ASHRAE
TRANSACTIONS

TECHNICAL AND SYMPOSIUM PAPERS
PRESENTED AT THE
1991 WINTER MEETING
IN NEW YORK, NEW YORK
OF THE
AMERICAN SOCIETY OF HEATING, REFRIGERATING
AND AIR-CONDITIONING ENGINEERS, INC.

1991

VOLUME 97, PART 1

NY-91-14-2

6103

COPING WITH AIR PRESSURE PROBLEMS IN TALL BUILDINGS

R.T. Tamblyn, P.Eng.
Fellow ASHRAE

ABSTRACT

All buildings exhibit stack effect in cold weather. This is a phenomenon caused by the difference in weight of warm air columns within the building and cold air columns outside. In tall buildings, stack effect causes unique problems such as elevator door sticking and washroom exhaust imbalance. This article explains the cause and outlines HVAC solutions.

Did you ever wonder why the elevator doors are sticky on cold days? They are sticky because the differential pressure across the door is causing the door guide to bind in the guideway. In turn, this pressure is caused by stack effect. HVAC designers can overcome the problem, but first they must understand stack effect and how to counteract it.

Stack effect relates to the pressure difference caused by the differential weight of two columns of air. One, the height of the building, is made up of air at room temperature, while the other is a heavier column of equal height made up of cold air at outside temperature. Figure 1 illustrates the total difference in pressure over the whole building height for various temperature differences. These data are calculated from the formula in ASHRAE (1985). If the building was hermetically sealed and open only at the bottom, the pressures would be equalized at the entrance doors with the full ΔP existing at the top (see Figure 2a). Other references that are useful in understanding stack effect are Tamura and Wilson (1967a, b). Conversely, if the bottom of the building was sealed and a penthouse door was opened, as in Figure 2b, the ΔP would be expressed fully at the base of the building.

In real life, building enclosures are not impervious to air passage. Instead, they are subject to various rates of leakage depending on the type and quality of construction. The ΔP caused by stack effect will now divide itself between the top and bottom of the building, as shown in Figure 2c. Air that exfiltrates from the top will be replaced by an equal amount infiltrating the bottom. The point of zero ΔP is called the neutral pressure level. Its location tends to be at mid-height, but it may be higher or lower depending on whether the building has more looseness at the top or bottom. The neutral pressure level is also influenced by the net positive or net negative supply of ventilation and exhaust air. Positive pressurization will move the building air profile to the right and lower the neutral pressure level. A surplus of exhaust over outside air make-up will lower the building pressure profile and cause the neutral pressure level to rise. Finding the neutral pressure level in a building can be accomplished by blowing smoke against the elevator doors. If the smoke lingers, it will be at the floor with the neutral pressure level. On other floors, the smoke will be drawn into the elevator shaft or blown back. Finding the floor at the neutral pressure level can help to direct air-tightening investigations to the top or bottom of the building.

If the walls are tight, the building profile will be as shown in Figure 3a. If they are loose, the profile will move closer to the outside profile, as in Figure 3b. The elevator shaft will tend to remain as a true inside profile, so the ΔP across the elevator doors will be the difference between the true profile and the building profile. The elevators in Figure 3b will tend to have stickier doors than the ones in Figure 3a.

It may not be practical to improve the building tightness in order to satisfy elevator door performance. Thus, the HVAC designer will inherit the problem of finding a way to force the building profile closer to the profile in the elevator shaft. That can be accomplished with central air-handling systems by using a ΔP sensor to damper the return air volume selectively on each floor. The sensor would be set to a value stipulated by the elevator supplier.

