DOAS & Building Pressurization

By Stanley A. Mumma, Ph.D., P.E., Fellow/Life Member ASHRAE

Dedicated outdoor air systems (DOASs) have become common and, for the most part, are delivering superb performance compared to conventional all-air systems.[1] However, the issue of building pressurization with DOAS warrants careful attention. The two main problems that occur with building pressurization using DOAS are: unbalanced flow through the total energy recovery (TER) equipment causing its performance to be compromised on the OA delivery side under design conditions; and, second, the return airflow has frequently been observed in the field to be only 20% to 40% that of the design supply airflow leading to such severe TER performance degradation that the cooling plant is unable to meet the load.

In addition, there is always uncertainty during the design and operational phases of a project concerning the latent load that must be removed from the occupied spaces in the field. This uncertainty is the result of nebulous initial occupancy information and changing future space use and density; and envelope integrity as a function of use and time. To avoid damaging condensation from chilled ceilings or beams, it is imperative that there be reserve capacity[2] in the DOAS to accommodate such latent load uncertainties.

In fact, even with packaged terminal equipment such as fan coil units, water source heat pumps, and variable refrigerant flow split systems, reserve capacity in the DOAS is necessary to prevent their condensate pans from becoming distributed septic[3] amplifiers. This reserve capacity can be economically made a part of the pressurization unit when compared to putting the reserve capacity into an enlarged unbalanced flow DOAS. Or perhaps better, the reserve capacity could be simply added to the pressurization unit at a later time in stages, avoiding unnecessary first cost investments. (Achieving reserve capacity by introducing recirculated space air to save energy and capacity is

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highly discouraged by this author. To do so would eliminate the many benefits of DOAS, which uses no recirculated air.)

Migration Path

The migration path from all air systems, to DOAS with unbalanced flow, to the integrated balanced flow DOAS with a pressurization unit, is illustrated in *Figure 1*. The figure focuses on the ventilation air components and their path back outside. Part A illustrates that a leaky building is not much of a problem as long as the ventilation requirements exceed exfiltration plus toilet and building exhaust.

Part B illustrates that a typical DOAS experiences unbalanced flow at least equal to the exfiltration. And, if the building is extra leaky, the unbalanced flow becomes excessive, adversely impacting the thermal performance and possibly the ability of the entire system to meet thermal loads. This is especially true when differential pressure is used in an attempt to achieve pressurization.

Part C illustrates the integrated concept where the pressurization component flow is held constant regardless of the building leakiness, and the airflow through the DOAS is intentionally held balanced.

