Stairwell Pressurization Systems

An Online Continuing Education Course for Engineers

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Introduction

In a high-rise building, the stairs typically represent the sole means of egress during a fire. It is imperative for the exit stairs to be free of smoke and to incorporate design features that improve the speed of occupant egress. Most building codes require the fire stairwells in a high rise building to be pressurized to keep smoke out.

The stairwell pressurization serves several purposes:

- Inhibit migration of smoke to stairwells, areas of refuge, elevator shafts, or similar areas.
- Maintain a tenable environment in areas of refuge and means of egress during the time required for evacuation.
- Facilitate the fire and rescue operation by improving visibility in the building for the firefighting crew.
- Protect life and reducing damage to property.

The International Building Code (IBC) enforced much throughout the United States, recognizes three specific means for providing smoke proof enclosures:

1. Naturally ventilated stair balconies
2. Mechanical ventilation of a stair
3. Stair pressurization

Due to the relative cost of the associated mechanical systems, and architectural space issues related to providing exterior balconies and stair vestibules, the stair pressurization system is the most widely selected design option.

This course discusses the smoke control systems and examines the design considerations associated with stairwell pressurization system.

CHAPTER 1: REVIEW OF SMOKE

1.1 Hazards of Smoke

- Smoke contains toxic and irritant gases.
- ¾ of all fire deaths are caused by smoke inhalation.
- Approximately 57% of fire deaths occur outside room of fire origin.
- 47% of fire survivors could not see more than 12'.
- Smoke travels 120 – 240 ft./min.

1.2 Smoke Management

Smoke management system includes all methods described below singly or in combination to modify or influence the smoke movement.

1.2.1 Limit the Fire

An important consideration when designing a smoke control system is to ensure that evacuation is faster than the spread of smoke/fire. Controlling fire size, typically by means of hosepipes, hydrants and sprinklers should be a part of the overall smoke management. An automatic fire suppression system would be expected to limit the heat release rate and control the spread of fire.

1.2.2 Compartmentation

Compartmentation involves use of barriers with sufficient fire endurance to prevent spread of smoke to spaces remote from the fire. The method employs walls, partitions, floors, doors, smoke barriers, smoke dampers, and other fixed and mechanical barriers. The effectiveness of compartmentation is limited by the extent to which the free leakage paths are controlled through the barriers. Smoke control system designers often use the compartmentation method in combination with the pressurization method.

1.2.3 Exhaust Ventilation

Smoke control in large open areas with high ceilings such as atria, shopping malls, concourse, airports etc. is best achieved by exhaust ventilation. Hot smoke is collected at the high level in a space where it is vented outside by means of a powered smoke exhausting fan. Make-up supply air below the smoke layer is also crucial and is provided from the adjacent spaces free of smoke.

1.2.4 Dilution

The dilution method clears smoke from spaces remote from a fire. The method supplies outside air through the HVAC system to dilute smoke. Using this method helps to maintain acceptable gas and particulate concentrations in compartments subject to smoke infiltration from adjacent compartments. In addition, the fire service can employ the dilution method to remove smoke after extinguishing a fire. Smoke dilution is also called smoke purging, smoke removal, or smoke extraction.

The approach may be used, for example, to clear smoke that has infiltrated a protected space such as an escape corridor or refuge lobby. Also dilution can be beneficial to the fire service for removing smoke after a fire has been extinguished.

1.2.5 Airflow

The airflow method controls smoke in spaces that have barriers with one or more large openings. It is used to manage smoke through open doorways, subway, railroad, and highway tunnels. The method employs air velocity across or between barriers to control smoke movement. A disadvantage of the airflow method is that it supplies increased oxygen to a fire. Within buildings, the airflow method must be used with great caution. The airflow method is best applied after fire suppression or in buildings with restricted fuel.

1.2.6 Pressurization Systems

The method employs a pressure difference across a barrier to control smoke movement. The pressurization systems are installed mainly in the stairwells, elevator shafts, refuge spaces and other egress routes. The high-pressure side of the barrier is either the refuge area or an exit route. The low-pressure side is exposed to smoke. Airflow from the high-pressure side to the low-pressure side (through construction cracks and gaps around doors) prevents smoke infiltration. A path that channels smoke from the low-pressure side to the outside ensures that gas expansion pressures do not become a problem. A top-vented elevator shaft or a fan-powered exhaust can provide the path. In contrast to exhaust ventilation and dilution systems, the pressurization systems are designed to protect zones away from the fire source.

Important

Smoke management systems are designed to modify, dilute, redirect, or otherwise influence the movement of smoke in a building experiencing a fire, but not necessarily to control it or limit its movement. The mechanisms of compartmentation, dilution, airflow, pressurization, and buoyancy are used singly or in combination to manage smoke conditions in fire situations.