Figure 4 illustrates the modifications to the building profile caused by the action of the return air dampers. It is apparent that a higher air pressure must be created on the

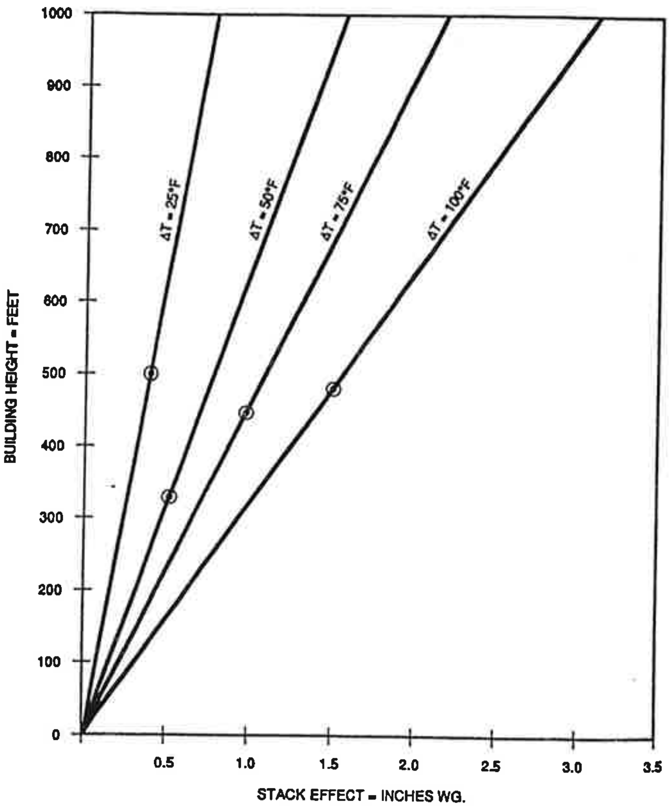

Figure 1 *Stack effect graph*

Robert T. Tamblyn is Chairman of Engineering Interface Ltd., North York, Ontario, Canada.

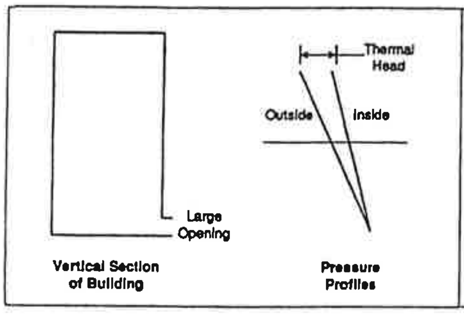

Figure 2a

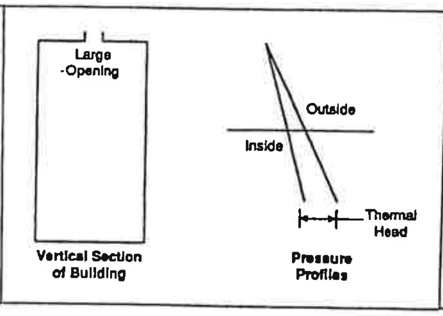

Figure 2b

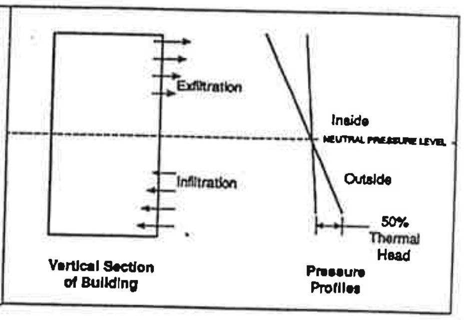

Figure 2c

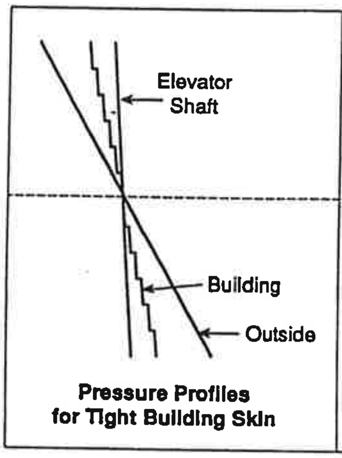

Figure 3a

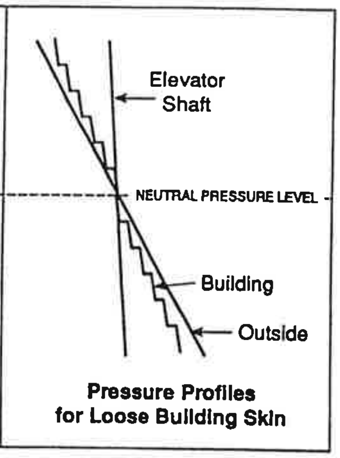

Figure 3b

top floors by restricting return air. On the lower floors, return air volume must exceed supply air in order to reduce air pressure. The excess return air should result from the flow restrictions on the upper floors, but the return air shafting and take-offs to the lower floors should be oversized to allow for increased flow on cold days.

