Transient Occupancy Ventilation By Monitoring CO_2

Standard 62 has produced an industry devoted to utilizing ventilation reset, thus reducing the energy used to condition OA, based generally upon holding the space with the highest CO_2 concentration at or below about 1,000 ppm. That may change with Addendum n.

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ANSI/ASHRAE Standard 62-2001, *Ventilation for Acceptable Indoor Air Quality*, has produced an industry devoted to utilizing ventilation reset, thus reducing the energy used to condition OA, based generally upon holding the space with the highest CO_2 concentration at or below about 1,000 ppm.

For example, a space designed for 40 people where each person is to receive 20 cfm (9.4 L/s) has a required ventilation rate of 800 cfm (378 L/s). If the occupancy drops to 20 people, dynamic reset would reduce the ventilation rate to 400 cfm (189 L/s), reducing the quantity of OA to be conditioned and energy use by 50%.

Standard 62-2001 states "Indoor air quality shall be considered acceptable if the required rates of acceptable outdoor air in Table 2 are provided for the occupied space." Table 2 lists the required ventilation rates in cfm (L/s) per person or cfm per ft^2 (L/s per m^2) for a variety of spaces. Where the ventilation rates are in cfm per person, the contamination produced is presumed to be proportional to the number of persons in the space.

ASHRAE is on the verge of replacing Table 2 and the Ventilation Rate Procedure of Standard 62-2001 with Addendum 62*n*, which has been approved by ASHRAE and awaiting ANSI approval. It recognizes that indoor air pollutants are generated by both building occupants and their activities as well as by the contents of a building. Consequently, the ventilation requirement in the breathing zone is the summation of an occupancy component and an area component.

Mostly, the design occupancy total ventilation requirements will not be greatly changed by Addendum 62*n*. High occupancy spaces, such as conference rooms, are an exception. The ventilation rate for such spaces generally will be less with Addendum 62*n*.

Dynamic Reset of Outdoor Air Intake

Section 6.2.6 of 62*n* permits dynamic reset of the design outdoor air intake flow during several conditions. One condition is "an estimate of occupancy or ventilation rate per person using occupancy sensors such as those based on indoor CO_2 concentrations." A literal reading would require the space CO_2 concentration to go down as the occupancy decreases.

Consider a classroom for 25 students (ages 9 or older) that has a floor area of 1,050 ft^2 (98 m^2). Table 6.1 of Addendum 62*n* calls for 10 cfm (4.7 L/s) per person and 0.12 cfm/ft^2 (0.6 L/s per m^2), or a 250 cfm (118 L/s) person component and a 125 cfm (59 L/s) floor component for a 375 cfm (177 L/s) total ventilation rate (same as the old standard where the ventilation rate per person was 15 cfm [7 L/s]). If the OA CO_2 concentration was approximately 300 ppm, the resulting room concentration would be approximately 1,000 ppm.

However, if the student population drops to 12, Addendum 62*n* would call for only a 120 cfm (57 L/s) person component and the same 125 cfm (59 L/s) floor component for a 245 cfm (116 L/s) ventilation rate (if the ventilation rate were divided by the occupancy the apparent per person ventilation rate has increased to 20.4 cfm [9.6 L/s] because of the constant floor component). The resulting room CO_2 concentration, assuming the OA concentration remained the same, would be approximately 800 ppm.

An alternative reading of the condition for dynamic ventilation rate reset using indoor CO_2 concentrations, would be to hold the space CO_2 concentration less than 700 ppm above the outdoor air concentration (or approximately 1,000 ppm as in the past) and use the floor component only as a minimum OA requirement. This alternative reading is inspired by Standard 62-2001, Section 6.1, Page 7, "Comfort (odor) criteria with respect to human bioeffluents are likely to be satisfied if the ventilation results in indoor CO_2 concentrations less than 700 ppm above the outdoor air concentration."

