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Restroom Exhaust Systems

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Designing restroom exhaust and makeup air systems should be a trivial matter, but many designs are expensive and inefficient. This month's column outlines some tips to design a system that performs effectively yet has low first costs and energy costs.

Figure 1 is an example of a poor design of a restroom exhaust and makeup air system for a typical nonresidential men's restroom. The design is summarized as follows:

- The exhaust rate is based on 10 air changes per hour;
- Air is exhausted above each water closet and urinal bank; and
- Makeup air is sized at 90% of the exhaust rate and supplied by a constant volume reheat box connected to the building's cooling system.

A much less expensive and more energy-efficient design is shown in *Figure 2.* Its design characteristics are discussed below.

Exhaust Rate Sizing

In the example design in *Figure 1,* the exhaust rate was based on air changes per hour (ACH), a rate proportional to the volume of the restroom. Using ACH to size any ventilation system is fundamentally flawed:*

- It implies that the rate of air needed to dilute odors in the room is proportional to the volume of the room. In fact, the ventilation rate is proportional to the source strength of odors which has no relationship to the volume of the room. Would there be more odors to dilute if the entry vestibule were larger or if the ceiling were higher? Clearly not.
- It requires larger ventilation rates for rooms with larger volumes. Under steady-state conditions, the required ventilation rate is the same for two rooms with identical source strength regardless of volume. Under non-steady-state conditions, the ventilation rate is smaller, not larger, for rooms with larger volumes since pollutants have more volume in which to mix.

Furthermore, ACH is inconvenient from a design perspective since rates must change as the design progresses if the size of the room or ceiling heights change.

A more rational metric for determining ventilation rates in restrooms is airflow per plumbing fixture (e.g., urinal or water closet) as prescribed by ASHRAE Standard 62.1[1] and the model building codes that are based on Standard 62.1 requirements. Standard 62.1-2013 requires an exhaust rate of 70 cfm (35 L/s) per water closet/urinal where long periods of heavy use are expected to occur, e.g., restrooms in theatres, schools, and sports facilities, and 50 cfm (25 L/s) in other applications, such as office buildings. For simplicity, and to be conservative, the higher rate is often used for all applications.

In our example restroom, the exhaust rate at 70 cfm (35 L/s) per plumbing fixture would be 420 cfm (210 L/s) (*Figure 2*), down from 560 cfm (280 L/s) based on 10 ACH (*Figure 1*).

Number of Exhaust Grilles

The design in *Figure 1* includes four exhaust grilles, one over each water closet and one over the bank of urinals. It may seem to make sense to exhaust above each fixture since that is where odors are emitted, but it actually does not improve ventilation effectiveness because the ceiling grilles cannot capture the odors before they diffuse into the space.

Figure 3 shows a computational fluid dynamics simulation of a typical exhaust grille. Note the velocity vectors are only high near the grille; 2 ft or 3 ft (0.6 m or 0.9 m) away from the grille face, the velocity vectors are zero which means that odors produced closer to the floor level will not be captured by the grille.** Thus, there is no value to placing an exhaust grille over each toilet; using

*This is true of hospitals and laboratories as well, but ACH has been used for so long there is bureaucratic momentum to retain it. Airflow rates per unit area or some other metric that comes closer to scaling with the source strength of contaminants should be used.

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a single exhaust grille results in almost exactly the same airflow patterns down at the toilet level.

Note that it is the makeup air that provides the dilution of odors; the fact that air is also exhausted, as opposed to returned or simply exfiltrated to adjacent spaces, has no effect on odor concentration in the restroom. It simply prevents the odors from being recirculated to other spaces in the building.

Providing multiple exhaust grilles also leads to higher balancing costs, not just for the labor to balance the outlets, but also because of the added costs of balancing damper remote control devices required by the inaccessible drywall ceilings used in most restrooms. A trick to eliminate the need for damper remote controls is:

- Use a lay-in (tee-bar) style grille frame rather than a drywall (surface mounted) frame;
- Install the grille into a so-called "plaster frame" (*Figure 4*), which is a frame that is mounted in the drywall ceiling and accepts a lay-in style grille;
- Connect the grille to the duct main using a flexible duct and locate the balancing damper within a few feet of the grille (*Figure 2*); and
- The grille can be balanced by popping it up above the frame (made possible by the flexible duct), reaching in to adjust the damper, replacing the grille into the frame, then measuring airflow, and iterating if needed until the desired airflow is achieved.

