Air Leakage Due to Stack Effect in Multi-story Buildings

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Forces that bring about stack effect in multi-story buildings are explained and suggestions presented for reducing air leakage. Stack effect makes the operation of doors difficult and interferes with the operation of dampers.

AIR leakage into a building is due primarily to stack effect and this in turn is influenced by structure height and the difference between inside and outside building temperatures. In winter, the cold air outside is dense and consequently heavier than inside air. This heavier air tends to displace the lighter building air by forcing its way in at the bottom of the building and pushing the warmer air out the top. In the summer, since the column of air within the air conditioned building is colder and more dense than the outside air, air currents are in reverse and travel down in the building.

Graphic Presentation

Expressing the effect graphically, it can be seen in Fig. 1 that the weights of columns w_1 and w_2 are equal since they are equal in temperature and consequently equal in density. The column of air within the building, w_4, however, is warmer and lighter than w_3, the adjacent air outside. Totaling the weights in each column, it is apparent w_1 plus w_3 is heavier than w_2 plus w_4, hence pressure P_1 is greater than P_2.

Mathematically, the pressure at the bottom of each column is:

$$P = (h \times d)/144$$

Where:

P = pressure, psi
h = height of building, ft
d = density of air column, lb per cu ft

The pressure difference $(P_1 - P_2)$ would indicate the net pressure creating the stack effect.

As an example, the Chase Manhattan Bank Building, New York City, now under construction, will have an overall height of 770 ft. It will have a theoretical stack draft of 1.9 inches of water when the building is heated to 70 deg F and the outdoor temperature is 0 deg, neglecting the influence of any exterior forces.

It is this basic physical law which dictates that cold winter air will seek to enter a warm building through entrance lobbies and lower floors, travel up elevator shafts, stairways and mail chutes and relieve out through upper floor openings.

This tendency for air to enter building lobbies manifests itself in two ways: (1) a reduced ground floor temperature which requires excessive quantities of heat to maintain comfortable conditions and (2) a pressure difference across the entrance which makes it difficult to open a hinged door.

Determining Air Leakage

Several consulting engineers were questioned in an attempt to arrive at some precise means of determining how much heat is required to offset air leakage into a lobby and at what building height the pressure difference created makes it necessary to use revolving rather than hinged doors. These engineers all stated that their basis for design is practical experience and past practices on similar type structures.

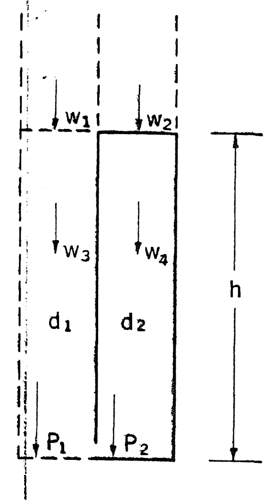

Fig. 1. Graphical presentation to show movement of columns of air due to temperature and density.

Upon consulting the American Society of Heating and Air Conditioning Engineers Guide for more definite information, the following formula expressing building stack effect was found.

$$Q = 9.4A\sqrt{h(t_1 - t_o)}$$

where:

Q = air flow, cfm
A = free area of inlet or outlet openings, sq ft
h = height from inlets to outlets, ft
t_1 = average temperature of indoor air in height h, Fahrenheit
t_o = outdoor temp., Fahrenheit
9.4 = constant including value of 65% opening effectiveness

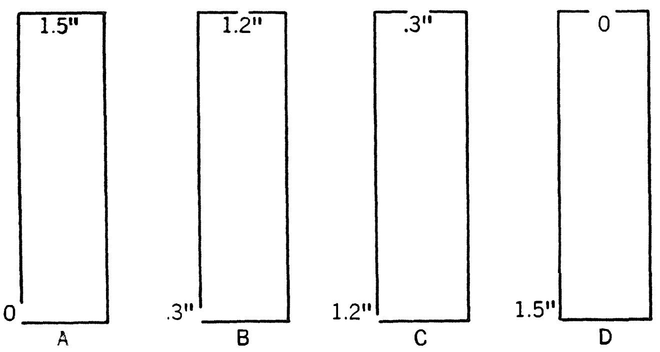

Fig. 2. Sketches to show the location of built-up pressure, due to the location of building openings.

