Impact of Stack Effect on Building Static Pressure Measurement

BY RICHARD FAHNLINE, P.E.

Accurate measurement of building static pressure is essential to enable a building's ventilation system to maintain a proper level of positive pressurization at the base of the building. The consequence of stack effect on building pressurization in tall and medium-height buildings is generally well understood, with good discussions on the subject in both *ASHRAE Handbook—Fundamentals*[1] and *ASHRAE Handbook—HVAC Applications*.[2] However, the impact of stack effect on the process of measuring building static pressure is often not properly addressed.

For example, substantial error in the measurement of building static pressure can occur when a building is operating in cold weather. On these occasions, the building's automation system could indicate the building static pressure is slightly positive relative to the exterior while, in fact, the static pressure at the base of the building is actually negative relative to the exterior.

Failure to maintain slightly positive or, at least, neutral pressurization at the base of the building will allow the infiltration of cold, unfiltered outdoor air into the building through construction gaps and exterior entryways. To a lesser extent, during warm weather the opposite error will occur, and the building's automation system could indicate the building static pressure is slightly positive relative to the exterior while, in fact, it is actually highly positive relative to the exterior.

The Dennis Maes Pueblo Judicial Building, a newly constructed, five-story county courthouse in southern Colorado, initially experienced problems with static pressure control during cold weather; significant infiltration was observed in the lower levels of the building, resulting in cold and freezing conditions within ceiling plenums throughout the lower levels.

The transfer of substantial amounts of cold outdoor air into the main entry and exit vestibules was also observed during cold weather operation. These problems were clearly caused by a substantial level of depressurization at the base of the building, despite an indication from the building's automation system that the building was positively pressurized to +0.05 in. w.c. (12.4 Pa). These problems occurred regardless of the wind conditions and increased in severity as the ambient air temperature became colder.

When a slight temperature difference exists between the exterior and interior of a building, minimal stack effect will occur. On these occasions, the static pressure differential between the exterior and interior of the building is primarily a function of the ventilation system

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operation and is independent of the height of the building. However, when the exterior air temperature differs significantly from the interior air temperature, stack effect will result.

During the winter, lower outdoor air temperatures will result in the depressurization of the lower floors and increased pressurization of the upper floors.

During summer operation, higher outdoor air temperatures will result in the increased pressurization of the lower floors and depressurization of the upper floors.

As shown in *Figure 1*, the ideal location for both the interior and exterior static pressure references is at the base of the building where maintaining a slightly positive building static pressure is essential.

As indicated in the *ASHRAE Handbook—HVAC Applications*,[3] mitigating wind effect is typically achieved by locating the exterior static pressure reference at 10 ft to 15 ft (3 m to 4.6 m) above the roof level. The interior static pressure reference is located at ground level, typically within an interior space of the building (*Figure 2*).

Although this arrangement minimizes wind effect on the building static pressure measurement process, it also introduces an error due to stack effect. Since the internal static pressure reference sensing line is routed within the building, the air temperature within the sensing line will be close to the internal building temperature (return air temperature). The rate of change in the pressure within the sensing line with change in elevation will be a function of the internal air temperature, with pressure decreasing from the internal static pressure sensing reference (P_{INT}) up to static pressure P^T_{INT} at the differential pressure transmitter.

The rate of change in the pressure within the outdoor reference sensing line with change in elevation will be a function of both the interior and exterior air temperatures, with pressure increasing from the outdoor static pressure reference (P^R_{OUT})