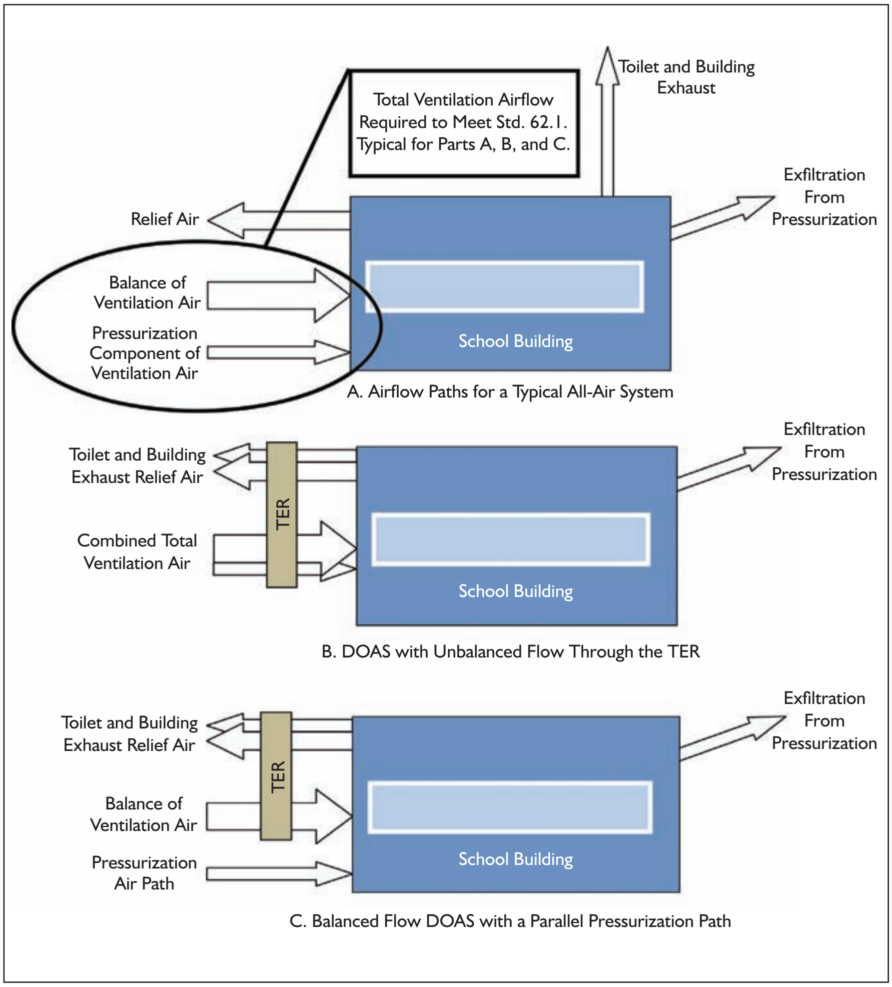

***Figure 1:** Elementary School. Migration path to the integrated balanced flow DOAS/pressurization package where the pressurization path is 30% of the ventilation.*

Building Pressurization

It is desirable to limit infiltration in buildings for comfort and IAQ reasons. Avoid infiltration by either providing such a tight envelope that there is no air leakage (something we have yet to do cost effectively) or by building pressurization. Therefore, most designs intend to pressurize buildings sufficiently to cause exfiltration during the cooling season to avoid comfort problems in the perimeter zones; and to limit IAQ problems from microbial growth associated with condensation that could occur when moist OA infiltrates into the cool building envelope. During the heating season, pressurization for the same reasons is desirable. However, the pressurization during the heating season needs only to stop infiltration, avoiding exfiltration of moist building air and potential condensation. During unoccupied periods, pressurization is not necessary for occupant comfort, or during periods when the outdoor air dew-point temperature (DPT) is below an allowable upper space DPT. Therefore, during much of the unoccupied periods, minimal or no pressurization is required.

At this point, it is important to establish building pressurization flow rates. This is an especially important issue with DOAS systems that use heat recovery. Unlike conventional all air systems without heat recovery that can use all of the ventilation air for pressurization, DOAS systems must maximize return airflow to deliver the greatest reduction in OA treatment costs. In other words, the TER is inversely proportional to the pressurization flow.

The pressurization flow is a function of many variables; building airtightness being a principal variable. To estimate the needed pressurization flow, the literature covering airtightness recommendations and actual test results[4] is useful. Most of the published data gives leakage rates per unit area of perimeter wall area at either 75 or 50 Pa (0.3 or 0.2 in. w.g.). For the most part, where pressurization controls are discussed, the differential pressure setpoint between inside and out is 0.03 in. w.g. (7.5 Pa).[5]

When published building envelope target leakage rates (0.2735 scfm/ft^2 [5 m^3/h·m^2] for offices and 0.4922 scfm/ft^2 [9 m^3/h·m^2] for schools at 50 Pa[6]) are adjusted for the control pressure differential (assuming flow is proportional to the square root of the pressure differential[5]), and the wall area leakage rate converted to a per unit floor area, the results are in the 0.04 to 0.06 scfm/ft^2

Occupancy Category	Floor Fraction	scfm/Person	scfm/ft²	Occupants/1,000 ft²	Occupants scfm/1,000 ft²	Floor scfm/1,000 ft²	Combined scfm/1,000 ft²	Combined scfm/Person	scfm OA/ft²
Classrooms (Ages 5–8)	0.3	10	0.12	25	250	120	370	14.8	0.4
Classrooms (Ages 9+)	0.3	10	0.12	35	350	120	470	13.4	0.5
Lecture Classroom	0.1	7.5	0.06	65	488	60	548	8.4	0.5
Conference/ Meeting	0.2	5	0.06	50	250	60	310	6.2	0.3
Office Space	0.7	5	0.06	5	25	60	85	17.0	0.1
Retail Sales	0.5	7.5	0.12	15	113	120	233	15.5	0.2

***Table 1:** Uncorrected fraction of floor to total ventilation air based on Standard 62.1.*

(0.2 to 0.3 L/s·m²) of floor area range. To put these numbers in perspective, that represents about 0.5 air changes per hour (ach).