The necessary decrease of return airflow at the top of the building and the increase at the bottom will appear exactly opposite from past practice to the HVAC designer. Previously, the designer may have thought to decrease return air on lower floors to lower the infiltration rate and increase return air on upper floors to lower exfiltration. While this would have had the desired effect of decreasing the heating load, it would have increased the pressure difference across the elevator doors and endangered their smooth operation. The best design, therefore, is one that limits the pressure differential across the elevator doors and depends upon good enclosure construction to resist any resulting increase of ΔP at the walls.

For compartmentalized systems, where there is no central air recirculation, the air pressure on the individual floors can be modified by selective dampering of the ventilation supply to each fan room. This would involve excess ventilation of upper floors and restriction of ventilation to lower floors. Although this would appear to violate ventilation codes, the flushing rate for airborne contaminants on lower floors will be made up, in part, by infiltration.

While it may be possible to use airflow restriction as a concept for maintaining every floor at the same pressure as the elevator shaft, this would be counterproductive. The greater the ΔP, the greater the infiltration, along with energy consequences. There is also the problem of moisture penetration through the building enclosure on upper floors of humidified buildings in cold weather. For this reason, the ΔP sensors should be set to permit as wide a pressure variation as the elevator door hardware will allow.

It is interesting to note the problems in high-rise residential buildings on cold days. While residents of upper floors can almost turn off their heat, the radiators on lower floors must operate in "double time." As long as residents demand openable windows and use them, the infiltration problem will be increased.

Another problem is the performance of central sanitary exhaust. Figures 5a and b show the air balance of a washroom exhaust duct made at a time when outside and inside temperatures were not far apart. On a cold day, the

