Standard 62.1-2007

Dynamic Reset for Multiple-Zone Systems

By Dennis Stanke, Fellow ASHRAE

ASHRAE Standard 62.1-2007[1] prescribes minimum breathing-zone outdoor airflow rates and the equations needed to determine zone-level and system-level (intake) outdoor airflow requirements for three major ventilation configurations: single-zone, 100% outdoor air, and multiple-zone systems.

As described previously,[2,3,4] designers must use Standard 62.1 rates and equations along with appropriate design parameters, such as zone population and floor area, to calculate the minimum breathing-zone outdoor airflow (V_{bz}) required for each zone (in any system), and the minimum system outdoor air intake flow (V_{ot}), which depends upon the ventilation system configuration. Designers need these minimum worst-case values to establish the mechanical system capacity for both heating and cooling. To comply with Standard 62.1, the model building codes,[5,6] and LEED-NC, ventilation systems must be *designed* using the Standard 62.1 rates and equations.

As conditions change during *operation*, however, the intake airflow required also changes. Standard 62.1 recognizes this fact and allows systems to be designed using optional dynamic reset controls to change either zone-level or system-level outdoor airflow, or both, in response to changes in zone population and system ventilation efficiency. The minimum outdoor airflow rates and most of the multiple-zone system equations used for design, along with appropriate non-design parameters, can be used to find the outdoor airflow values needed at any operating condition. Designers may specify optional controls that allow the system to operate with less-than-design intake airflow while still providing no less than the currently required outdoor airflow values. Resetting intake airflow downward as population decreases and/or as efficiency increases saves energy while maintaining the proper dilution ventilation in the system.

Dynamic reset approaches based on changes in population (demand controlled ventilation [DCV]) have been described[7,8,9] for single-zone systems, wherein one air handler supplies a mixture of outdoor air and recirculated air for one ventilation zone. Zone-level DCV in 100% outdoor air systems, wherein one central air handler supplies only outdoor air to more than one zone without any

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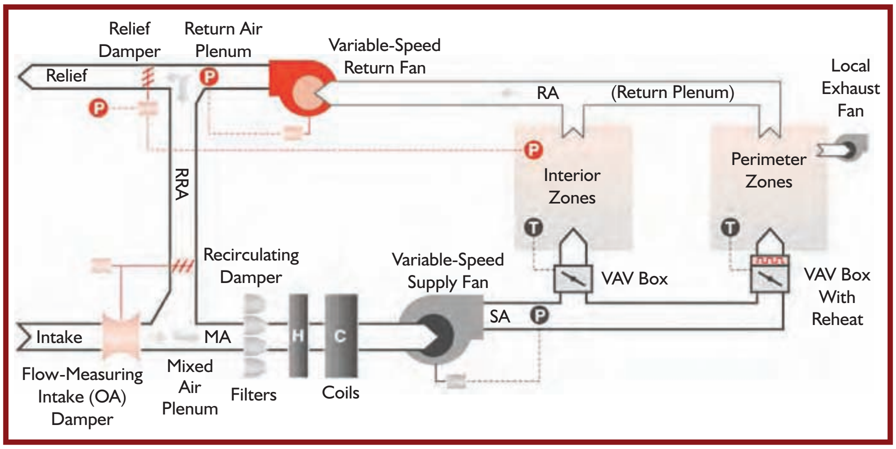

Figure 1: Typical single-path VAV system.

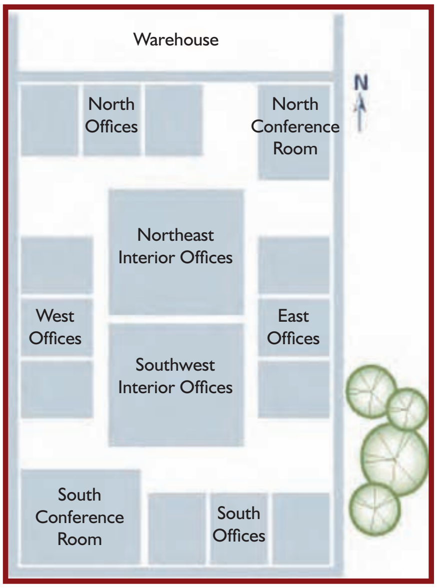

Figure 2: Multiple-zone office building.

recirculation between zones, follows directly from the single-zone approaches, provided each zone includes the necessary controls (airflow sensor, modulating damper and so on). But published information related to dynamic reset for multiple-zone systems, wherein one central air handler supplies a mixture of outdoor air and recirculated air for two or more zones, is limited.