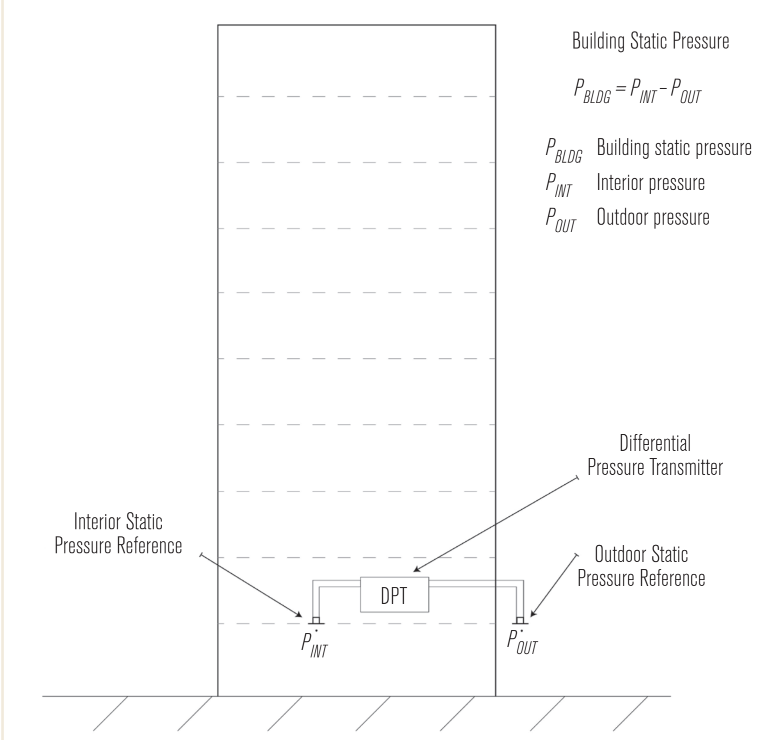

FIGURE 1 Building static pressure measurement with interior and exterior references located at base of building.

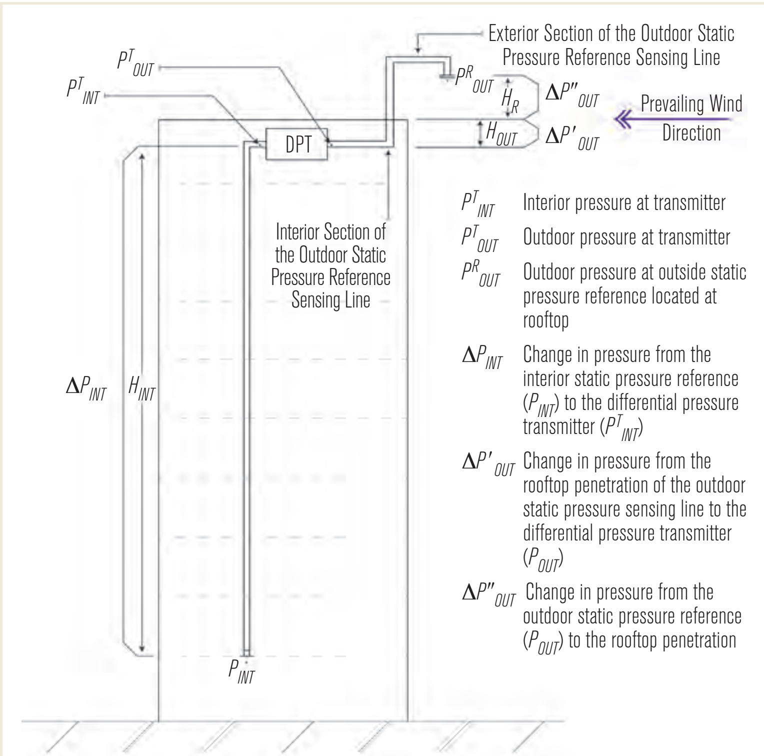

FIGURE 2 Building static pressure measurement with static pressure reference located at the base of building and the exterior static reference located above the roof.

down to the static pressure P^T_{OUT} at the differential pressure transmitter. The pressure change for the interior section of the outdoor static pressure reference sensing line will be a function of the internal air temperature. The pressure change for the exterior section of the outdoor static pressure reference sensing line will be a function of the outdoor air temperature.

The measurement of interest is the differential pressure from the interior to the exterior at the base of the building, not between the roof level and the base of the building.

Figure 3 shows a virtual pressure sensing line routed from the roof level exterior pressure reference down to the base of the building. Since this virtual line is in the exterior air, the pressure change with change in elevation will be a function of the exterior air temperature, with the pressure decreasing from the virtual static pressure sensing reference (P_{OUT}) to the actual outdoor static pressure reference (P^R_{OUT}).