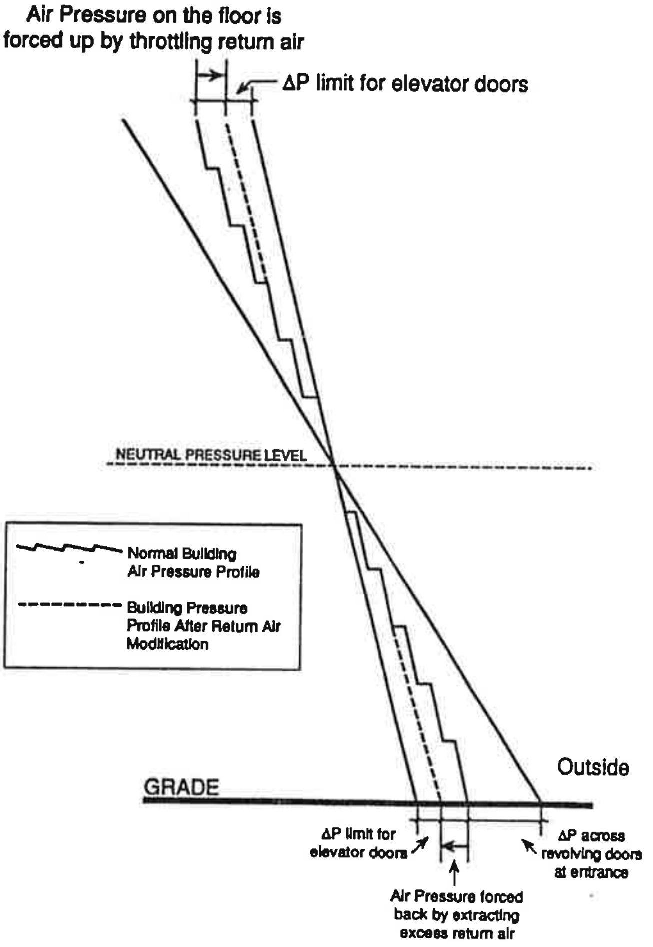

Figure 4 *Controlling return air to limit ΔP on elevator doors*

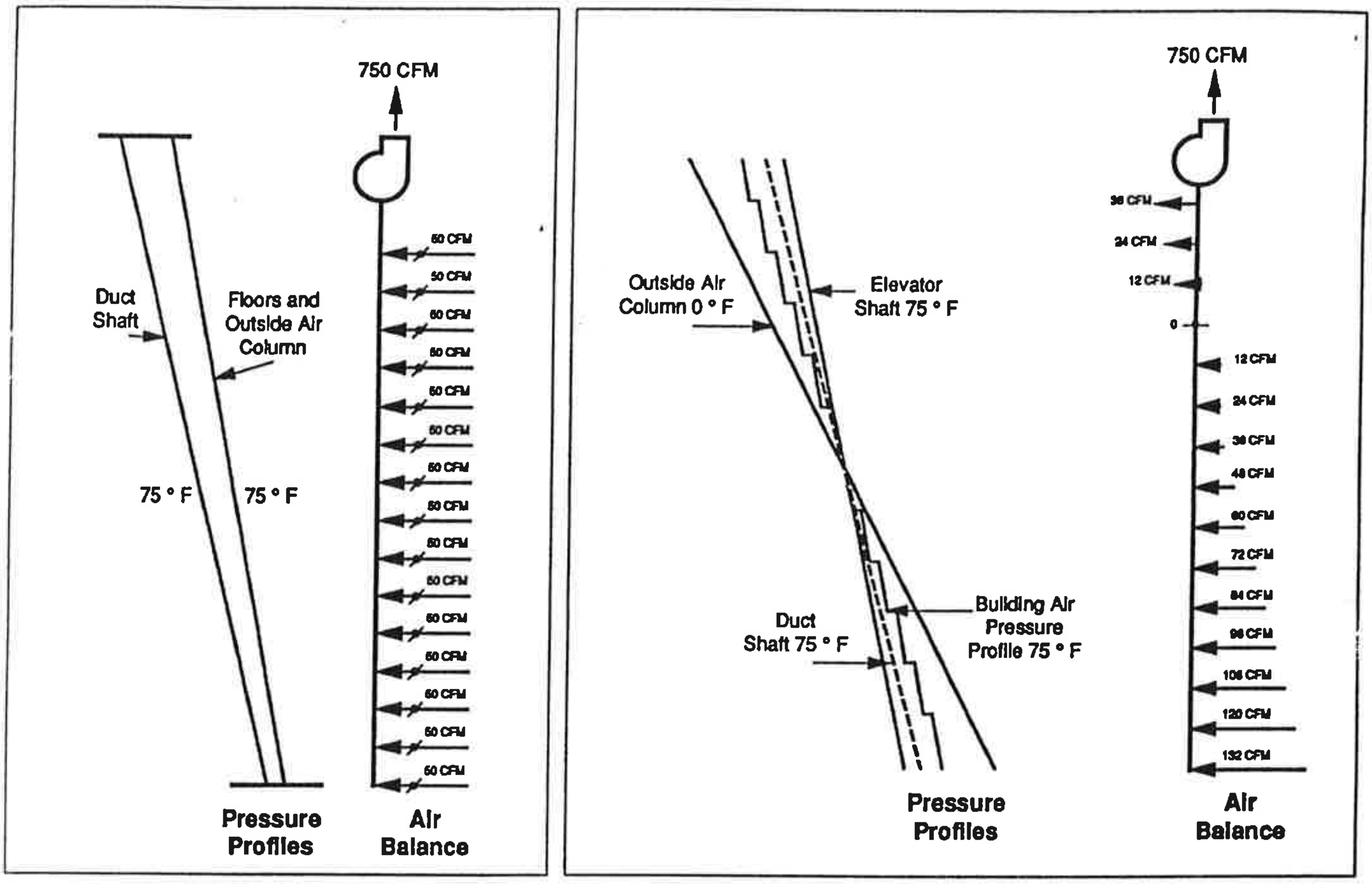

Figure 5a Summer

Figure 5b Winter

Figure 5 *Change in air balance for a washroom exhaust shaft*

fan may exhaust the same volume of air, but the grilles at the base of the riser may handle double the summer volume, while grilles at the top are discharging contaminated air into the suites themselves. At the same time, the central ventilation supply to the corridors will be unbalanced, supplying additional air to upper floors and, possibly, drawing air into the base of the riser on the entrance floor.

Airflow controllers may be required on tall buildings to resist the winter imbalance caused by stack effect. When these are placed in the duct connections that are trying to pass excess air, they will throttle the flow, causing the fan outlet pressure to rise. If the fan has a steep "pressure-to-volume" curve, the increased pressure will help to overcome the tendency of some outlets to reverse their direction of flow.

Pressure profiles can be related to HVAC design with the following example.

Problem:

A 40-story building is 500 ft high. The typical floor has a perimeter of 520 ft and a wall area of 6,000 ft^2. The walls are fairly loose, with an average leakage value of 0.5 cfm/ft^2 at a reference pressure of 0.3 in. WG. Four elevators are arranged to open on each floor. The elevator door crack area is 0.8 ft^2 each.

On a 0°F day, when the building air is at 75°F, what will the air pressure be on the second floor (the entrance floor is a special case), and how much additional return air will be required to draw the air pressure back to the elevator door limit of $\Delta P = 0.1$ in. WG?

Solution:

An equivalent area of opening in the outside wall can be gained from the equation

$$A_{cw} = \frac{\text{cfm}}{2{,}400 \times (\Delta P)^{1/2}} \tag{1}$$

where