The User's Manual for Standard 62.1-2004 included one possible approach to DCV in multiple-zone systems, which responded to increased zone-level CO_2 by first opening the local VAV damper, then the outdoor air damper; but since it was largely unproven, it was removed in the 2007 User's Manual.

Warden[10] advocated sensing and maintaining the CO_2 concentration in the supply air by adjusting intake airflow in a trim-and-respond fashion, but this approach focused on Standard 62-1989 rates and equations and it did not account for changes in population or airflow in each zone. Murphy[9] described ventilation reset control (VRC), an approach that adjusts intake airflow based on current system ventilation efficiency (E_v), accounting for changes in zone airflow.

This article revisits the design process for single-path multiple-zone systems (focusing on VAV-reheat systems), and explores actual outdoor airflow requirements at partial thermal-load conditions, adding justification for dynamic reset of intake airflow in these systems.

Ventilation at Design

Constant-volume reheat systems, single-path VAV systems with terminal reheat in some zones, dual-path fan-powered VAV systems, and dual-path dual-duct VAV systems are all multiple-zone systems for ventilation purposes. This article considers the most common of these: the single-path VAV system (*Figure 1*) with terminal reheat in some zones.

Design of these systems has been covered in detail previously[3] as an 11-step design-calculation process. Revisiting that step-by-step process (which uses equations and concepts first required by Standard 62-1989 and subsequently updated by Standard 62.1-2004 and 2007), the following paragraphs describe the calculations used to find the *design* outdoor airflow needed for the illustrative office area shown in *Figure 2*. Note that the ventilation zones in this example are extraordinarily large. We've assumed that multiple identical VAV boxes serve each zone, controlled by a single thermostat. This may not be realistic, but it helps to illustrate the ventilation calculation concepts.

For each ventilation zone, determine zone-level outdoor airflow requirements for the design zone populations shown in *Table 1*, using the following three steps:

Step 1 Find the minimum breathing zone outdoor airflow ($V_{bz} = R_p \times P_z + R_a \times A_z$) required, using the people outdoor air rate (R_p, cfm/person) and area outdoor air rate (R_a, cfm/ft^2) from Table 6-1 in Standard 62.1. For design purposes, use design zone population ($P_z = P_{z\text{-}des}$) to find the minimum requirement at the ventilation-design condition.

Step 2 Look up the zone air-distribution effectiveness (E_z) in Table 6-2 of

						Procedural Step		
						1	2	3
		R_p cfm/p	P_{z-des} Person	R_a cfm/ft^2	A_z ft^2	V_{bz} cfm	E_z	V_{oz} cfm
Ventilation Zones	South Offices	5	18	0.06	2,000	210	1.0	210
	West Offices	5	20	0.06	2,000	220	1.0	220
	South Conference Room	5	30	0.06	3,000	330	1.0	330
	East Offices	5	20	0.06	2,000	220	1.0	220
	Southwest Interior Offices	5	50	0.06	10,000	850	1.0	850
	Northeast Interior Offices	5	50	0.06	10,000	850	1.0	850
	North Offices	5	16	0.06	2,000	200	1.0	200
	North Conference Room	5	20	0.06	2,000	220	1.0	220

Table 1: Zone calculations: Design population.

Variables

A_z	Zone Floor Area, ft^2
D	Occupant Diversity
E_v	System Ventilation Efficiency
E_{vz}	Zone Ventilation Efficiency
E_z	Zone Air Distribution Effectiveness
P_z	Zone Population, Persons
P_{z-des}	Design Zone Population, Persons
R_a	Area Outdoor Air Rate, cfm/ft^2
R_p	People Outdoor Air Rate, cfm/person
V_{bz}	Breathing Zone Outdoor Airflow, cfm
V_{dz}	Zone Discharge Airflow, cfm
V_{dz-des}	Zone Discharge Airflow at Design Cooling Condition, cfm
V_{dz-min}	Zone Discharge Airflow at Minimum Expected at Design Condition, cfm
V_{ot}	Outdoor Air Intake Flow, cfm
V_{ou}	Uncorrected Outdoor Air Intake Flow, cfm
V_{oz}	Zone Outdoor Airflow, cfm
V_{ps}	System Primary Airflow, cfm
X_s	Average Outdoor Air Fraction
Z_{dz}	Zone Discharge Outdoor Air Fraction