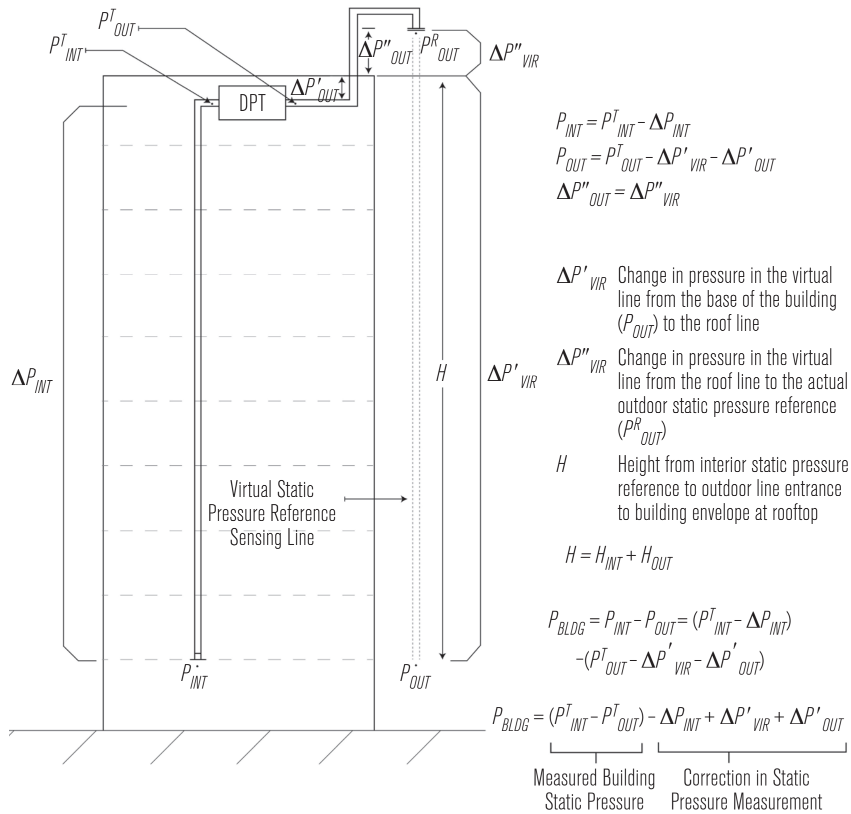

FIGURE 3 Building static pressure measurement with the virtual static pressure reference located at base of building.

The corresponding change in pressure within the virtual pressure reference sensing line will be at a different rate than in the interior pressure reference sensing line whenever there is a difference between the interior air and exterior air temperatures. Over a vertical distance of greater than a few dozen feet, this difference in the rate of change in the pressure can result in a significant error in the measured building static pressure differential.

To eliminate this error, the measured building differential pressure should be corrected in accordance with the following equation.[4]

$$\Delta P_{CORRECT} = 7.64 \times C_{ALT} \times H \times \left[\frac{1}{(T_{INT} + 460°R)} - \frac{1}{(T_{OUT} + 460°R)} \right] \quad (1)$$

This equation corrects for the difference in the change in pressure (in in. w.c.) within the interior static pressure reference sensing line, the interior section of the outdoor static pressure reference sensing line, and the change in the virtual outdoor pressure sensing line. Because the exterior section of the outdoor pressure reference sensing line is at the outdoor air temperature, the pressure change within this section of the line will be canceled out by that section of the virtual sensing line, which is above the rooftop penetration of the outdoor static pressure reference sensing line.

The change in the pressure in the virtual pressure sensing line should be calculated from the base of the building to the roof line or at a point where the outdoor static pressure reference sensing line penetrates into the building. This equation also includes an altitude correction factor based on the change in the atmospheric pressure and corresponding change in the air density, which ultimately impacts stack effect.

As indicated previously, the main air-handling unit return air temperature can be used for the internal building temperature (T_{INT}). The total height (H) will be the sum of the internal static pressure reference sensing line elevation change and the elevation change of that portion of the outdoor static pressure reference sensing line, which is routed within the interior of the building (provided the air within the exterior pressure probe sensing line is maintained close to the internal building temperature).

This equation holds true regardless of whether the differential pressure transmitter (DPT) is located near the roof level, such as in a penthouse, or at the base of the building.

In either DPT location, the temperature of the interior sensing line is assumed to be essentially the same as the interior building temperature. The exterior sensing line is assumed to be the same as the outdoor air temperature where the sensing line is located outside. Upon entering the building, the exterior sensing line is assumed to be at the same temperature as the building interior.