The 0.04 to 0.06 scfm/ft² (0.2 to 0.3 L/s·m²) of floor area range is similar to the 0.06 scfm/ft² (0.3 L/s·m²) floor area component of ASHRAE Standard 62.1. That means the arrows labeled pressurization component of ventilation air in *Figure 1* could be labeled the floor component of Standard 62.1. At this point, the correlation will be considered purely coincidental, especially since envelope leakage is a function of many uncertainties such as; construction workmanship, building type, wall to floor area ratios, building height and climate. However, the floor and occupant components of Standard 62.1 for various occupancy categories may provide insight into the issue of an integrated balanced flow DOAS/pressurization package.*

While the pressurization flow requirement is generally independent of occupancy type (such as the floor component of Standard 62.1), the balance of the OA flow is a highly variable function of the occupancy density and prescribed scfm/person. As a result, the ratio of the pressurization flow to the total OA flow, as summarized in *Table 1*, varies widely by occupancy category. That variation, illustrated by the ratio of pressurization flow to total ventilation flow rate (floor fraction), falls between 0.1 for lecture rooms to 0.7 for offices, with elementary classrooms in-between at around 0.3.

DOAS Equipment

The details of DOAS equipment arrangements are beyond the scope of this paper. However, most will use TER (enthalpy wheel) as depicted simply in *Figure 2*. When the DOAS is used for pressurization it leads to unbalanced flow through the TER device, increasing its effectiveness (ε) as defined in *Figure 3*, but decreasing the heat recovery rate (it decreases the apparent effectiveness ($\varepsilon_{apparent}$) on the OA stream. As the flow imbalance increases, even when all of the building toilet exhaust air is returned to the TER, the recovered energy decreases.

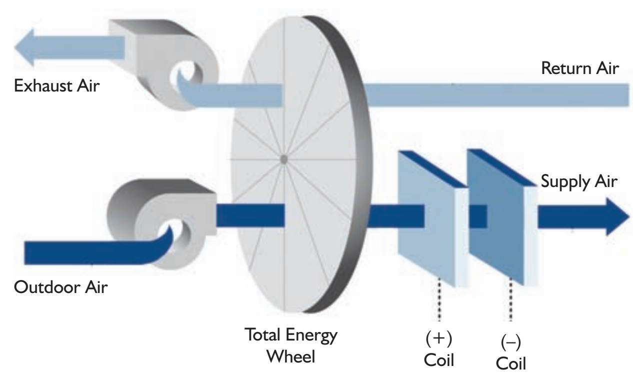

***Figure 2:** Simple depiction of a DOAS.*[10]

Eight examples are presented in *Table 2*. These were selected[7] as representative examples, but are by no means exhaustive.

*Standard cubic feet per minute (scfm) is used throughout this article because Standard 62.1 specifies ventilation airflows at room condition where a cfm closely equals a scfm. When dealing with OA flows at an air-handling unit, the unconditioned OA temperatures are generally well above or below standard conditions where the specific volumes vary widely. For example, the mass flow rate of 10,000 cfm (4700 L/s) of air at room conditions is 43,890 lb_{mDA}/hr (5.7 kg/s). For the same mass flow rate at 0°F (–18°C) and 100% RH only 8,480 cfm (4000 L/s)—15% lower flow rate—is needed, and at 95°F (35°C) and 40 gr/lb_m (0.006 kg/kg) humidity ratio the required flow rate is 10,320 cfm (4870 L/s)—3% greater flow rate.