				Procedural Step 1–3 (above)	4	5–8	9–11
		V_{dz-des} cfm	V_{dz-min}[1] cfm	V_{oz} cfm	Z_{dz}	–	E_{vz}
Ventilation Zones	South Offices	1,900	475	210	0.442	–	0.708
	West Offices	2,000	500	220	0.440	–	0.710
	South Conference Room	3,300	825	330	0.400	–	0.750
	East Offices	2,000	500	220	0.440	–	0.710
	Southwest Interior Offices	7,000	1,750	850	0.486	–	0.665
	Northeast Interior Offices	7,000	1,750	850	0.486	–	0.665
	North Offices	1,600	400	200	0.500	–	0.650
	North Conference Room	1,800	450	220	0.489	–	0.661

Step	Variable		
5	D^2	0.732	–
6	V_{ou}	2,800	–
7	$V_{ps}{}^3$	18,600	–
8	X_s	0.150	–
–	–	–	–
10	E_v		0.650
11	V_{ot}		4,300

NOTES

[1] Minimum discharge (primary) airflow set arbitrarily to 25% of design airflow

[2] $D = P_s/\Sigma P_z$, where P_s (system population) = 164 people, ΣP_z (sum of zone peak population) = 224 people

[3] $V_{ps} = DF \times \Sigma V_{dz-des}$, where DF (thermal diversity factor) = 0.70

Table 2: System calculations: Design condition.

Standard 62.1, based on supply diffuser and return grille location and supply air temperature. Remember, some zone configurations result in more breathing zone bypass than others, and this effectiveness can be a dynamic value; in some zones it's $E_z = 1.0$ when delivering cool air, but it may drop to $E_z = 0.8$ when delivering very warm air from overhead diffusers.

Step 3 Find the minimum required zone outdoor airflow ($V_{oz} = V_{bz}/E_z$). This outdoor airflow rate must be delivered to the zone, usually in the discharge (supply) airstream.

The first three steps apply at the zone level, regardless of ventilation-system configuration. For multiple-zone systems, however, several more calculation steps are needed to properly account for system ventilation efficiency (see sidebar "Watch Out for Panaceas"). Using the calculated approach described in Standard 62.1, Appendix A, the following additional steps apply for our example.

Table 2 shows the maximum discharge airflow for each zone, and documents the results of Steps 4 through 11 of the design calculation process.

Step 4 For each zone, determine the minimum discharge outdoor air fraction ($Z_{dz} = V_{oz}/V_{dz}$). For design purposes, use the design minimum zone outdoor airflow found in Step 3, and the *minimum expected* (see sidebar "Good Judgment Required") zone discharge airflow ($V_{dz} = V_{dz\text{-}min}$). What's the minimum expected value for discharge airflow?

Conservative designers might use the minimum primary airflow setting on the VAV box, which equals minimum discharge airflow in a single-path multiple-zone system. Even though this minimum airflow might not actually be expected at cooling design, it's easy to determine and it yields a conservative design. The resulting outdoor air intake flow definitely would be the highest (worst-case) value ever needed at any operating condition. But, very low primary airflow settings lead to very high Z_{dz} values and very high intake flow values, perhaps too high for some designers. If the minimum flow setting equals the zone outdoor airflow, and if this setting is used as the minimum expected zone discharge airflow, the

Watch Out for Panaceas

Standard 62.1 requires *direct accounting* for system ventilation efficiency in buildings using multiple-zone ventilation systems—systems that inherently overventilate noncritical zones. The standard does not require such direct accounting in buildings using several single-zone systems (such as a school with one rooftop unit per classroom) or using a 100% outdoor air system, but that doesn't mean that these systems are perfectly efficient.

Remember, all zones in these systems must be designed to provide proper ventilation for the design zone population, without regard to population diversity, so the total outdoor airflow *required* in all zones exceeds the total actually *used* in all zones at any given time.

Configuring the example office area with eight single-zone systems or one 100% outdoor air system, the total outdoor air intake flow (V_{ot}) required would be 3,100 cfm (the sum of the zone outdoor airflow values for 224 people) even though actual system population is only 164 people, who use only 2,800 cfm (V_{ou}) of outdoor air. Calculating an *effective* system ventilation efficiency, $E_v = V_{ou}/V_{ot}$ = 2,800/3,100 or 0.9—not 1.0 as many designers assume. In other words, no ventilation system configuration is 100% efficient at design.

In this example office building, the 100% outdoor air system may be more efficient than the multiple-zone system, but in buildings with high occupant density zones (such as schools), the effective efficiency for a 100% outdoor air system is often lower than that for a multiple-zone system applied to the same building. In other words, a 100% outdoor air system in a given building might actually require more outdoor airflow than a properly designed multiple-zone system applied to the same building.

zone requires 100% of its discharge airflow to be outdoor air ($Z_{dz} = V_{oz}/V_{dz\text{-}min} = V_{oz}/V_{oz} = 1.0$). The system must be designed for 100% outdoor air intake flow.