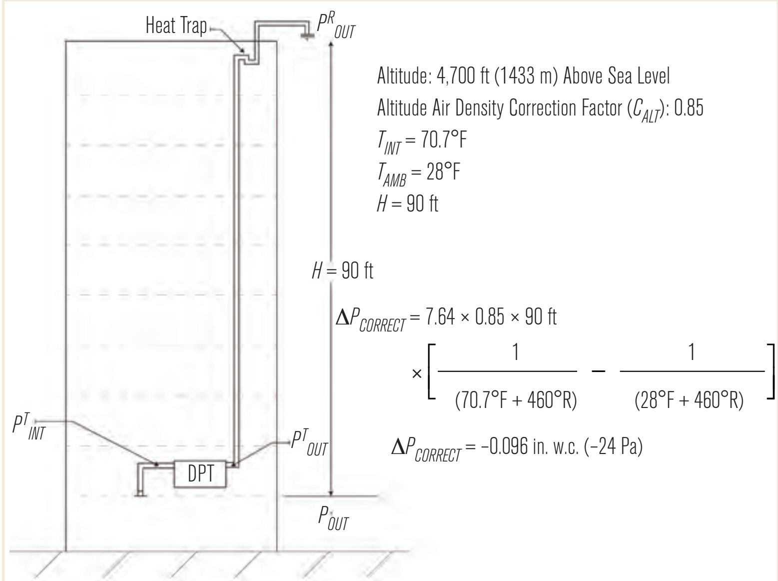

FIGURE 4 Differential pressure transmitter location at the base of building.

Using the results from the Dennis Maes Pueblo Judicial Building as an example (*Figure 4*), a total elevation change from the interior static pressure reference to the top of the building is 90 ft (27.4 m). Since the building is located at an elevation of approximately 4,700 ft (1433 m) above sea level, an air density correction (C_{ALT}) of 0.85 was used for the building automation system calculation.

With an internal building air temperature (air-handling unit return air temperature) of 70.7°F (21.5°C) and an exterior air temperature of 28°F (–2.2°C), the resulting stack effect correction was calculated to be –0.096 in. w.c. (–24 Pa). The building automation system indicated an uncorrected building static pressure of +0.01 in. w.c. (+2.5 Pa), while the actual building static pressure was manually determined using a differential pressure gauge to be approximately –0.086 in. w.c. (–21.3 Pa) at the base of the building, with the manual reading taken across an exterior door at grade level. Applying the stack effect correction to the static pressure indicated by the building automation system resulted in a building static pressure of 0.086 in. w.c. (–21.3 Pa). This is in agreement with the manually measured static pressure.

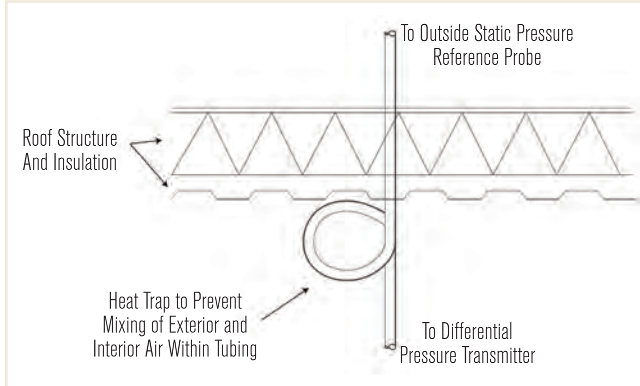

FIGURE 5 Typical heat trap.

After reprogramming the building automation system to include the static effect correction equation, the control system was able to recognize the actual building static pressure at the base of the building as needed to properly operate the HVAC system equipment to maintain positive pressurization.

When designing and installing the static pressure reference sensing lines, it is important to maintain the exterior pressure reference sensing line at the internal building temperature once inside the building. This can be accomplished by installing a heat trap (as shown in *Figure 5*) within the exterior pressure sensing line immediately after the sensing line enters the building envelope. A heat trap is not as essential if the DPT is located near the roof, whereby the majority of the elevation change is made by the interior sensing line.

Conclusion

Correcting for error in the building static pressure measurement resulting from stack effect is essential for maintaining proper building pressurization during cold weather operation. Without correction of this error, the building's temperature control system will indicate the building is properly pressurized when, in fact, the building may be negatively pressurized.

References

1. *2013 ASHRAE Handbook—Fundamentals*, Chap. 16.
2. *2015 ASHRAE Handbook—HVAC Applications*, Chap. 4.
3. *2015 ASHRAE Handbook—HVAC Applications*, Chap. 47.
4. Klote, J.H., J.A. Milke, P.G. Turnbull, A. Kashef, M. J. Ferreira. 2012. *Handbook of Smoke Control Engineering*, 128–129. Atlanta: ASHRAE. ■