Example	SA Flow, scfm	RA Flow, scfm	Wheel Dia., in.	FV, sfpm	DP, in. w.g.	ε	Apparent ε	Q, MBH
1	19,500	19,500	130	510	0.35	74.5%	74.5%	929
2	19,500	15,000	130	510/390	0.35/0.27	86%	66%	822
3	15,000	15,000	130	390	0.27	79%	79%	753
4	15,000	15,000	114	510	0.35	74.5%	74.5%	715
5	19,500	5,850	130	510/152	0.35/0.11	99.7%	29.9%	364
6	5,850	5,850	92	321	0.22	81.7%	81.7%	304
7	19,500	17,550	130	510/456	0.35/0.31	79.4%	71.5%	889
8	17,550	17,550	124	510	0.35	74.5%	74.5%	836

The data in this table assumes outdoor air conditions of 85°F DBT and 140 gr/lbm humidity ratio and return air conditions of 75°F DBT and 50% RH. They also assume no seal leakage or purge. The presence of either will cause a reduction in effectiveness, heat recovered, and an increase in both face velocity and pressure drop. Wheels with excellent seals and no purge are recommended for those reasons. Where purge is considered necessary to safeguard against toxic cross contamination, it is probably not the correct application for a wheel style TER.

Table 2: Eight examples, including balanced and unbalanced total energy recovery flow.

Example 1 shows a 130 in. (3.3 m) diameter TER wheel with balanced flow of 19,500 scfm (9200 L/s), which has an effectiveness of 74.5% and a heat recovery rate of 929,000 Btu/h (929 MBH) (272 kW).

When unbalanced flow of 19,500 scfm (9200 L/s) supply air (SA) and 15,000 scfm (7080 L/s) return air (RA), shown in Example 2 (representative of a facility with a pressurization (floor) ventilation rate to total ventilation rate ratio of 0.23), is applied to the same wheel, it's effectiveness rises to 86%. This may seem better, but the actual heat recovered is only 88% that for the balanced flow of Example 1. The drop in recovered heat is consistent with the poor apparent effectiveness, i.e., 66%, on the OA path side.

Example 3 illustrates the performance for the same 130 in. (3.3 m) wheel at a balanced 15,000 scfm (7080 L/s) flow integrated with a 4,500 scfm (2125 L/s) pressurization unit (see *Figure 4* for an illustration). In Example 3 the effectiveness is 20% higher than the apparent effectiveness of Example 2, but the recovered energy is only 8% less.

Example 4 is for a balanced flow of 15,000 scfm (7080 L/s), but with a smaller wheel (114 in. [2.9 m]) selected to match the 510 sfpm (2.6 m/s) face velocity of the larger wheel under 19,500 scfm (9200 L/s) flow conditions. The effectiveness for the 23% smaller wheel area is 94% that of the larger wheel for the same flow conditions. The recovered heat is, similarly, 95% that of the larger wheel. A 5% energy penalty for a 23% reduction in the DOAS equipment first cost, if realized, may be a good compromise. Those implications will be discussed later.

Examples 5 and 6 compare selections for an office type application where the pressurization (floor) ventilation component to total ventilation ratio is 0.7, which means only 30% of the total ventilation air is available for return to the TER and energy recovery. Seventy percent of the required ventilation flow exfiltrates for pressurization. Example 5 is for a single DOAS with unbalanced flows of 19,500 scfm (9200 L/s) of supply ventilation air and 5,850 scfm (2760 L/s) of return air. With such unbalanced flow, the TER $\varepsilon_{apparent}$ drops to a 29.9% and transfers only 364 MBH (107 kW)—far below the performance with the more nearly balanced flow of Example 2. Example 6, a balanced 5,850 scfm (2760 L/s) flow DOAS in an integrated package, has a 50% smaller TER wheel, but still recovers 85% as much energy. This also represents a great fan energy savings since so much less SA, i.e., 13,650 scfm (6440 L/s) less, must pass through the flow resistance of the TER wheel.

Examples 7 and 8 reflect a pressurization (floor) component to the total ventilation flow ratio of only 10%, perhaps typical of a lecture room facility. In this example, the TER wheel can step down two sizes and still deliver 95% as much recovered energy.

At this point, one might question the potential to downsize the TER in the integrated balanced flow DOAS, so that a cost effective reduction can be realized.

