32°C); and

• Conforms to Standard 90.1.

Hourly Atlanta Typical Meteorological Year (TMY) weather data, starting at 7 a.m. Monday through Saturday, are plotted and presented in *Figure 3*. In addition, the influence of an 80% effective TER (enthalpy wheel) on the CC entering conditions is also shown by the small shaded area in the data. The small shaded area assumes that the enthalpy wheel operates at full speed for outdoor air conditions with a dew-point temperature above 44°F (7°C) when dehumidification is required. Note that, when dehumidification is not required for OA conditions below a 44°F (7°C) dew-point temperature (DPT), on-off capacity control is acceptable. As can be observed, the variation in the CC entering air enthalpy without the use of an enthalpy wheel is 26.0 Btu/lb, while the enthalpy variation with the enthalpy wheel is only 3.5 Btu/lb.

Assuming that the supply air condition required to completely decouple the space latent and sensible loads is saturated air at 44°F (7°C),[9] the load variation seen by the OA CC is 75% to 100% of design capacity with the TER. Twenty-five percent or less variations are easy to accommodate with both DX and chilled water systems. On the other hand, without the TER, the load on the CC must vary between 0% and 100% of design load. Such a wide range is a difficult task for the CC to accommodate simply and inexpensively with either the DX or the chilled water systems, as is pointed out in the literature on the dual-path systems. The reduced enthalpy variability after the TER equipment also reduces the peak OA load on the CC.

For example: to condition 10,000 cfm (4720 L/s) of OA with an enthalpy of 43.1 Btu/lb takes 44 tons (155 kW) more cooling than when the air is preconditioned with TER equipment to 31.1 Btu/lb, or a 46% reduction in the CC load.

The annual energy required to cool and dehumidify the OA is reduced by 2% compared to not using TER when the saturated supply air is assumed to be at 44°F (7°C) and the TER is allowed to operate for all OA conditions with a dew-point temperature above 44°F (7°C). Such operation substantially shrinks the variability of the conditions seen by the CC, resulting in simple controls.[10] If the TER equipment is off during all OA conditions with an upper boundary set by the return air enthalpy and with a lower boundary of 44°F (7°C) DPT, the TER reduces the energy required by 20% compared to not using TER. Clearly there is a trade-off available between energy savings and control simplicity when using TER.

Finally, the TER will recover heat from the relief airstream and heat the OA in the winter to avoid the need to use OA heating energy. It can also be used effectively to humidify the OA, further reducing energy consumption for humidification. Without the TER, simultaneous cooling of the recirculation air and heating of the OA may result during some seasons of the year.

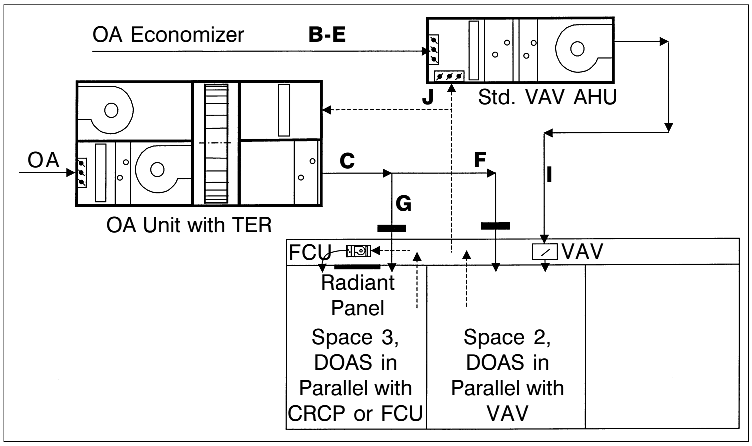

Figure 4: Recommended arrangements for decoupling both the ventilation air delivery and the space latent loads.

Merits of DOAS with TER

The merits of the DOAS using TER over a single air delivery path to the space provide the following added benefits:

• 20% to 70% smaller OA units since the multiple spaces equation of Standard 62 does not apply, with associated first and operating cost savings;

• Simpler OA unit controls, with associated first cost savings;

· No VFD;

· No flow stations required or associated flow controls;

· Overventilate the spaces at off design without any energy penalty compared to a single air delivery system. Low RH is maintained and occupant sense of well-being enhanced.

• Improved IAQ and thermal comfort;

• Reduced plenum depth when using a CRCP parallel system; and

• No ventilation air distribution problems.

Conclusion

A DOAS with TER delivers the synergies provided by a dual-path system of:

• Decoupling the OA thermal treatment from the space thermal treatment; and

• Eliminating the cases of heating the OA while cooling the recirculating air.

In addition, the DOAS-TER system:

• Resolves the difficult problem posed by the highly variable OA conditions and associated CC/plant controls;

• Eliminates the need to use the sophisticated DCV controls to meet the ventilation requirements;

• Reduces the first and operating costs of the system;

• Reduces the size of the cooling equipment substantially; and

• Allows overventilation of the spaces at off design with lower operating costs.

For these reasons, the industry will almost certainly adopt one of the two arrangements illustrated in *Figure 4* for both new and renovation work.

It is important to note that no single approach is best for every application. The issues discussed here are no exception.

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