Comparing Economizer Relief Systems

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Member ASHRAE

An outdoor air economizer is a damper arrangement and automatic control system that allows a cooling air handler to supply outdoor air instead of recirculated air to reduce or eliminate the need for mechanical cooling during mild or cold weather. One of the key elements of an economizer is a system to relieve the excess outdoor air supplied to the building when the economizer is enabled. Without an adequate relief system, the building can become over-pressurized, causing exterior doors to stand open (a potential security issue) and air to whistle through exterior doors and elevator doors. For very tight buildings, the pressure buildup can reduce supply air rates. Maximum building pressure to avoid these problems is typically about 0.05 in. w.g. to 0.10 in. w.g. (12 Pa to 25 Pa).

There are three common types of relief systems:

1. Relief dampers (*Figure 1A*).
2. Relief fans (*Figure 1B*).
3. Return fans (*Figure 1C*).

This article discusses application considerations and advantages and disadvantages of each of these systems.

Relief Dampers

The relief damper system (*Figure 1A*) consists of either a barometric damper (also called a gravity damper or backdraft damper) or a motorized damper. Air is pushed through the dampers by building pressure. A counterbalance is sometimes provided with barometric dampers to allow for adjustment of building pressure, or it may be required if the damper blades are so heavy that too much pressure is required to open them. The damper also may be motorized and powered open whenever the economizer is enabled. The relief air pressure drop from conditioned spaces to and through the relief damper and louver to the outdoors, including the pressure required to push open barometric dampers, must be less than the maximum desired building pressure.

Advantages of relief dampers compared to the other options include:

• Lowest first costs. No fan or controls are required.

• Least amount of space required.

• Flexible configuration. The dampers may be located anywhere in the return air system from the conditioned space to the economizer recirculating damper.

• Lowest energy costs. The only energy penalty is a slight increase in supply fan energy due to the pressure buildup required to open the relief damper.

• Simple, reliable operation. No controls are required, so there are none to fail. Unlike the other two options, relief dampers can never cause a negative pressure to occur in the building even if it fails. Negative pressure causes infiltration, which can increase energy usage and cause comfort problems.

• Quiet operation. Little or no noise is produced since there is no fan. In some cases, barometric dampers can "chatter" when building pressure fluctuates due to opening and closing exterior doors, but this is usually resolved by using soft material such as neoprene for weather seals on damper blades and/or locating the dampers far from occupied spaces where noise is of no concern.

While relief dampers clearly have many advantages, they also have many application limitations:

• Usually limited to small systems. The relief damper is often located near the supply fan and economizer mixing plenum, as shown in *Figure 1A*. If so, the low air

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pressure drop required from the space through the damper to prevent building over-pressurization limits the application to small systems with very low pressure drop return air paths (less than about 0.10 in. w.g [25 Pa]), such as systems that use the ceiling attic as a return air plenum. This limitation can be avoided by simply locating the relief damper closer to the space (e.g., behind a louver over the exit doors), but architectural considerations often limit this option.

• Increased damper leakage. Barometric dampers inherently cannot provide a tight shut-off. Outdoor air can leak through the damper when the economizer is off in warm weather, particularly when the damper is located in the return air system near the supply fan, which will be under negative pressure when the economizer is off.

Leakage also will occur when the HVAC system is off during unoccupied periods due to wind and stack-effect. This has no direct energy impact since the HVAC system is off, but it accelerates the cooling down or warming up of conditioned spaces, which increases the energy required to bring the building back to comfort temperatures. Using a motorized damper in lieu of or in addition to the barometric damper can reduce leakage, but at a small increase in first costs and complexity. (Note that ASHRAE/IESNA Standard 90.1-1999[1] requires motorized dampers in buildings three stories or more in height and for buildings of any height located in cold climates.)

• Limited packaged unit options. Barometric relief is a common option on small packaged air-conditioning units, but the system is often so poorly designed that it does not work well. For instance, on many units the damper is too small or has too high a pressure drop. On others, the relief damper is located in the same hood as the outdoor air intake! This unbelievably poor design obviously results in short circuiting of relief air into the intake, reducing economizer energy savings. When packaged unit relief damper options are inadequate, a separate relief system must be used, such as a roof-mounted relief hood with barometric or motorized dampers.