FIGURE 1 Poor restroom exhaust and makeup system design.

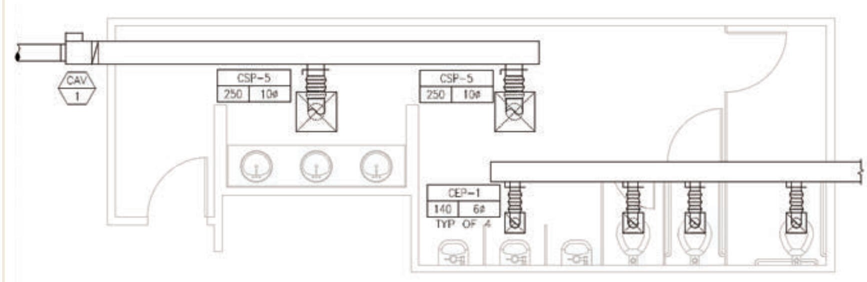


FIGURE 2 Better restroom exhaust and makeup system design.

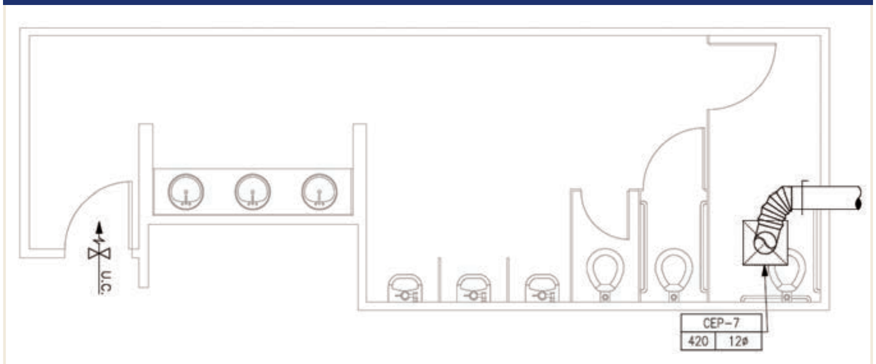
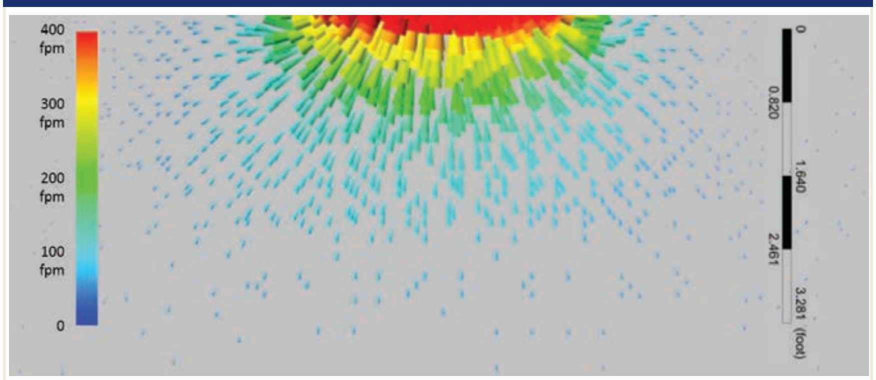


FIGURE 3 CFD analysis of exhaust grille; velocity vectors (courtesy of Price Industries).



Makeup Air

In *Figure 1*, makeup air is supplied by a constant volume reheat box. The exhaust rate is much higher than the cooling load in the space so a reheat coil is required to prevent the space from being overcooled. This is an expensive and inefficient design and, in fact, does not meet ASHRAE Standard 90.1[2] prescriptive limitations against excessive reheat. The building's hot water heating system would also have to operate even in warm weather to prevent overcooling.

Alternative means of providing makeup air that are both less expensive and more energy efficient include the following, listed from lowest to highest first cost:

1. Door undercut or door louver (*Figure 2*). This option is applicable only if the restroom door is not rated and will only perform well if restroom lighting loads are low.

** This behavior is described in the old expression, "You cannot suck out a match," or at least not without burning your lips.