Controls to strictly maintain the minimum floor component may be tricky. If this alternative reading is what the drafters of Addendum 62*n* had in mind, it should have been explicitly stated. So read, it follows that, in practice, VAV system box minimums will be set at the floor component flow, or in the previous example, greater than 125 cfm (59 L/s). I believe this alternate reading of Addendum 62*n* is flawed since it essentially ignores a portion of the contribution from the floor component when the occupancy drops below design.

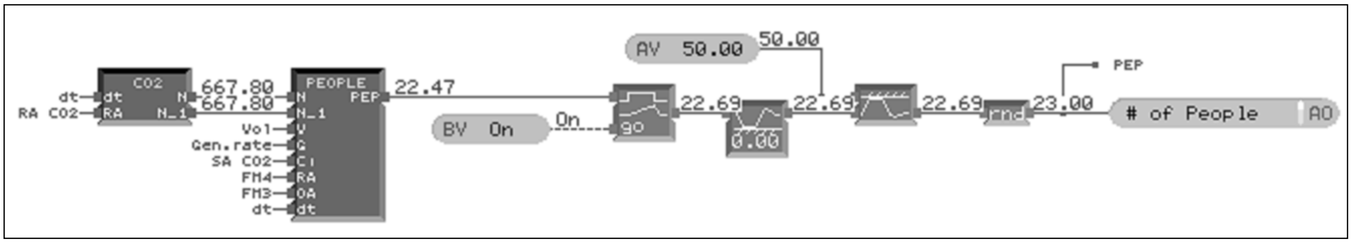

Figure 1: Logical blocks used to estimate occupancy.

For example, eight people in the space designed for 25 would result in a space CO_2 concentration of 1,000 ppm with just the floor component flow of 125 cfm (59 L/s). Such operation would be 80 cfm (38 L/s) deficient and fail to provide the needed OA to adequately dilute both the occupant- and nonoccupant-related source of contaminants.

CO_2 Testing Dynamic Occupancy

Given this background, an experiment to test the ability of space CO_2 concentrations to accurately predict real-time occupancy was undertaken. If the real-time occupancy can be determined, the space CO_2 concentration setpoint can be computed dynamically, and conventional PID control loops can be used to modulate the OA flow to meet the new Addendum 62*n* requirements.

The site of the experimental work is a 3,200 ft^2 (297 m^2) classroom/studio facility served by a dedicated outdoor air system. The design occupancy is 45 students and their studio critics. Addendum 62*n*, Table 6.1, calls for the ventilation rate to be 450 cfm (212 L/s) for the person component and 385 cfm (182 L/s) for the floor component for a total 835 cfm (394 L/s) of OA.

The supply and relief air CO_2 concentrations and the supply airflow rate are monitored in real time. The commercial instrumentation used in the experiment is at or near the top of the line for quality and accuracy. The signals are connected to the system's DDC hardware, where the software computes the dynamic occupancy.

Computing Occupancy From Measured Data

Both steady state and transient equations can be used to solve for occupancy.[1] The transient equation in difference form is:

$$Pep = \left(V \times \left(N - N_{-1}\right) / \Delta\tau + SA \times \left(N - C_i\right)\right) / \left(G \times 1{,}000{,}000\right)$$

where

- Pep = number of occupants
- V = the space air volume, ft^3
- N = the space CO_2 concentration at the present time step, ppm
- N_{-1} = the space CO_2 concentration one time step back, ppm
- $\Delta\tau$ = the time step, min.
- SA = the supply airflow rate, scfm
- C_i = the CO_2 concentration in the supply air, ppm
- G = the CO_2 generation rate per person, scfm

The transient equation is easily converted to a steady state equation by setting the term, $V \times \left(N - N_{-1}\right)/\Delta\tau$, equal to zero.

The graphic program blocks used to make this calculation are illustrated in *Figure 1*. The first block at the left is used to store the N_{-1} value as well as obtain the current value of N at time intervals $\Delta\tau$. The second block solves the *Pep* equation dynamically. The third block limits the rate of change of *Pep* to 1 person/15 seconds to dampen transients caused by fluctuating CO_2 values and supply air fluctuations.