Using a separate relief system has the advantages of allowing the relief damper and outlet to be properly sized and located well away from the outdoor air intake, but it is not as convenient as having the relief system supplied in the factory package and it adds to first costs.

• Wind problems. Relief dampers are more susceptible to wind effects than fan powered relief systems. Wind pressure can easily prevent dampers from opening. This can be mitigated by protecting the dampers from wind, such as locating them horizontally in roof-mounted hoods.

• Larger louver size. Relief louvers and dampers usually need to be larger than those used with fan-powered relief systems to minimize pressure drop.

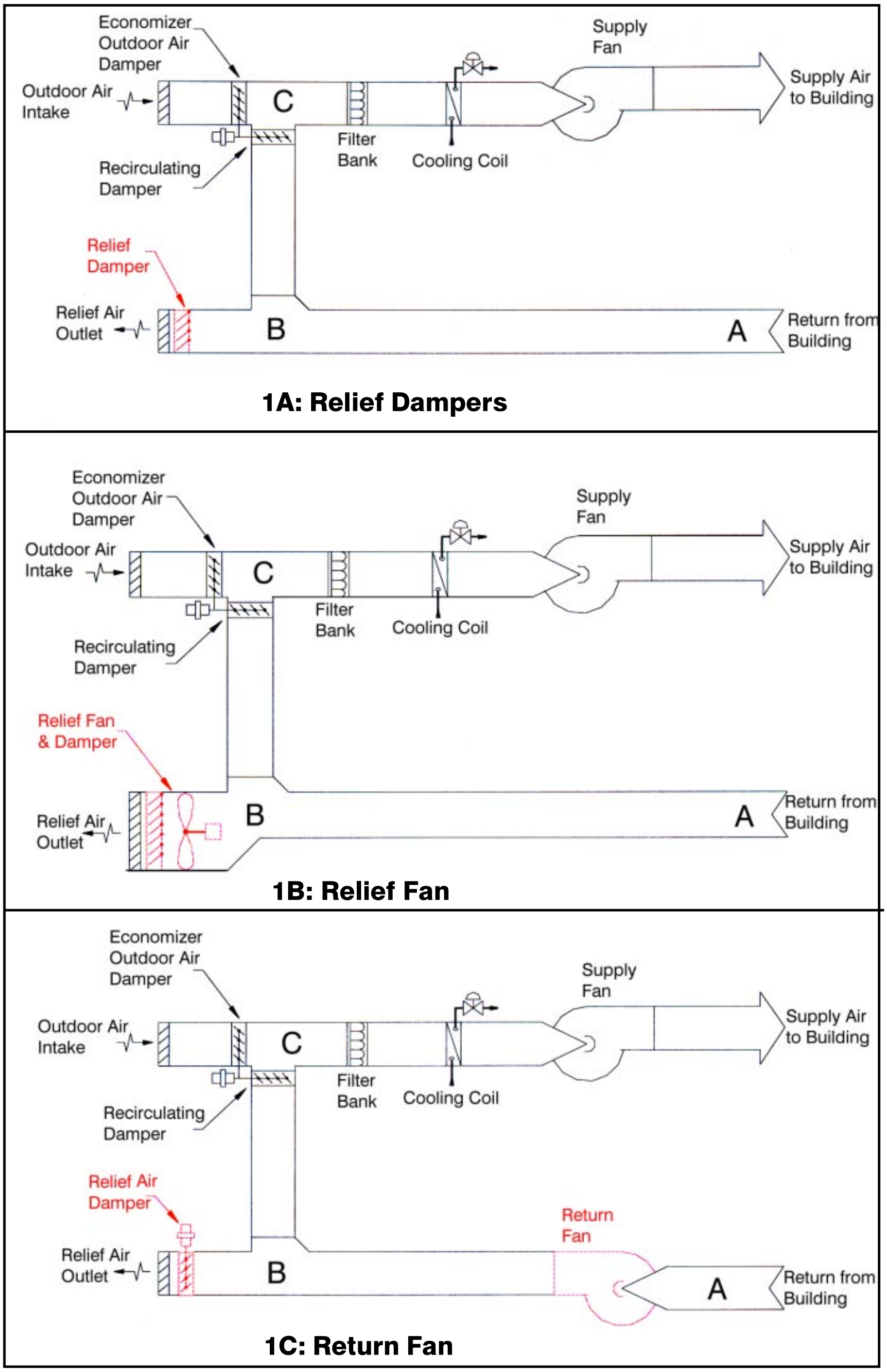

Figure 1: Three common types of relief systems

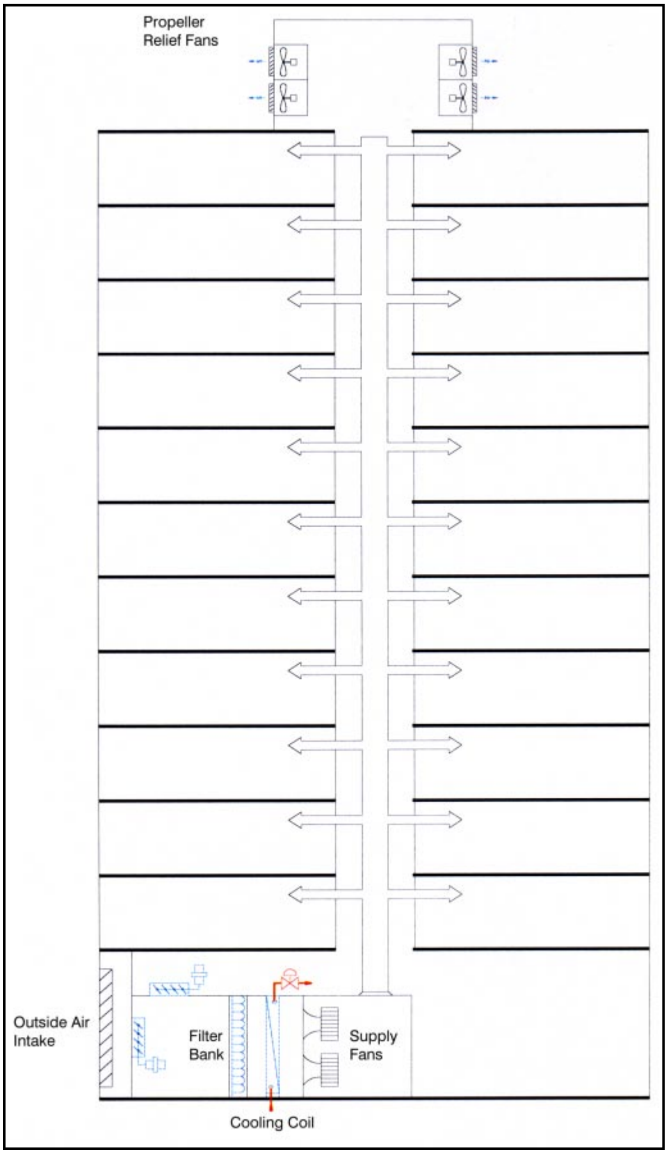

Figure 2: Split supply and relief fans.

Relief Fans

Relief fans, also called powered-relief or powered-exhaust, are located in the system as shown in *Figure 1B*. The fans typically operate only when the economizer is enabled and are shut off when the system reverts to the minimum outdoor air mode during warm weather or very cold weather. Because outdoor air intake rates vary from 100% air during mild weather down to near minimum outdoor air rates when the weather is very cold, relief fans must have some type of capacity control to maintain building pressure within an acceptable range. Common capacity control systems include variable-speed drives, discharge dampers, inlet guide vanes, multi-speed motors, or multiple fans that can be staged. Fan capacity is typically controlled directly from building pressure measurement.

Advantages of relief fans compared to return fans include:

• Greater layout flexibility. Relief fans may be located any-

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where in the return air path from the space to just upstream of the recirculating damper at the economizer mixing plenum. Return fans, on the other hand, must be located near the supply fan and upstream of the mixing plenum (*Figure 1C*). Relief fan location flexibility is particularly advantageous for large built-up systems.