TER wheels in the diameter range of 92 to 174 in. (2.3 to 4.4 m) come in about 3 in. (0.076 m) increments, or approximately 5% change in area. That would suggest that if the unbalanced flow difference is at least 5%, the smaller balanced flow TER could use at least one step smaller wheel. From *Table 1,* one might conclude that the balanced flow TER could be two sizes smaller when handling lecture hall type conditions, six sizes smaller for the classroom conditions, and up to 14 step sizes smaller for office applications.

For large wheels between 174 and 251 in. (4.4 and 6.4 m) in diameter (these are big wheels), the wheel area increments are about 16%. Flows in the range where such large wheels are used would still lend themselves to wheel selections for balanced flow of two to five step sizes smaller for the occupancy categories presented in *Table 1*.

Reserve Capacity

The justification for reserve capacity has been discussed previously. The implementation could be either the selection of a larger unbalanced flow DOAS or the selection of an integrated balanced flow DOAS/pressurization package. All of the reserve capacity in the integrated package would be assigned to the pressurization unit. The hypothesis implicit in this paper is that, for most cases, the integrated approach would be the best choice to accommodate the need for reserve capacity as well as pressurization.

Reserve capacity could be considered optional for some terminal equipment selections that are fitted with condensate pans, provided distributed septic[3] amplifiers are acceptable. On the other hand, it is hard to imagine a situation where the ventilation system could be allowed to come up short of latent load capacity where the terminal equipment included chilled ceilings or beams.[8]

Configuration

With the background provided earlier, no doubt there are many possible configurations. It is hoped that the industry will soon provide a number of options from which the design community may select.

At the risk of oversimplification and stifling creativity, one possible arrangement is illustrated in *Figure 4*. The pressurization unit is integrated in parallel with a simple DOAS. In an effort to promote minimal fan energy consumption, bypass dampers are included around the cooling coil(s) (CC) and TER. The separate pressurization fan further minimizes the operating cost.

In the simplest sense, two separate pieces of equipment[9] could be used to meet the technical objectives addressed in this paper. However, for this approach to provide maximum cost effectiveness, the duplicate costs of installation and controls need to be eliminated via integration. (When surplus ventilation air is used for a LEED credit or a favorable supply air DPT, it should pass through the balanced flow DOAS, not the pressurization unit.)

Control Sequence

The overview that follows is for the purpose of clearly describing how the author envisions the operation of the pressurization unit. This sequence is neither in complete detail, nor has it been field tested:

- Pressurization unit to operate during all occupied periods;
- Pressurization unit to operate during unoccupied periods provided dehumidification is required as indicated by the OA DPT (in excess of 60°F (15.5°C)—adjustable setpoint);
- Damper A to modulate open in sequence (to ensure the pressurization enclosure is not damaged by negative pressure) with the fan when the system is to operate.
- When the pressurization air fan is to operate, setpoint (adjustable but initially set to the floor component of Standard 62.1) shall be maintained with a VFD based upon the flow station (FS_P). Setpoint can also be adjusted as necessary to accommodate unforeseen pressurization or reserve capacity needs;
- When pressurization unit is to operate, the CC shall cool the air to setpoint (adjustable, but initially set at 48°F [9°C] DBT) provided the OA DPT >48°F (9°C);
- When pressurization unit is to operate and the OA DPT ≤48°F (9°C), the CC shall cool the air only as required to handle the space sensible load in cooperation with the DOAS; and
- When pressurization unit is to operate and cooling is not required, fully open the CC bypass damper. Otherwise, the damper is to be fully closed.

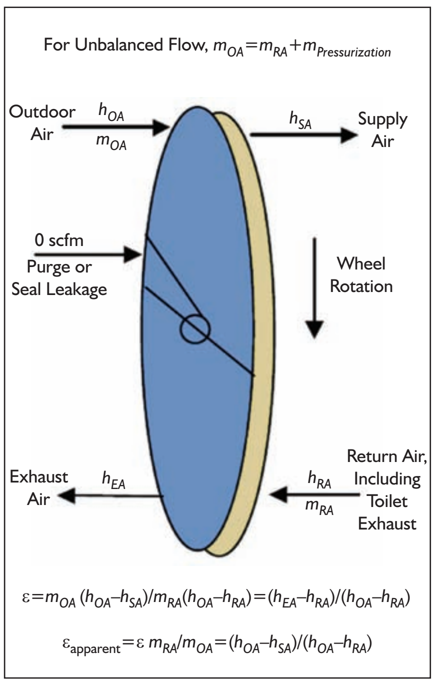

Figure 3: Total energy recovery effectiveness and apparent effectiveness.