Figure 2A illustrates CO_2 fluctuations that are 10 to 15 ppm. *Figure 2B* shows supply air fluctuations that are generally less than 25 cfm (11.8 L/s). The fourth and fifth blocks limit the occupancy numbers between 0 and 50. Finally, the sixth block limits the display of occupants to integer values. For the test case, the active space volume (room volume less the estimated volume of furniture, occupants, and other objects in the space) is 32,800 ft^3 (929 m^3). The assumed CO_2 generation rate per person, G, is 0.01 scfm (0.005 L/s). The time step, $\Delta\tau$, varied considerably from 0.05 minutes to 1 minute in the experiments with little impact. To appreciate how well the third block dampens fluctuations, consider two cases.

Case 1: When the $\Delta\tau$ was 0.5 minutes, the N and N_{-1} values were 644 and 630.6 ppm respectively. The C_i was 386 ppm and the *SA* flow rate about 850 scfm (401 L/s). Under these transient conditions, the computed occupancy was 109.36. If the transient term of the equation were set to 0, the steady state occupancy would be $850 \times \left(644 - 386\right)/\left(0.01 \times 1{,}000{,}000\right) = 21.9$ people. At that moment, the displayed number of people was 21.

Case 2: Occurring several minutes later, N and N_{-1} had values of 633 and 643.4 ppm, respectively. The C_i was 386.9 ppm and the *SA* flow rate about 850 scfm (401 L/s). Under these transient conditions, the computed occupancy was –47.53. If the transient term of the equation was set to 0, the steady state occupancy would be $850 \times \left(633 - 386.9\right)/\left(0.01 \times 1{,}000{,}000\right) = 20.9$ people. At that moment, the displayed number of people was 22. The presence of the transient term causes some oscillation in the estimated occupancy, but is able to respond correctly and rapidly to abrupt changes in occupancy. However, when the occupancy is steady or changing slowly, the transient equation oscillates by only one or two people.

Implicit in the equation is the assumption that the space is held at a positive pressure, so that air with a CO_2 concentration higher or lower than the space air is not drawn inward, which would alter the concentration balances. When the space is held at a positive pressure, all of the room air leaves with an assumed uniform CO_2 concentration equal to that measured in the return airstream. In the case of the test facility, the use of high induction supply air diffusers produces well-mixed air.

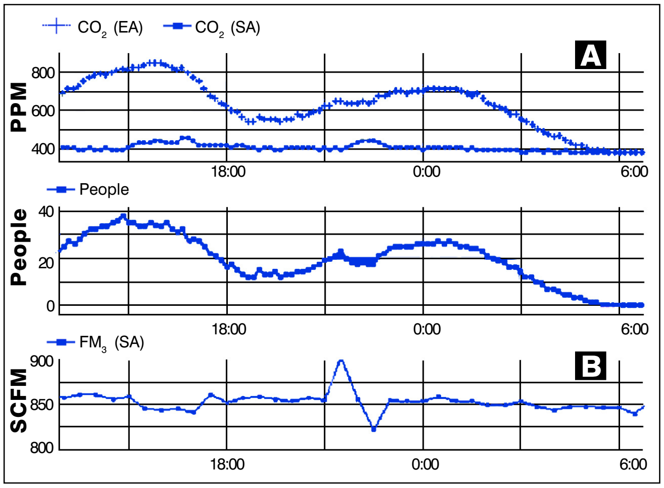

Figure 2: CO_2 data and estimated occupancy.