To avoid this outcome, designers must use a more reasonable minimum expected value, perhaps based on experience or on an hourly system performance simulation. For most designs, the minimum expected value for design purposes is much higher than the zone outdoor airflow value. If a zone truly needs very low airflow at ventilation-design conditions, the minimum expected discharge airflow can be increased by using a local fan (a series fan-powered box, for instance) to add local recirculation from the plenum or a transfer fan to draw more supply air from adjacent zones.

For the example calculations in *Table 2,* using the conservative approach, minimum expected discharge airflow equals the minimum primary airflow setting in each zone, arbitrarily set to 25% of the maximum zone discharge airflow ($V_{dz\text{-}min} = 0.25 \times V_{dz}$).

Step 5 For the system, find the occupant diversity fraction ($D = P_s/\Sigma P_{z\text{-}des}$) based on the peak system population (P_s) and the sum of the design population for all zones ($\Sigma P_{z\text{-}des} = 224$ people in this example). This fraction reduces people-related outdoor airflow for design purposes, since peak population does not occur simultaneously in all zones. In this example, with a peak system population ($P_s = 164$ people), a system-wide diversity factor ($D = 164/224 = 0.732$) was used to spread population diversity evenly among all zones.

Step 6 Find the outdoor air usage rate in all breathing zones, that is, the uncorrected outdoor air intake flow ($V_{ou} = D \times \Sigma[R_p \times P_z] + \Sigma[R_a \times A_z]$). In VAV systems, the occupant diversity factor D "adjusts" the rate at which people use outdoor air in the system to account for actual system population. For the example system, the outdoor air used in all breathing zones is adjusted for system-wide population diversity ($V_{ou} = 0.732 \times 1{,}120 + 1{,}980 = 2{,}800$ cfm).

Step 7 Establish the system primary airflow (V_{ps}) at the ventilation-design condition. For design purposes, the VAV system primary airflow, i.e., the central supply airflow, usually equals block airflow at cooling-design conditions. The highest system primary airflow usually results in lowest system ventilation efficiency (E_v) and therefore, highest or worst-case intake airflow (see sidebar "Good Judgment Required"). System primary airflow at cooling-design can be found by applying a load-diversity factor (0.70 in the example) to the sum-of-peak zone discharge airflow ($V_{ps} = 0.70 \times \Sigma V_{dz} = 0.70 \times 26{,}600 = 18{,}600$ cfm) or by using a load calculation program to find the highest primary airflow needed at the ventilation-design condition.

In VAV systems with one or two very large zones, worst-case intake flow can occur at less than block airflow, so designers should carefully check intake requirements at other-than-block primary airflow rates, too. And, in systems with overhead heat, lower values of zone air-distribution effectiveness can also change the primary airflow at the worst-case intake airflow condition, so again, designers must be careful.

Step 8 Find the average outdoor air fraction ($X_s = V_{ou}/V_{ps}$), i.e., the fraction of outdoor air needed in the primary airstream if all breathing zones needed exactly the same discharge outdoor air fraction. In the example, it's the ratio of outdoor airflow used in all breathing zones (V_{ou}) at ventilation-design conditions to the system primary airflow at ventilation-design conditions ($X_s = 2{,}800/18{,}600 = 0.150$).

Step 9 Find zone ventilation efficiency for each zone ($E_{vz} = 1 + X_s - Z_{dz}$), based on the average outdoor air fraction for the system and the discharge outdoor air fraction needed for the zone. *Table 2* shows the result of these calculations for each zone in the example system.

Step 10 Find the system ventilation efficiency, that is, the lowest zone ventilation efficiency (E_v = lowest $[E_{vz}]$). At design conditions for single-path multiple-zone systems, the lowest zone ventilation efficiency occurs in the ventilation-critical zone, that is, the zone needing the highest fraction of outdoor air in its discharge airstream. For the example system, the North Offices area becomes the ventilation-critical zone ($E_v = 0.650$).

Step 11 Finally, find the minimum required system outdoor air intake flow ($V_{ot} = V_{ou}/E_v$). At ventilation-design conditions, this value represents highest (worst-case) intake airflow required. In the example system, a low system ventilation efficiency results in relatively high intake airflow ($V_{ot} = 2{,}800/0.650 = 4{,}300$ cfm) for design purposes.