Energy Use

Energy performance is sensitive to wheel selections such as size, effectiveness, pressure drop, leakage, purge, and desiccant used. Also, an important variable in the energy performance is the fraction of total ventilation air needed for pressurization. The fraction impacts both the cooling energy use as well as the fan energy consumption. For representative TER equipment (balanced/unbalanced effectiveness/apparent effectiveness pairs of 0.73/0.64 and 0.64/0.53) with a pressurization fraction of 30% (representative of elementary classrooms), the results demonstrate that the cooling energy increases by 15% and 4% with the integrated package for a Columbus, Ohio, climate (i.e., much of 40° N Lat). But the fan energy dropped by 12% when compared to an unbalanced flow DOAS. This amounts to between about $100/year increased operating cost and no increase in operating cost for the integrated package, when compared to a similar unbalanced flow DOAS with a supply flow of 19,500 scfm (9200 L/s) where 4,500 scfm (2125 L/s) is used for pressurization.

First Cost Implications with the Integrated Package

Carrying forward the Example 2 of 19,500 scfm (9200 L/s) of ventilation air, of which 4,500 scfm (2125 L/s) of the flow is for pressurization, the following first cost observations can be made:

- The DOAS part of the integrated package handles 23% less air than the unbalanced flow DOAS;

- Since first cost of DOAS units are on an scfm basis, at about \$8/scfm (\$17/L/s), the cost differential is about \$36,000, and the 4,500 scfm (2125 L/s) pressurization unit adds about \$2/scfm (\$4.25/L/s), or \$9,000; and
- For these flows, the integrated package, without regard for reserve capacity, saves about \$27,000 over an unbalanced flow DOAS.

This article has not provided specific guidance with respect to extent of needed reserve capacity. However, if 20% reserve capacity were deemed necessary, the following economic impact would occur:

- An additional 20% reserve capacity would add 3,900 scfm (1840 L/s) at \$8/scfm (\$17 per L/s), or \$31,200 to the unbalanced flow unit.
- Adding the reserve capacity to the pressurization unit of the integrated package would add about \$7,800.
- DOAS with unbalanced flow and 20% reserve capacity increases the first cost over the integrated package by:
  - \$27,000 savings over the unbalanced flow equipment for pressurization;
  - \$31,200 savings over the unbalanced flow equipment for 20% reserve capacity;
  - \$7,800 added cost of reserve capacity put into the pressurization unit; and
  - \$50,400 estimated savings by selecting the integrated package for both pressurization and 20% reserve capacity. It represents an estimated 27% reduction in first cost.