Figure 2 shows a schematic of an HVAC system serving a high-rise building. As is common in modern high-rises, the floor area available for mechanical equipment at the top of the building often is limited by architectural elements (e.g., stepped back floors, sloped roof). Relief fans allow the built-up air system to be split with supply fans located near the bottom of the tower and relief fans located at the top. Space required for the mechanical system on the lower floors in this example is reduced. This design also takes advantage of stack effect—relief air naturally will exit the building from the top during cool weather so the relief fans do not have to overcome as much pressure.

• Lower energy costs. Energy costs for both relief fan and return fan systems will depend significantly on the style of fans selected and how they are controlled, but all else being equal, relief fans will have lower annual fan energy costs than return fan systems. See the sidebar for a detailed example supporting this statement.

• Less complicated controls for VAV applications. As discussed in the following section, control of return fans in variable air volume (VAV) systems can be complex. Control of relief fans from building pressure is straightforward, although not without potential problems (see additional discussion under application limitations later).

• Lower first costs. The reduced cost of controls and the layout flexibility of the relief fan system usually will result in somewhat lower costs relative to return fan systems for systems with low static pressure return air systems. (As noted in the next section, for systems with high return air pressure drop, the opposite may be true.) In practice, the savings can be even greater due simply to common design practices in the area in which our firm practices. Relief fans in low pressure drop return air applications (such as ceiling plenum returns) are commonly inexpensive propeller fans, whereas return fans for the same application are typically more expensive centrifugal fans or vane-axial fans.

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Application limitations and considerations for relief fan systems include:

• Control instability with high pressure drop return air systems. *Figure 4* shows a VAV system with relief fan operating in the 100% outdoor air mode. In this example, the return air pressure drop is high, typical of ducted return air systems, resulting in a negative pressure of 1.25 in. w.g. (311 Pa) in Plenum B. The pressure in the mixed air plenum (Plenum C) is only 0.25 in. w.g. (62 Pa) negative relative to the outdoors since the economizer outdoor air dampers are wide open.

Now assume that the outdoor air temperature falls below the supply air temperature setpoint so that the economizer controller requires some return air to temper the cold outdoor air. The recirculating damper will then open, but because of the very low pressure at Point B, instead of return air flowing into the mixed air plenum (Point B to Point C), outdoor air from the mixed air plenum will flow backwards through the damper (Point C to Point B). This causes the relief fan to exhaust outdoor air rather than building air so building pressure will rise. This, in turn, causes the capacity control device on the relief fan to exhaust even more air. In short order, the relief fan will be operating at full volume and building pressure will continue to rise, perhaps to very high levels. Fortunately, the problem is temporary: because the relief fan is keeping return air from warming the outdoor air being drawn into the mixed air plenum, the economizer controller will not be satisfied and thus, will continue to open the recirculating damper and close the outdoor air damper. Eventually this action will cause the mixed air plenum pressure to become more negative than Plenum B, causing return air to flow in the correct direction. Once that occurs the relief fan operation and building pressure return to normal.

• Negative building pressures at low outdoor air rates. Relief fans must be able to operate down to very low rates when little more than minimum outdoor air is being introduced into the building. Most fan capacity control devices will have a minimum turndown ratio. For instance, fans using inlet guide vanes for capacity control have limited turndown due to leakage through the inlet vanes, and the minimum speed on variable speed driven fans is often limited to ensure motors are properly cooled. Fans operating at their minimum exhaust rate when outdoor air rates are low can draw the building negative.

• Fluctuating building pressure controls. While controlling relief fans from building pressure may seem straightforward, there are some problems that can arise. Pressure is measured using a differential pressure (DP) sensor with a low range, such as 0 in. w.g. to 0.25 in. w.g. (0 Pa to 62 Pa).