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Noise transfer may also be a concern if the adjacent space is anything but a corridor or other non-noise-sensitive space.

All makeup air is from the adjacent space so the restroom will be warmer based on the exhaust rate and the lighting load (occupant loads are sufficiently transient, so they can generally be ignored). If only warmer by 1°F or 2°F (0.5°C to 1°C), temperatures are generally considered acceptable and are often preferred particularly at water closets. In the past, lighting loads in restrooms were high enough that this approach resulted in overly warm restroom temperatures. But energy codes have reduced lighting power to 1 W/ft^2 (0.1 W/m^2) (Standard 90.1) and 0.6 W/ft^2 (0.06 W/m^2) (California's Title 24 Energy Standards[3]). At 0.6 W/ft^2 and at the exhaust rate shown in *Figure 2,* the temperature rise is 1.6°F (1°C) above adjacent spaces, which is likely to be acceptable.

The undercut or door louver must be sized so that the differential pressure across the restroom door is not so high that it will cause whistling or keep the door ajar. A pressure differential of 0.08 in.w.g. (20 Pa) is generally acceptable. This equation can be used to determine approximate transfer-free area:

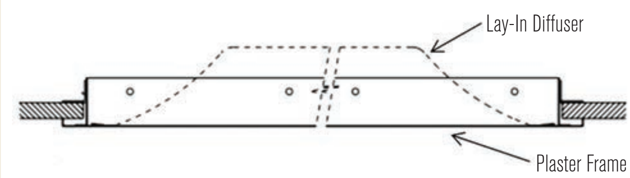
$$A = \frac{Q}{4005}\left(\frac{C}{DP}\right)^{0.5} \qquad (1)$$

where A is free area in ft^2, Q is the flow rate in cfm, DP is the pressure drop in in.w.g., and C is the loss coefficient which varies according to various sources from 1.6 to 2.7.[4] Assuming a loss coefficient of 2.5 and 0.08 in.w.g. (20 Pa) pressure drop, door undercut height is approximately:

$$H = \frac{0.2\,Q}{W} \qquad (2)$$

Where H is the height (inches) and W is the door width (inches). For the example shown in *Figure 2,* with a 36 in. (0.9 m) wide door, an undercut of about 2.5 in. (65 mm) is required. If more than 3 in. (75 mm) or so is required, a door louver can be used instead to improve appearance. Either must be coordinated with the architect to be sure they are included in door schedules on architectural drawings.

FIGURE 4 "Plaster frame" for lay-in grille used for access to balancing damper.



2. Ducted transfer to the ceiling return air plenum (*Figure 5b*). This option will result in even warmer restroom temperatures than the previous option if the return air plenum temperature is above space temperatures due to the heat from recessed light fixtures. However, the reduced lighting power and the increasing use of pendent light fixtures in many modern buildings results in little temperature rise, making this option viable.

Sizing the transfer grille is somewhat tricky because the return air plenum is also negatively pressurized. If it is too negative relative to the adjacent space (close to

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the 0.08 in.w.g. [20 Pa] maximum across the door), transfer from the return air plenum is not possible. If the plenum pressure is 0.05 in.w.g. (12 Pa), the pressure drop through the transfer grille and duct, including entry losses into the duct, must be less than 0.03 in.w.g. (7.5 Pa) to keep the total differential pressure below 0.08 in.w.g. (20 Pa). With perforated face grilles, this can be achieved with a duct velocity of less than about 325 fpm (1.65 m/s).

3. Ducted transfer to the adjacent space (*Figure 5a*). This option results in the same space temperature as Option 1. As with the undercut, the grilles and ducts must be sized for a total pressure drop of less than 0.08 in.w.g. (20 Pa). With perforated face grilles, this can be achieved with a duct velocity less than about 375 fpm (1.9 m/s).

4. Ducted transfer to ceiling return air plenum with integrated supply air (*Figure 6a*). When the space will be too uncomfortable without some cooling (or heating if the room is on the building perimeter), conditioned air must be supplied along with transfer air. This typically can be air from an adjacent VAV zone; there is little benefit to providing a separate zone for the restroom since most of the air supplied to the room is neutral transfer air which buffers any temperature excursions. The supply air rate should be sized just for the cooling or heating load, 40 cfm (20 L/s) in this example, with the remainder of the makeup air supplied through the transfer opening. If the adjacent zone is VAV, the makeup air must be sized for the airflow required when the VAV zone airflow is at its minimum.