A_{cw} = equivalent opening area of the outside wall, ft^2
cfm = total wall leakage
ΔP = reference pressure, 0.3 in. WG.

Thus,

$$A_{cw} = \frac{0.5 \times 6{,}000}{2{,}400 \times (0.3)^{1/2}} \text{ or } 2.28 \text{ ft}^2 .$$

The equivalent opening area for elevators is 4 × 0.8 = 3.2 ft^2. There are other openings between floors that will influence the result, but the elevator openings are the principal ones.

Total distance from a mid-height neutral pressure level to the second floor = 500/2 or approximately 250 ft.

From Figure 1, thermal head at 75°F ΔT and 250 ft = 0.6 in. WG. ΔP across elevators = thermal head $\times$ $1/1 + [A_s/A_{cw}]^2$

where

A_s = equivalent opening in elevator shaft in ft^2

$$\Delta P = 0.6 \times \frac{1}{1 + \frac{3.2^2}{2.28}} = 0.2 \text{ in. WG} .$$

This is high enough to cause elevator door problems.

To lower the building pressure so the ΔP on the elevator doors is reduced to 0.1 in. WG, there must be a volume increase of return air to the floor sufficient to cause a (0.2 - 0.1) or 0.1 in. WG pressure shift. Since the supply air volume is calibrated to equal internal sensible heat gain, it is the return air that must be adjusted.

Figure 6 illustrates the situation both before and after the ΔP sensor has caused the return air damper to open further and pass more return air. The wall leaks 0.5 cfm/ft^2 $\times$ 6,000 ft^2 or 3,000 cfm at 0.3 in. ΔP.

Before modifying the system, the wall would have leaked

$$\left(\frac{0.6 - 0.2}{0.3}\right)^{1/2} \times 3{,}000 \text{ or } 3{,}464 \text{ cfm} .$$

If we drew down the pressure on the floor to 0.1 in. WG, the wall would leak

$$\left(\frac{0.6 - 0.1}{0.3}\right)^{1/2} \times 3{,}000 \text{ or } 3{,}872 \text{ cfm} .$$

However, the leakage into the elevator shaft would now be less. At the new ΔP of 0.1 in. WG, this would be 2,400 $\times$ 3.2 ft^2 $\times$ $(0.1)^{1/2}$ or 2,428 cfm. It is now clear that the return air must be increased by 3,872 − 2,428 or 1,444 cfm.