A common mistake is locating the indoor (high pressure) port of the DP sensor in the main entry lobby. This may seem like the best location since that is where high pressures can cause problems such as pushing open exterior doors. However, it is actually a very poor location because the pressure in the lobby fluctuates considerably as doors are opened and closed due to piston effect from elevators. This, in turn, causes relief fan capacity control to become unstable. A better location is a space where pressure is fairly constant, such as an interior space far from exterior doors, elevators, and diffusers. Similarly, the out-

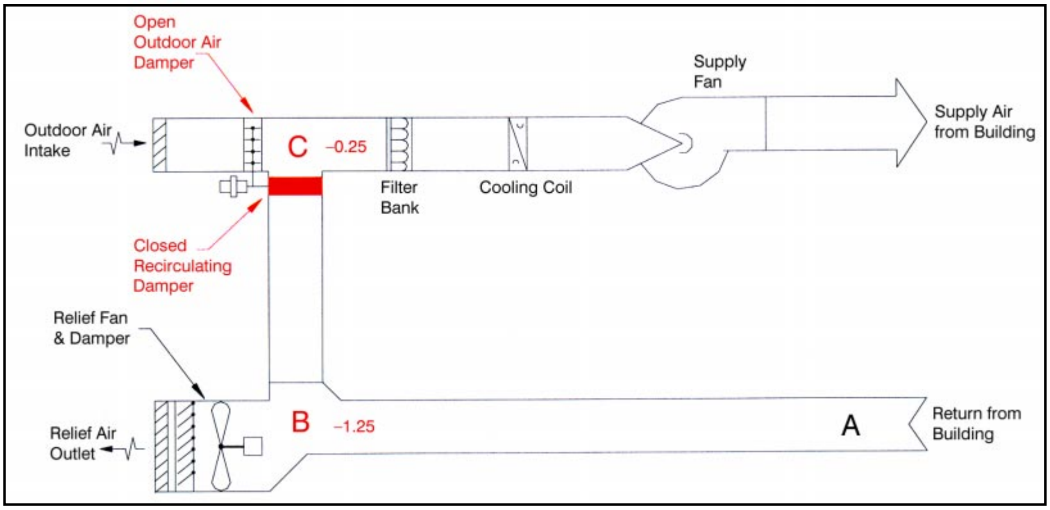

Figure 4: Relief fan system with high return air pressure drop.

door air pressure connection to the DP sensor must be located to avoid direct exposure to wind, which will also cause signal fluctuations. Some DP manufactures make wind shield housings to mitigate this problem.

Return Fans

A system with a return fan (often called a return/relief or return/exhaust fan) is shown in *Figure 1C*. The return fan is in series with the supply fan.

Advantages of return fans compared to relief fans are:

• Smaller supply fan and motor. Typically, power requirements for return fans and relief fans are about the same, but the supply fan on the return fan system will require less power

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because it does not need to overcome the return air path pressure drop. Lower fan power usually results in a smaller supply fan motor, which will reduce the size of the variable-speed drive for systems using these devices for fan control. For systems with low return air pressure drops, the supply fan power reduction using return fans may be insignificant, but for systems with high return air pressure drops, the reduction can be one motor size or more. In this case, the supply fan may also be one size smaller. Together, these size reductions can reduce the cost of the return fan system to below that of the relief fan system.

• Preferred for constant volume systems. For VAV systems, control of return fans is typically more expensive and more complicated than control of relief fans (see discussion later). But for constant volume systems, the opposite is true. For these systems, return fans require no control since the sum of the return airflow rate and relief airflow rate is constant. The relief fan, on the other hand, would require the same modulating capacity and building pressure controls required for VAV systems since outdoor air intake rates will vary depending on the load and outdoor air temperature.

Very few application limitations exist for return fans. They may be used with virtually any size or type of system and for virtually any HVAC application. Return fans have none of the application limitations mentioned earlier for relief dampers and relief fans. They are, however, prone to control problems due to some flawed but commonly used control schemes:

• Signal tracking. The simplest method to control the return fan is to send it the same capacity control signal that is sent to the supply fan. Because of differing supply and return fan and system curves, this indirect control usually results in widely varying building pressures. It can be acceptable nevertheless if the range of acceptable building pressure is broad (e.g., 0 in.w.g. to 0.15 in. w.g. [0 Pa to 37 Pa]).