1.3 Smoke Control

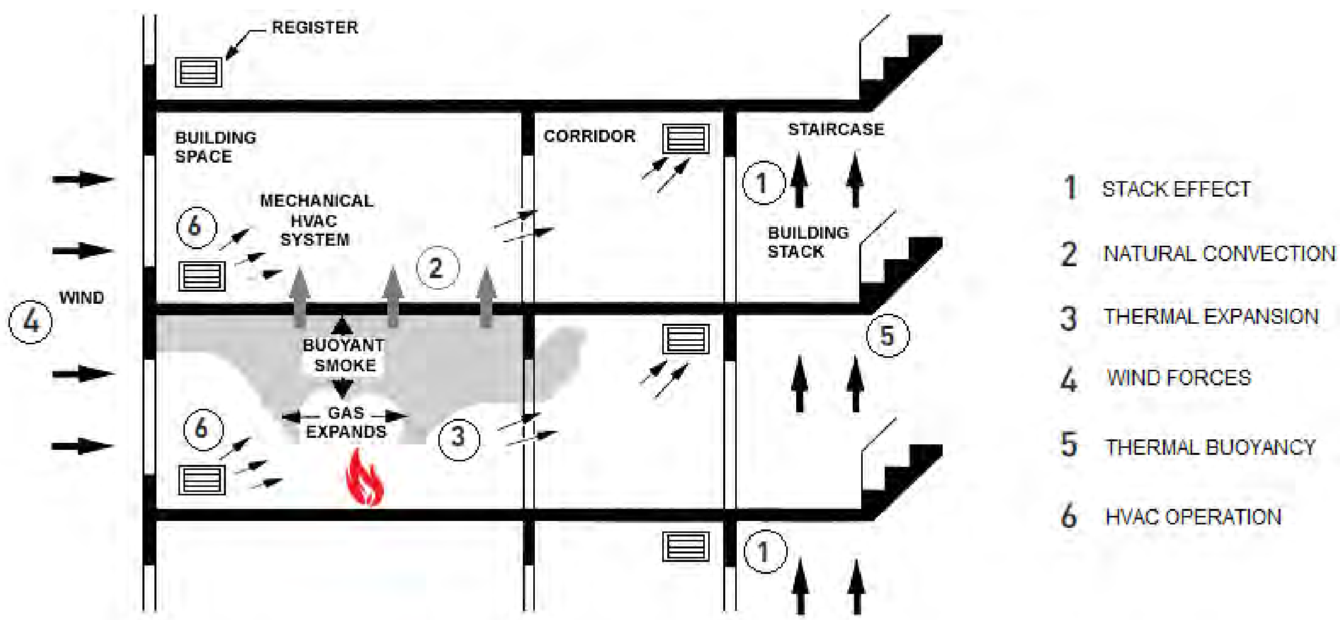
Smoke control systems are intended to limit and control the movement of smoke during a fire. The most common approach involves using pressure differences on either side of the boundaries of fire area. The example is a stairwell pressurization system. Typically the pressure differentials are created by actively controlling dedicated mechanical fans and dampers (if applicable) to supply the stairwell with 100% outdoor air.

The design requirements are discussed in subsequent sections.

CHAPTER 2: SMOKE MOVEMENT

A building can be considered a series of spaces each at a specific pressure with air movement between them from areas of high, to areas of low pressure. While in practice it is possible for pressure gradients to exist in large vertical spaces, such as stairwells, the significant pressure differences can generally be considered as occurring across the major separations of the building structure, i.e. doors, windows, walls and floors. The difference in pressure determines whether it will flow at all, and how much and how quickly it will flow. Large pressure differences produce large flows. The principal factors responsible for the pressure differences and smoke movement are:

1. Differences in temperature between outdoor and indoor air (stack effect)
2. Natural convection
3. Thermal expansion
4. Wind forces
5. Buoyancy of combustion gases
6. HVAC operation



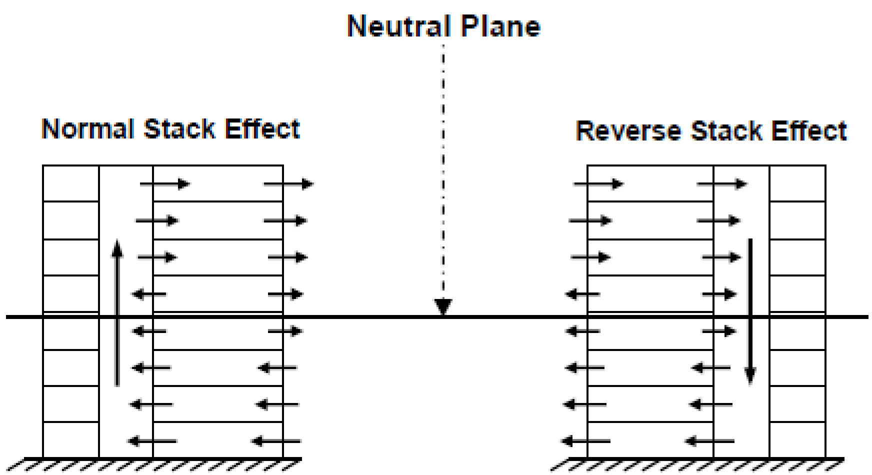
FACTORS AFFECTING THE MOVEMENT OF SMOKE

2.1 Stack Effect

Stack effect is a result of different air densities inside and out of a building that cause the pressure distribution of air in a building to be different from the outdoors.