As an example the Chase Manhattan Bank building, with a height of 770 ft, a 0 deg outside temperature, 70 deg inside temperature and 20 sq ft of opening top and bottom, will create an air current into and up through the building of 44,000 cfm.

External Forces Affecting Stack Effect

Since the stack effect is due to a greater pressure outside and at the bottom of a building than exists inside the building, it is readily understood that any condition increasing the interior pressure or any constriction of the bottom and top building openings will, in turn, reduce the flow of air up through the building and out the top. Most modern buildings are under some interior positive pressure due to the mechanical ventilation systems supplying more air than is exhausted. Although the Guide states that positive pressures from ventilation systems have an important influence on stack effect, the formula does not take that into consideration and therefore it should not be used for ventilated buildings. The formula does reflect size of openings, however, and here we have the single most important factor on stack effect, since it not only determines the amount of infiltration, but, depending on the location of these openings, produces the point of pressure differences. This is best illustrated by Fig. 2.

If the building is completely sealed at the top, *A* of Fig. 2, and has openings at the bottom, the entire pressure, due to stack effect, is felt at the top. Since air cannot relieve out the top, no additional air would enter at the bottom and the pressure difference across the entrance doors would be nil.

Sketch *D* reverses the condition of *A* and for a building with a stack draft of 1.5 inches of water, the entire pressure would be exerted at the lobby doors. This calls for an opening at the top as shown.

Sketch *B* indicates a small opening at the top and a much larger opening at the bottom with a consequent greater pressure at the top of the building.

Sketch *C* reverses *B* with a resultant shifting in the point of greater pressure.

To illustrate the magnitude of this pressure on doors, should one attempt to open a hinged door with a pressure of 1.5 inches of water exerted against it the pull required would be the same as that necessary to lift a horizontal weightless door covered with a layer of water 1.5 inches deep.

Stack Effects

To observe the stack draft first-hand, we inspected first a sealed or fixed sash type building, and a non-sealed type.

With both doors of a double door vestibule open in the non-sealed building, and a 30 deg outdoor temperature, an anemotherm (an instrument sensitive to air velocities), registered a reading of 1000 fpm. This is equivalent to an 11.5 mph wind into the lobby.

A shaft which opens into the mechanical equipment room on the 33rd floor was checked next. Air was pouring into the room at the rate of 1100 fpm, and an investigation revealed that air was being relieved from the area through open doors to the cooling tower section and the fire tower. Closing these doors reduced the inlet velocity to 600 fpm, which indicates less upward draft as the top building openings are restricted. The velocity could not be reduced further since there were several pipes up to 16-inch dia through the wall to the cooling tower section with 2-inch clearance around each. in addition to leakage at doors and windows.

Another door, as well as the one mentioned, was found open to the fire tower with a velocity of 1000 fpm across it. It was observed that the door's self-closer could not overcome the opposing pressure due to the stack effect.

An inspection of the elevator machine room indicated a velocity of 700 fpm across each of the shaft smoke holes and 1500 fpm through a window open to the outdoors.

Sealed Type Buildings

Proceeding to the sealed type of building, we found a velocity of 1600 fpm across the entrance doors when opened, which caused foliage of plants in the lobby, 35 feet from the door to sway in the breeze.

The elevator smoke hole velocity in the 46th floor machine room was 1600 fpm, and upon opening a door to the adjacent equipment room, the velocity increased to 2100 fpm, indicating the effect of openings on stack draft.

We observed that the exhaust system in this room, in the form of two 48-inch axial flow fans was shut down. The chief engineer of the building informed us that there was sufficient ventilation with the fans off and that motorized dampers had to be installed at the fan discharges to prevent the fans spinning at a tremendous rate although shut off. In this case, the stack effect created a pressurized condition within the room which was relieved through the fans to the outdoors.