• Fan volume tracking. With this control scheme, return fan capacity is controlled to maintain the return airflow rate at a preset differential below the supply airflow rate. If the supply-return differential is correctly set, this control is an effective, although indirect, way of controlling building pressure. However, it can have other problems. As shown in a several articles[2,3] and a recently completed research project,[4] fan tracking is not an effective means to control minimum outdoor air rates in VAV systems. Depending on how the outdoor, recirculating, and relief air dampers are sequenced, this control scheme can also result in outdoor air being drawn in backwards through the relief damper.[5]

Probably the most reliable control design is to control the return fan to maintain a positive static pressure in the exhaust plenum (Plenum B) and to modulate the relief air dampers to maintain building static pressure, in much the same way that relief fans are controlled as described above. This design is simple and relatively inexpensive, and accordingly is the approach recommended in draft ASHRAE Guideline 16P.[6]

Summary

Because of their many advantages, relief dampers should be

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Relief Fans vs. Return Fans

Fan energy for relief fans and return fans will be similar when the systems are in the economizer mode. But relief fans will use less energy than return fans when the systems are in the minimum outdoor air mode during either warm/hot weather or very cold weather. With the relief fan system in this mode, the relief fan is off and the supply fan handles the entire return air pressure drop. With the return fan system, both supply and return fans continue to run. There are two primary reasons why the latter system uses more energy:

• First, the overall pressure drop is higher, as shown in *Figures 3A* and *3B*. The pressures shown in the figures are typical of a VAV system with a low pressure drop ceiling plenum return air system. The return fan must maintain a positive pressure relative to the outdoors in the exhaust air plenum (Plenum B in *Figure 3B*) in order for air to be exhausted and to prevent outdoor air from being inadvertently drawn into the exhaust air dampers when in economizer mode.

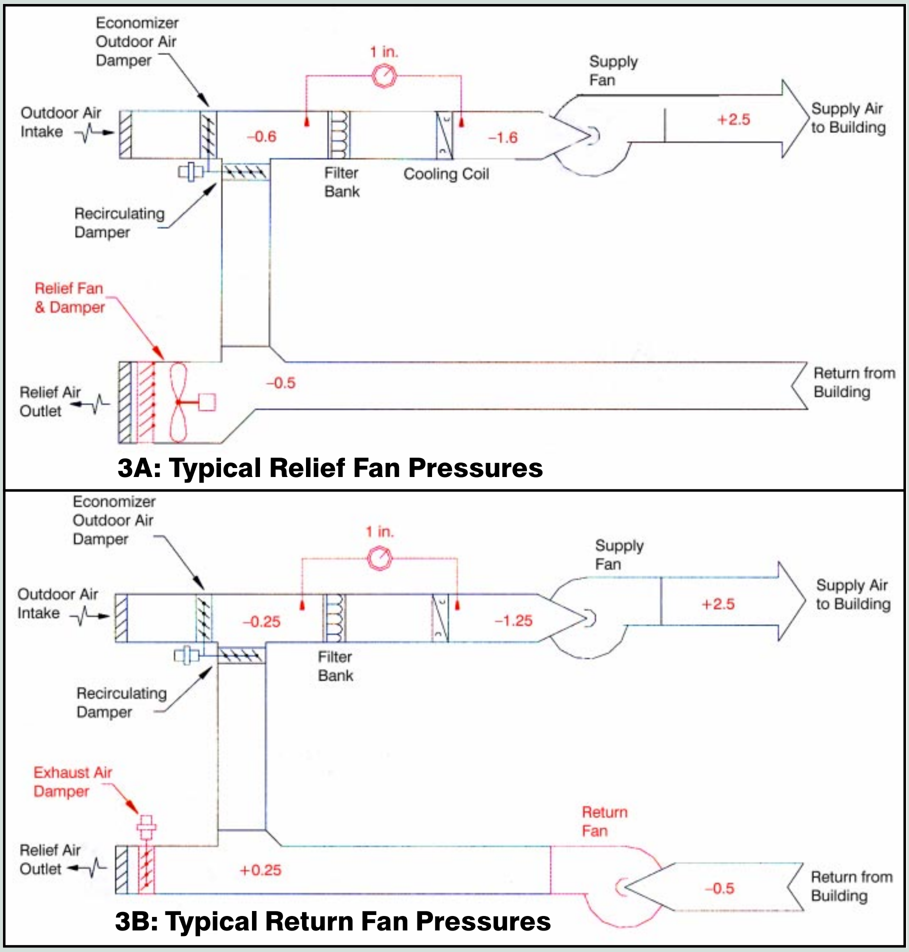

Figure 3: Relief fan vs. return fan.