If the airflow is from bottom to upwards, it is normal stack effect. It happens in winters when the less dense warmer air (indoor) rises and cold outside air rushes in to take its place. The reverse happens in summers when the cooler air inside the building sinks and draws warmer, outside air in through the top of the building.

The stack effect is more pronounced in the winter; when it's cold outside, the stack effect creates about 4 pascals of pressure for every floor in the building. In the summer, this drops to 1.5 pascals per floor.



Air Movement Due to Normal and Reverse Stack Effect

At standard atmospheric pressure, the pressure difference due to normal or reverse stack effect is expressed as:

$$\Delta P = K_s \text{ x } \left(\frac{1}{T_o} - \frac{1}{T_i}\right) \text{ x } h$$

Where

- ΔP = Pressure difference inches of water.
- Ks = Coefficient, 7.64
- T_o = Absolute temperature of outside air, °R
- T_i = Absolute temperature of the air inside the shaft, °R
- h = Distance above neutral plane, ft.

At some intermediate point between top and bottom, the pressure is neutral and called the neutral pressure plane. The height of the "neutral plane is determined by the relative leakage areas of the buildings structure at high and low levels. Generally the neutral plane is at, or near mid-height. It is possible to shift the neutral plane close to the position of the opening by providing sufficiently large openings at the top or bottom of a building.

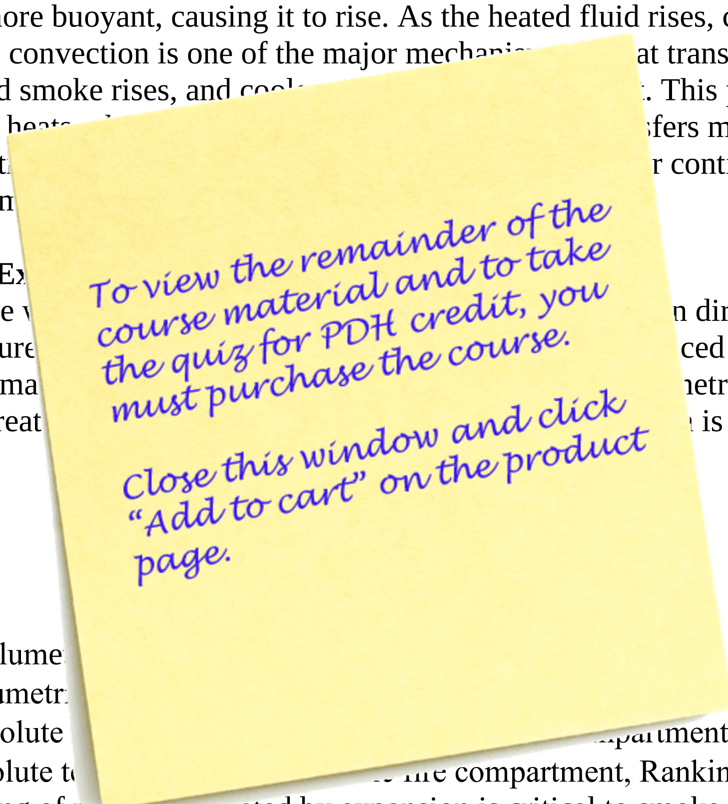
This is the underlying principle behind natural venting to control smoke movement. Assuming winter conditions, the pressure at the top will be lesser than the lower floors. It will result in infiltration of air at each floor level. In the event of a fire, the shaft will be filled with smoke, which can be dangerous for people escaping the building. This situation can be averted by pressurizing the stairwell.

Stack effect will be significant in very tall buildings. The table below shows the impact height can have on stack effect induced pressure differentials- given a constant temperature differential.

Building Height	**Outside Temp [°F]**	**Inside Temp [°F]**	**ΔP [in. w.c.]**
75 ft.	0	70	0.08
300 ft.	0	70	0.33
984 ft.	0	70	0.54
2133 ft.	0	70	0.72

2.2 Natural Convection

Natural, or free convection, results from temperature differences within a fluid. As a fluid is heated, it expands while mass remains the same. Decreased density (mass/unit volume) makes the heated fluid more buoyant, causing it to rise. As the heated fluid rises, cooler fluid flows in to replace it. Natural convection is one of the major mechani... at transfer in a compartment fire; heated air and smoke rises, and cool... . This process transfers thermal energy; it heat... sfers mass as smoke moves out of the compart... r continued combustion) moves into the com...



2.3 Thermal Ex...

As the temperature ... n direct proportion to their absolute temperature ... ced from the zone, depending on the ma... metric flow of smoke out of a fire zone is great... is expressed as:

$$\frac{Q_{out}}{Q_{in}} = \frac{T_{out}}{T_{in}}$$

Where:

- Q_{out} = Volume... cfm
- Q_{in} = Volumetr...
- T_{out} = Absolute ... partment, Rankine (R)
- T_{in} = Absolute t... fire compartment, Rankine (R)

Venting or relieving of p... created by expansion is critical to smoke control.