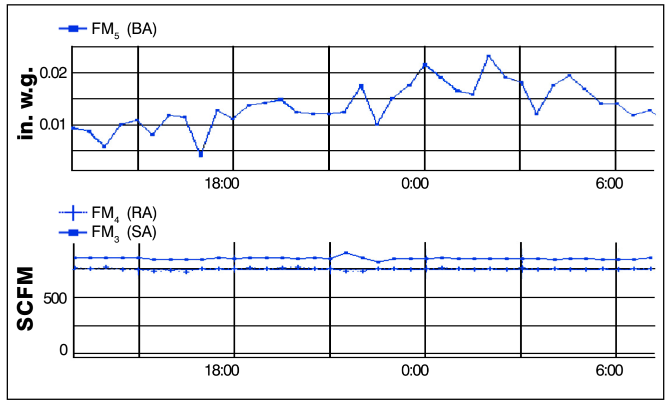

Figure 3: Measure of the space pressure.

Verification that the space pressures were maintained positive during testing is given in *Figure 3*. The upper curve is a plot of the space pressure, ranging from about 0.005 in. w.g. (1.25 Pa) to 0.02 in. w.g. (5 Pa). The lower curve shows the supply and return airflow rates of approximately 850 and 760 scfm (401 and 359 L/s), respectively.

CO_2-Based Estimates, Observed Occupancy

Walk-through occupancy counts have been made during several months and compared with the computed occupancy. The actual occupancy count agrees with estimated occupancy within two people. It also gives accurate counts when there is a rapid change in occupancy.

Dynamically Resetting the Ventilation Rate

By measuring the supply air CO_2 concentration and the supply airflow rate, real-time occupancy estimates are made. The estimated occupancy and the floor area can be used along with Table 6.1 of Addendum 62*n* to compute the space outdoor airflow at the breathing zone. The actual space OA airflow rate may be more or less than the summation using Table 6.1 due to the zone air distribution effectiveness factor (E_Z) presented in Table 6.2 of Addendum 62*n*. For cooling via ceiling diffusers, E_Z is 1.

By knowing the space outdoor airflow rate requirements, the space CO_2 setpoint easily can be computed using the following steps:

1. Compute the floor component ventilation air;
2. Compute the occupant component ventilation air;
3. Sum the components;
4. Divide the sum by the number of occupants to get an equivalent cfm/occupant, V_o; and
5. Compute the room CO_2 setpoint with the equation:

$$\text{room setpoint (ppm)} = 10500/V_o + C_{OA}$$

C_{OA} is the OA CO_2 concentration, assumed to be 300 ppm in the example.

Using the example classroom:

- The floor component is 125 cfm (59 L/s)

Estimated Occupancy	Room Setpoint Assuming 300 ppm OA	Space Concentration Above OA Level
25 Design Occupancy	1,000 ppm	700 ppm
20	940 ppm	640 ppm
15	870 ppm	570 ppm
10	770 ppm	470 ppm
5	600 ppm	300 ppm

Table 1: Space CO_2 setpoints for estimated occupancies.

- The occupant component (10 people) is 100 cfm (47 L/s)
- The sum is 225 cfm (106 L/s)
- V_o = 225/10 = 22.5 equivalent cfm (11 L/s) per person
- Room setpoint (ppm) =770

Table 1 gives room CO_2 setpoints for various other occupancy estimates. Note the setpoint is not constant, but decreases from 1,000 ppm for full occupancy to 600 ppm when only five people are present. The changing setpoint is brought about by the constant ventilation requirement of the floor component.

Conclusion

Dynamic OA intake reset with Addendum 62*n* should be accurately achieved where the design team chooses to measure occupancy based upon supply and return air CO_2 concentrations. The actual algorithms and stability issues associated with this approach obviously have not been addressed in this column. By choosing to use the occupancy estimates and a strict reading of Addendum 62*n*, contaminants from both the occupant- and non-occupant related sources can be accommodated. Dynamic reset is a valuable tool for VAV systems when it comes to saving heating and cooling energy. VAV systems fan energy reduction with Dynamic OA reset does not occur.

Reference

1. Ke, Y., S. Mumma. 1997. "Using carbon dioxide measurements to determine occupancy for ventilation controls." *ASHRAE Transactions* 103(2):365–374.

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