The design shown in *Figure 6a* is a bit unusual and often generates a clarification request from mechanical contractors: the conditioned supply air from the adjacent zone is ducted into a standard wye fitting with one end open at the return air plenum. The negative pressure in the restroom ensures that the supply air will not go backwards into the plenum.

FIGURE 5 Other transfer air options.

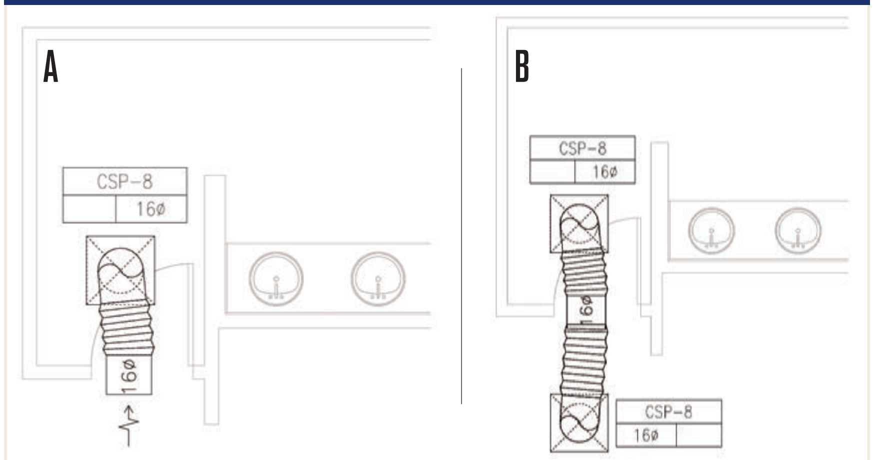
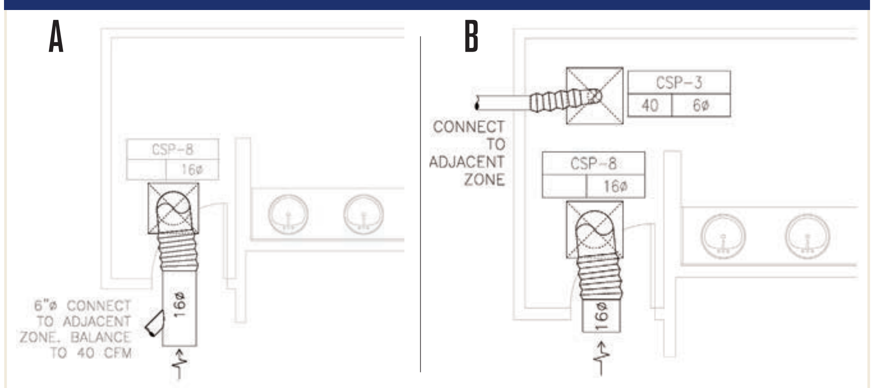


FIGURE 6 Transfer air plus cooling supply options.



5. Ducted transfer to ceiling return air plenum with separate supply air (*Figure 6b*). If the design in *Figure 6a* is felt to be too confusing, conditioned air may be supplied by a separate diffuser. This option is more expensive than Option 4 but easier to understand and to balance.

Conclusions

Traditional restroom exhaust and makeup air systems can be both expensive and energy inefficient. The tips in this month's column show how to reduce first costs and minimize energy use.

References

1. ASHRAE Standard 62.1-2013, *Ventilation for Acceptable Indoor Air Quality.*
2. ASHRAE Standard 90.1-2013, *Energy Standard for Buildings Except Low-Rise Residential Buildings.*
3. 2013 Building Energy Efficiency Standards for Residential and Nonresidential Buildings, Title 24, Part 6 CEC-400-2012-004-CMF.
4. "Discussion of the Use of Transfer Grilles to Facilitate Return Air Flow in Central Return Systems." http://tinyurl.com/o4sghcf; and "Discussion of the Use of Transfer Grilles to Facilitate Return Air Flow in Central Return Systems." http://tinyurl.com/ovabs66 are two examples. ■