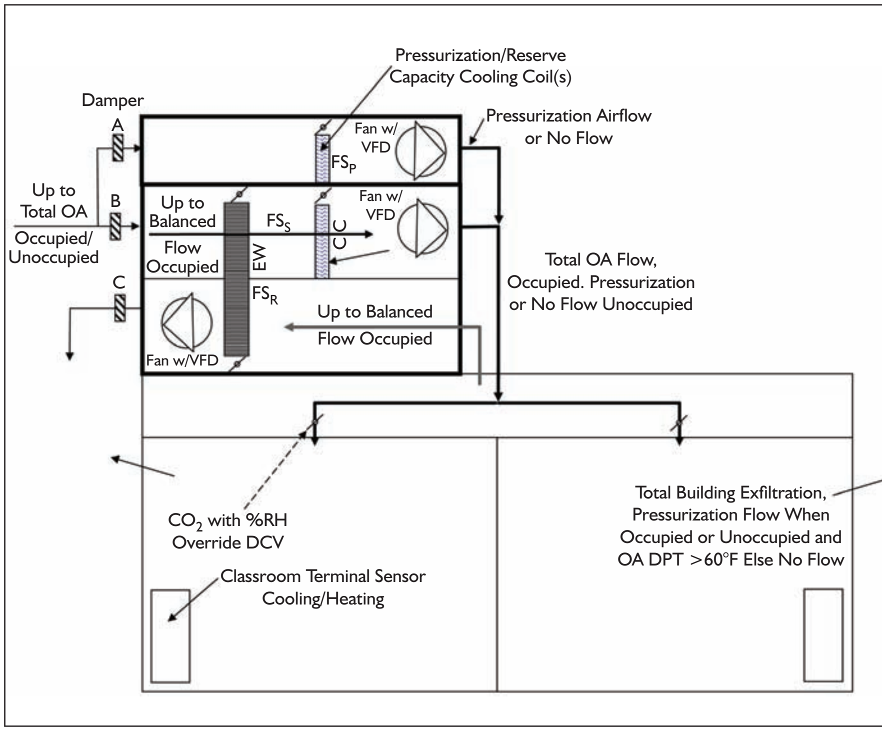

Figure 4: Integrated balanced flow DOAS/pressurization package schematic.

Advantages and Disadvantages

The integrated package, when commercially available, has the potential to offer the following advantages:

- Enables reduction of the first cost of the balanced flow DOAS by nearly the fraction of pressurization flow;
- Does not degrade the TER performance resulting from unbalanced flow;
- Allows reduced fan energy use since less combined supply air and purge airflow occurs on both sides of the wheel; this is important because fan energy use is significant;
- Allows lower operating cost, even though the cooling/dehumidification energy use may increase a little;
- Eliminates the added installation first cost for two systems (DOAS and pressurization);
- Allows energy use for pressurization to be limited with flow measurement control;
- Allows the addition of reserve capacity to the pressurization unit, at much lower first cost than in the DOAS where expensive heat recovery is used; and
- Simplifies controls by dividing the duties.

Disadvantages related to the integrated package include:

- May use more cooling energy;
- Energy use results are sensitive to equipment selection, i.e., coil ΔP, fan η, TER selections (ΔP and effectiveness), air required for pressurization, cooling COPs;
- May be falsely perceived as more complicated; and
- Not very beneficial for unbalanced flows of less than 15%.

Conclusions

Pressurized buildings improve comfort and IAQ by reducing or eliminating inward air leakage at the envelope. DOASs are capable of providing building pressurization and must do so. It was illustrated previously that adequate pressurization can be achieved with about one-half an air change per hour, or 0.06 scfm/ft^2 (0.3 L/s·m^2). To ensure this flow, it is recommended that the traditional hunting differential pressure control be replaced with measured constant flow control.

The adequate pressurization flow, drawn from a part of the combined Standard 62.1 ventilation requirement, is 30% of the total ventilation requirement for schools and 70% for office spaces. Consequently, the heat recovery equipment in DOAS can experience significant unbalanced flow. It was shown that such unbalance adversely impacts heat recovery.

Therefore, it is recommended that an integrated balanced flow DOAS/pressurization package be developed and introduced into the marketplace. The first cost savings, significant in most cases, resulting from the integrated package is expected to cause an even greater expansion of DOAS penetration into the market. Significantly, this can be achieved without an increase in operating costs over unbalanced flow DOAS. In addition, the pressurization unit offers a relatively inexpensive place to accommodate necessary reserve capacity.

With respect to DOAS in general, and the integrated approach specifically, there are still three areas where more information/research would further support the previous conclusions:

- Confirm the recommended limiting/bounding flow rate for pressurization, i.e., 0.5 ach (0.06 scfm/ft^2 [0.3 L/s·m^2]);
- Confirm that the recommendation to use fixed measured pressurization flow control, with the occasional few hours of moisture migration through the envelope when infiltration may occur, does not lead to IAQ or comfort problems; and
- Establish a systematic method for determining the appropriate reserve capacity, or a way to accommodate it in stages.

The intent of this article has been to encourage the use of pressurization with DOAS and to motivate the industry to consider the following two situations: the need for pressurization and reserve capacity, and bringing integrated balanced flow DOAS/pressurization packages into the marketplace. It will be most interesting to see which companies will be first to bring the integrated package into the marketplace.

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