That's it for design calculations. While designers don't always use them (see sidebar "VAV Design Errors"), these calculations

Good Judgment Required

Assigning a value to the expected zone discharge airflow at the ventilation-design condition requires more designer judgment than any other parameter in these calculations. The ventilation-design condition (that set of airflows which result in highest required outdoor air intake flow) almost always occurs when the primary airflow equals block load-cooling airflow for the system, and the ventilation-critical zone primary airflow equals either the minimum airflow setting for the VAV box, or the minimum expected airflow at the ventilation-design condition. (For very small systems with a few small zones and one very large zone, the ventilation-design condition actually can occur at less than block load airflow. In this case, the system needs its highest outdoor air intake flow when the primary airflow equals the sum of the small-zone design airflows and the large-zone minimum-expected airflow.)

Worst-case intake airflow at the ventilation-design condition can be found by assuming the *minimum expected* primary airflow in the critical zone equals the minimum airflow setting. This approach is simple, but it results in conservatively high outdoor air intake flow. Alternatively, a less conservative intake airflow value can be found by assuming that the critical-zone *minimum expected* primary airflow exceeds the minimum airflow setting (the higher the better, since more primary airflow lowers Z_{dz} and raises E_z). The question to be answered by the designer is simply: What's the minimum primary airflow expected in the critical zone at the ventilation-design condition? Perhaps load simulation programs can help answer this question. Or, perhaps someday, Standards 62.1 or 90.1 can address this problem prescriptively. Meanwhile, designers must use their judgment.

have been required for compliance with Standard 62 since 1989. They result in worst-case outdoor air intake flow, which is a key value when selecting cooling and heating coils. Incorporated into the model codes[5,6] and included as a prerequisite for LEED-certified projects, these rates and equations lend themselves to spreadsheet analysis and have been incorporated into some of the major system energy/economic performance programs.

Ventilation During Operation—80% of Design Primary Airflow

Properly designed single-path VAV systems must sense outdoor air intake flow (or in some other way compensate for changes in system primary airflow and mixing box pressure) and maintain it at the design value by modulating the position of the outdoor air damper as conditions change. But systems do not need this worst-case design value during all operating conditions to ensure proper ventilation. This section presents eleven calculation steps, very similar to those described previously for design, but using *actual* population for each zone along with *actual* airflow values at 80% system airflow and at two populations, to show that ventilation airflow can be reduced at non-design conditions.

Assuming that at some occupied time, zone population matches those values shown in *Table 3,* the sum of which equals the design population for the system. Following Steps 1 through 3 using the actual zone population (P_z) for each zone, we can find the current zone outdoor airflow required ($V_{oz} = [R_p \times P_z + R_a \times A_z]/E_z$) in each zone. Note that lower-than-design population reduces some of these outdoor airflow values compared with *Table 1*.

At the same occupied time, cooling loads could result in the actual zone discharge airflow (V_{dz}) values shown in *Table 4*. All zones need less than cooling-design airflow.

Step 4 Find the zone outdoor air fraction for each zone ($Z_{dz} = V_{oz}/V_{dz}$) using the zone outdoor airflow (V_{oz}) values based on actual population (*Table 3*) and actual zone discharge airflow values (V_{dz}) shown in *Table 4*.

					Procedural Step		
					1	2	3
Ventilation Zones	R_p cfm/p	P_z Person	R_a cfm/ft²	A_z ft²	V_{bz} cfm	E_z	V_{oz} cfm
South Offices	5	16	0.06	2,000	200	1.0	200
West Offices	5	18	0.06	2,000	210	1.0	210
South Conference Room	5	16	0.06	3,000	260	1.0	260
East Offices	5	16	0.06	2,000	200	1.0	200
Southwest Interior Offices	5	42	0.06	10,000	810	1.0	810
Northeast Interior Offices	5	32	0.06	10,000	810	1.0	760
North Offices	5	14	0.06	2,000	190	1.0	190
North Conference Room	5	10	0.06	2,000	170	1.0	170

Table 3: Zone calculations: Design system population.

		Procedural Step			
		1–3	4	5–8	9–11
Ventilation Zones	V_{dz} cfm	V_{oz} cfm	Z_{dz}	–	E_{vz}
South Offices	1,600	200	0.125	–	1.063
West Offices	1,800	210	0.117	–	1.071
South Conference Room	2,500	260	0.104	–	1.084
East Offices	700	200	0.286	–	0.902
Southwest Interior Offices	3,000	810	0.270	–	0.918
Northeast Interior Offices	3,500	760	0.217	–	0.971
North Offices	1,000	170	0.190	–	0.998
North Conference Room	800	220	0.213	–	0.975

Step	Variable		
5	D	1.000	–
6	V_{ou}	2,800	–
7	V_{ps}	14,900	–
8	X_s	0.188	–
–	–	–	–
10	E_v		0.902
11	V_{ot}		3,100

Table 4: System calculations: 80% of design (with design system population).