On the other hand, the mixed air plenum (Plenum C in *Figure 3B*) must be negative relative to the outdoors in order to draw in outdoor air. The recirculating damper then must be sized (or controlled) to throttle the pressure difference between these two plenums. With relief fans (*Figure 3A*), the pressure in Plenum B is negative and the recirculating damper may be selected for low-pressure drop. In the example in *Figure 3,* the total pressure drop that the return fan must overcome is 0.5 in. w.g. plus 0.25 in. w.g. (125 Pa plus 62 Pa) for a total of 0.75 in. w.g. (186 Pa). The supply fan must overcome 2.5 in. w.g. (625 Pa) + 1 in. w.g. (250 Pa) (coil, filter) + 0.25 in. w.g. (62 Pa) (intake dampers) = 3.75 in. w.g. (937 Pa) This example assumes 0.25 in. w.g. (62 Pa) is required at the outdoor air intake plenum to draw in minimum outdoor air and 0.25 in. w.g. (62 Pa) is required to exhaust air through the exhaust air damper and louver. Overall, the pressure drop of the supply and return fans is 4.5 in. w.g. (1125 Pa)

With the relief fan system, the total pressure handled by the supply fan is 2.5 in. w.g. (625 Pa) + 1 in. w.g. (250 Pa) (coil, filter) + 0.5 in. w.g. (125 Pa) (return air system) + 0.1 in. w.g. (25 Pa) (recirculating damper) = 4.1 in. w.g. (1025 Pa) assuming the recirculating damper is selected for a pressure drop of 0.1 in. w.g. (25 Pa). This is a reduction of 0.4 in. w.g. (100 Pa) of pressure. Savings could be more or less depending on how dampers are selected, how minimum outdoor air is controlled, and how the return fans are controlled, but in almost all applications, the pressure drop should be less for relief fans.

• The second reason relief fans use less energy is that the supply fan in this design can typically handle the added pressure drop of the return system more efficiently than the return fan. The supply fan is almost always more efficient than the return fan because it operates against a higher-pressure difference. Operating against a low-pressure drop, the return fan's efficiency can be low, particularly if a centrifugal fan is used.

the system of choice for small HVAC systems and for single-story buildings. They can be made to work well with almost any building and HVAC system when the relief dampers can be located near the conditioned space, such as behind wall louvers. However, wind problems and leakage due to stack effect typically eliminate this option on high-rise buildings.

The many advantages of relief fans compared to return fans make relief fans the system of choice for applications where relief dampers cannot be used and where return air pressure drop is relatively low, typical of systems with return air ceiling plenums.

Return fans are the system of choice for applications with high return air pressure drops, such as ducted return systems. They are also a better choice than relief fans for constant volume systems since they require no controls.

References

1. ASHRAE/IESNA Standard 90.1-1999, *Energy Standard for Buildings Except Low-Rise Residential Buildings.*

2. Kettler, J. 1995. "Minimum ventilation control for VAV systems: fan tracking vs. workable solutions." *ASHRAE Transactions* (101)2: 625–30.

3. Kettler, J. 2000. "Measuring and controlling outdoor airflow," *ASHRAE IAQ Applications*, Winter 2000.

4. Krarti, M. 1999. "Techniques for measuring and controlling outside air intake rates in variable air volume systems." *ASHRAE RP-980 Final Report*.

5. Seem, J., et al. 2000. "A damper control system for preventing reverse airflow through exhaust air dampers of variable air volume air-handling units." *International Journal of HVAC&R Research* 6(2):135–48.

6. ASHRAE Guideline 16P, *Selecting Outdoor, Return, and Relief Dampers for Variable Air Volume Systems.* First Public Review Draft, September 1999.

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