To maintain a maximum ΔP of 0.1 in. WG across the elevator doors, the HVAC system must extract 1,444 cfm of additional air from this floor. The return air duct must therefore be sized to permit the passage of this much air.

A wall leakage rate of 0.5 cfm at 0.3 in. WG is a high rate for a sealed building. An excellent design would have an overall average leakage objective of, perhaps, 0.12 cfm/ft^2 at 0.3 in. WG. Nevertheless, the mechanical designer has little control over building envelope infiltration, so he would be playing his cards well to size both the perimeter heating and the return air duct safely to allow for the worst situation.

In summary, the stack effect in tall buildings can cause problems with elevator door operation as well as air quality problems in washrooms. As shown above, these can be controlled within acceptable limits by understanding the problem and modifying the HVAC design.

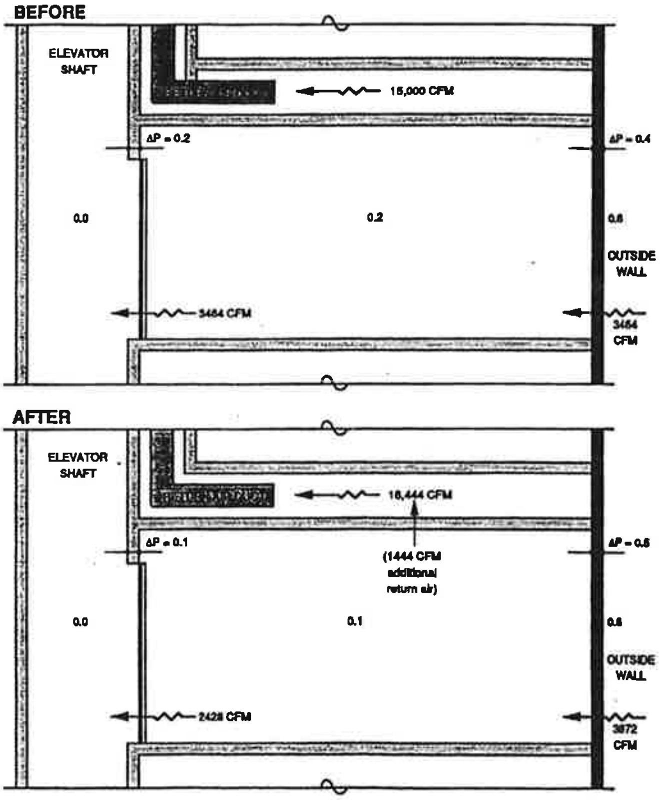

Figure 6 *Return air compensation to limit ΔP on elevator doors on second floor of building*

REFERENCES

ASHRAE. 1985. *ASHRAE handbook—1985 fundamentals*, chapter 22. Atlanta: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.

Tamura, G.T., and A.G. Wilson. 1967a. "Pressure differences caused by chimney effect in three high buildings." *ASHRAE Transactions*, Vol. 73, Part 2.

Tamura, G.T., and A.G. Wilson. 1967b. "Building pressures caused by chimney action and mechanical ventilation." *ASHRAE Transactions*, Vol. 73, Part 2.

DISCUSSION

Bob England, Senior Mechanical Engineer, The Cohos Evany Partners, Calgary, Alberta, Canada: Could you comment on the effects of compartmental fan rooms and atria in the context of your paper?

R.T. Tamblyn: This has been covered to some extent in our paper. The same reduction in ΔP across the elevator doors can be obtained with a compartmented system if the ventilation supply to the lower floors is restricted. The surplus can then be supplied to the upper floors to gain a similar effect.

This might seem to prejudice ventilation ratios. However, the ΔP problem was caused in the first place by a leaky building fabric. A calculation would show that the excess infiltration to lower floors will exceed the loss of ventilation from the central supply riser.