Step 5 Since this example focuses on *actual* zone and system population, system population equals the sum of zone population, so population diversity has no impact on these calculations ($D = P_s/\Sigma P_z = 1.0$).

Step 6 Find the uncorrected outdoor airflow ($V_{ou} = D \times \Sigma[R_p \times P_z] + \Sigma[R_a \times A_z]$) using actual population in each zone and a population diversity of $D = 1.0$.

Step 7 In a single-path VAV system, zone primary airflow (V_{pz}) equals zone discharge airflow at each VAV box. Consequently, determine the system primary airflow (V_{ps}) during operation as the sum of actual zone discharge airflow values (V_{dz}) (plus any supply duct leakage). In the example, assuming no duct leakage, system primary airflow equals the 80% of the design value ($V_{ps} = 0.80 \times \Sigma V_{dz} = 14{,}900$ cfm).

Step 8 Determine the actual average outdoor air fraction based on current uncorrected outdoor airflow and the actual system primary airflow ($X_s = V_{ou}/V_{ps}$). In the example, this fraction is a little higher than the design value (0.188 versus 0.150) because system primary airflow is reduced.

Step 9 For each zone, find the current zone ventilation efficiency using the actual values for average outdoor air fraction and zone discharge outdoor air fraction ($E_{vz} = 1 + X_s - Z_{dz}$). These values differ from the design values due to changes in primary airflow, as well as zone discharge airflow.

Step 10 Find actual system ventilation efficiency, which equals the lowest efficiency among all zones. At this example condition, efficiency rises compared to the worst-case design condition (0.902 versus 0.650).

Step 11 Find the outdoor air intake flow ($V_{ot} = V_{ou}/E_v$) required. It's lower than the worst-case value at design conditions. When designed for worst-case, the outdoor air intake flow required at any part-load condition is always lower than the design value.

As *Table 4* shows, lowering system primary airflow alone (with no change in system population) increases efficiency, so in this example, the minimum required outdoor air intake flow drops from 4,300 cfm at design to only 3,100 cfm at this 80% airflow condition.

Ventilation During Operation—80% of Design Population

So, reduced airflow alone increases efficiency and reduces required intake airflow. But, what happens if both system primary airflow and system population drop to 80% of design values?

Assume that at some occupied time, some occupants leave the building and zone population matches the values shown in *Table 5*, resulting in a system population of 131 people, 80% of the design population. Following Steps 1 through 3 above, we can find the current zone outdoor airflow required ($V_{oz} = [R_p \times P_z + R_a \times A_z]/E_z$) in each zone. Note that we assumed that the North Offices require reheat, and are configured so that $E_z = 0.8$ in heating, so zone outdoor airflow rises in this zone.

						Procedural Step		
						1	2	3
		R_p cfm/p	P_z Person	R_a cfm/ft²	A_z ft²	V_{bz} cfm	E_z	V_{oz} cfm
Ventilation Zones	South Offices	5	16	0.06	2,000	200	1.0	200
	West Offices	5	18	0.06	2,000	210	1.0	210
	South Conference Room	5	11	0.06	3,000	235	1.0	235
	East Offices	5	16	0.06	2,000	200	1.0	200
	Southwest Interior Offices	5	32	0.06	10,000	760	1.0	760
	Northeast Interior Offices	5	22	0.06	10,000	710	1.0	710
	North Offices	5	6	0.06	2,000	150	0.8	187
	North Conference Room	5	10	0.06	2,000	170	1.0	170

Table 5: Zone calculations: 80% of design system population.

			Procedural Step			
			1–3	4	5–8	9–11
		V_{dz} cfm	V_{oz} cfm	Z_{dz}	–	E_{vz}
Ventilation Zones	South Offices	1,600	200	0.125	–	1.052
	West Offices	1,800	210	0.117	–	1.060
	South Conference Room	2,500	235	0.094	–	1.083
	East Offices	700	200	0.286	–	0.891
	Southwest Interior Offices	3,000	760	0.289	–	0.924
	Northeast Interior Offices	3,500	710	0.203	–	0.974
	North Offices	1,000	187	0.188	–	0.989
	North Conference Room	800	170	0.213	–	0.964

Step	Variable		
5	D	1.000	–
6	V_{ou}	2,630	–
7	V_{ps}	14,900	–
8	X_s	0.177	–
–	–	–	–
10	E_v		0.891
11	V_{ot}		2,960

Table 6: System calculations: 80% of design primary airflow (80% of design system population).

As shown in *Table 6*, solving Steps 4 through 11 using lower-than-design system population and system primary airflow results in a further increase in efficiency, and a further drop in required outdoor air intake flow (from 4,300 cfm at design to 3,100 cfm at 80% airflow and to 2,960 cfm at 80% system population). In this illustrative example, resetting intake airflow based on airflows alone has much more impact than resetting based on both zone airflow and system population, but this outcome will vary from one system to the next. Also, note that the reduced outdoor air intake flow rates determined are the

VAV Design Errors

Incorrect ventilation design seems to be very common in VAV systems. Some designers simply find the zone outdoor airflow values (*Table 1*) and add these values together to determine "outdoor air intake flow;" with no correction for efficiency. This approach results in inadequate ventilation (in the example, 3,100 cfm versus the 4,300 cfm actually needed) at many conditions. Other designers follow all of the design calculation steps (*Tables 1* and *2*) to find design outdoor air intake flow, but then convert this airflow to a fraction of the primary design airflow (4,300/18,600 = 0.23, in our example) and set the outdoor air damper *minimum position* to correspond to this fraction. This approach results in adequate ventilation at high thermal loads, but as primary airflow drops, mixing box pressure rises and outdoor airflow drops to a less-than-adequate value. Depending upon the relationship of damper position to flow, at a 60% load condition with the intake damper fixed at 23%, intake airflow in the example system may drop to 0.23×0.60×18,600 = 2,570 cfm, even though 3,300 cfm is actually needed. So, ignoring the multiple-zone system calculations and/or maintaining a fixed *fraction* of outdoor air (rather than modulating the damper to ensure outdoor air intake *flow*) can lead to underventilated VAV systems and associated IAQ problems.

Approach	Description of Logic	Possible Advantages	Possible Disadvantages
No Reset	Maintain design intake airflow at all conditions.	Simple and never underventilates.	Overventilation wastes energy.
Zone-Level CO_2-Based Reset	Sense zone(s) CO_2 level; increment the outdoor air damper open or closed in proportion to apparent outdoor air needs of the most critical zone.	No outdoor airflow calculation required during operation.	Compliance with airflow requirements may be difficult to validate without airflow measurement. May need CO_2 sensing in many zones. Inaccurate CO_2 sensing may introduce significant errors. Large population changes can result in small changes in CO_2 concentration, especially in high-density zones. Requires base outdoor airflow level for building (R_a).
Supply Air CO_2-Based	Sense supply air CO_2 level with respect to outdoor air; increment outdoor air damper open or closed to maintain supply CO_2 concentration at the design level.	No outdoor airflow calculation required during operation. Very few CO_2 sensing locations needed, and no outdoor airflow calculation needed.	Compliance with airflow requirements may be difficult to validate without airflow measurement. Requires base outdoor airflow level for building (R_a).
Airflow-Based Ventilation Reset Control (VRC)[1]	Sense current zone airflow; using design population and sensed airflows, solve the MZS equations to find current outdoor air intake flow setpoint.	Responds to changes in efficiency based solely on airflow values, which are usually available in DDC VAV systems. Solves the MZS equations dynamically to reset intake airflow setpoint. Allows validation of compliance with outdoor airflow requirement.	No direct adjustment for changes in zone population.
VRC With Population Counting[2]	Count people and sense airflow in each zone; use these actual values to solve the MZS equations to find current outdoor air intake flow setpoint.[1]	Lowest possible V_{ot} at all conditions since it accounts for both actual population and actual airflow variations. BAS can solve MZS equations. Ensures base outdoor airflow level for building (R_a).	Accurate people-counting systems may be prohibitively expensive, impractical, or not readily available.
VRC and Population Estimating Based on Schedules	Estimate zone population based on time-of-day schedule and sense airflow in each zone; use estimated (rather than actual) population and actual airflow to solve the MZS equations to find current outdoor air intake flow setpoint.	TOD scheduling capability is standard for most building automation systems (BAS). Schedules can be entered without adding sensors. Primary airflow values are usually available in DDC VAV systems. BAS can solve MZS equations. Ensures base outdoor airflow level for building (R_a).	Population estimates based on TOD can be very inaccurate, leading to under- or overventilation at many conditions.
VRC and Occupancy Sensing	Estimate zone population based on binary occupancy sensors (design population or zero population) and sense airflow in each zone; use estimated population and actual airflow to solve MZS equations to find current outdoor air intake flow setpoint.	Only zones with significant unoccupied intervals require occupancy sensors. Primary airflow values are usually available in DDC VAV systems. BAS can solve MZS equations. Ensures base outdoor airflow level for building (R_a).	Population never goes to zero in many zones so savings beyond VRC-only may be small.
VRC and CO_2-Based Breathing Zone Outdoor Air Estimating	Use CO_2 sensors to estimate breathing zone outdoor airflow currently required; sense airflow in each zone; use estimated breathing zone outdoor airflow and actual discharge airflow to solve the MZS equations to find current outdoor air intake flow setpoint.	CO_2 sensors only needed in zones with highly variable population. Primary airflow values are usually available in DDC VAV systems. BAS can solve MZS equations. Ensures base outdoor airflow level for building (R_a).	Inaccurate CO_2 sensing may introduce significant errors. Large population changes can result in small changes in CO_2 concentration, especially in high-density zones.

[1] Tables 3 and 4 show the results of using this approach

[2] Tables 5 and 6 show the results of using this approach, assuming each zone includes accurate people-counting capability

Table 7: Some possible multiple-zone systems (MZS) dynamic reset approaches.

minimum required rates at a particular operating condition. In practice, these minimum rates could only be achieved by using a control approach that accurately counts people in each zone.

In summary, considering *actual* population and *actual* zone primary airflow values (and in some cases, accounting for changes in zone air-distribution effectiveness), the lowest outdoor air intake airflow needed at any condition can be found. And, since design intake airflow (which should be the worst-case value in properly designed systems) always equals or exceeds the intake airflow needed at non-design conditions, it makes sense to consider resetting intake flow dynamically as zone airflow values, population and perhaps even zone air-distribution efficiency changes.

Possible MZS Control Approaches

Standard 62.1 recognizes this potential for part-load outdoor air intake flow reduction due to changes in population and zone airflow, so Section 6.2.7 allows optional dynamic reset control of breathing-zone outdoor airflow (V_{bz}), outdoor air intake flow (V_{ot}) or both, in response to the current demand for ventilation. The standard includes variations in ventilation efficiency and variations in population (both of which impact intake airflow, as shown previously) as examples of conditions that may be used as the basis for optional dynamic reset control.

Table 7 (see Page 32) lists several possible dynamic reset control approaches that could be considered for multiple-zone systems. This is not intended to be a complete or detailed list, but rather some approaches that have been or could be examined and compared. Some of these approaches comply with Standard 62.1 indirectly since they adjust outdoor air intake flow based on contaminant levels, rather than currently calculated airflow requirements. The standard requires outdoor air intake flow, determined using prescribed zone outdoor airflow rates and prescribed equations but it does not require direct control of specific contaminant (or surrogate) concentrations. One approach uses airflow-only ventilation reset control (VRC), solving the multiple-zone system equations to adjust for variations in efficiency due to changes in zone airflow while assuming design population in all zones. And, several approaches combine system-level VRC with zone-level DCV to find the current outdoor air intake flow, accounting for changes in zone airflow and zone population.

Any of these approaches and their potential advantages and disadvantages can be debated. Future articles on dynamic reset in multiple-zone systems should examine some of these control approaches in more detail and compare them at specific operating conditions, to improve the accuracy of this table and demonstrate the viability of various multiple-zone system dynamic reset approaches. The annual energy performance for systems using some of these control approaches (and presumably others) is the subject of ASHRAE Research Project 1547.

Summary

Standard 62.1-2007 establishes outdoor airflow rates and calculation procedures needed to determine the minimum required outdoor air intake flow at *design*. It also allows optional dynamic reset approaches to determine intake airflow required during *operation*. This article summarized the multiple-zone system design process, then showed how outdoor air intake flow requirements change during operation due to changes in both population and zone airflow. Some key observations about dynamic reset in multiple-zone systems include:

- Design calculations are independent of dynamic reset controls.
- During operation, the required minimum outdoor air intake flow drops, compared to design levels, due partly to changes in zone airflow and partly to changes in zone population (as well as possible changes in zone air distribution efficiency).
- Since the required intake airflow never exceeds the design (worst-case) value, dynamic reset control approaches may be justified for multiple-zone systems, depending upon relative first cost and operating-cost savings.
- A detailed discussion of several demand-controlled ventilation approaches in multiple-zone systems is needed.

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