Our inspection showed that a considerable amount of air was leaking into a mechanical equipment room at the top level and we checked to determine how this air was in turn transmitted to the outdoors. We found an open door to the outdoor cooling towers, and the automatic dampers in duct discharges from an indoor cooling tower and exhaust air fan were both stuck open, although the fans were off. This served to indicate how difficult it was to attempt to seal the openings in a building.

Another effect, observed at the entrance to the penthouse club, was the constant moan of the air crowding out through the cracks around the elevator and the fire tower doors, creating weird and annoying sounds.

Descending to the 27th floor elevator machine room, we determined the smoke hole velocity had decreased to 1000 fpm, indicating the stack effect is a function of height.

The part that a positive pressure developed by the ventilating system plays in the overall effect was seen when a 2nd floor door to an interior fire tower was opened. The air was forced into the tower due to the stack effect plus the positive pressure within the building and the velocity registered was 3600 fpm. It took all of the writer's strength to close the door once the door had been opened.

All these effects were observed while the outdoor temperature was 30 deg. During colder weather, the stack effect, which is proportional to the temperature difference, will increase accordingly.

Another building condition was observed that the building engineer referred to as "building settlement". Cracks developed in the core walls adjacent to elevator shafts and stairwells which permitted air to leak through from the hung ceilings. Although these cracks are ¼ inch wide, when multiplied by the number of feet per floor and the number of floors, the effective opening with the resulting leakage becomes considerable.

A similar effect was observed at a 20-story building on Madison Avenue when the building there was completed. A large retail store occupied the ground floor and in cold weather, the amount of air infiltration through the single row of doors was a continual cause for complaint. It was finally determined that the hung ceiling, which was used as a return air plenum for the air conditioning system, was leaking its air through masonry wall cracks into the elevator shafts. When the cracks were pointed and the entire wall sprayed with a plastic compound, the infiltration was reduced to a bearable level.

Conclusions and Recommendations

To summarize, the stack effect in buildings is a function of the height and temperature difference between indoors and outdoors.

The created draft, is in turn, affected by certain external conditions, primarily: Size and locations of openings and pressures exerted on the draft.

In the category of openings, the following conclusions can be drawn:

1. Cracks around doors to lobbies, elevators, stairwells and fire towers, should be sealed as much as possible by some means of weatherstripping.
2. Lobby entrances, especially in tall buildings, should be equipped with revolving doors.
3. Retail shops incorporated in buildings should be studied carefully for proper control of openings between the shop and an adjacent lobby which could be another path for air infiltration.
4. All openings for mechanical equipment such as fresh, exhaust and relief air louvers should be equipped with motorized dampers having neoprene edges so that positive shut-down with minimum leakage can be achieved. Any other openings made to accommodate mechanical work, such as clearance around piping in wall and floor should be effectively plugged to reduce air flow.
5. Care should be taken in the construction of core walls to eliminate the possibility of excessive cracking and consequent leakage.
6. Careful consideration should be given to the selection of door self-closers for stairwells and fire towers to insure that they can function and close against stack pressure.

G. L. Smith attended New York University and studied heating and air conditioning under the late Dean Mario Gianinni, completing his studies in 1941. He has worked for several consultants such as Meyer, Strong and Jones and Lockwood Greene. After three years of Army service in airborne radar, he worked for the J. C. Penney Company from 1947-1951 as assistant chief engineer in charge of heating and air conditioning design for the chain's stores. Since 1951, he has been with Skidmore, Owings & Merrill as chief mechanical engineer for the New York office. He has been in charge of mechanical design for such projects as the Hilton Hotel in Istanbul, Morocco air bases, Hoffman Beverages and Pepsi-Cola plants and acted as coordinator with several of his office's mechanical consultants. Mr. Smith is a professional engineer licensed in New York.

In regard to pressures influencing draft, the following important points can be made:

1. A positive pressure developed within a building will effectively reduce the amount of infiltration. Consequently, the mechanical ventilation system should introduce a decidedly greater quantity of fresh air into the building in comparison to the amount of air exhausted.
2. Since stack pressures will be developed in elevator machine rooms through the shaft smoke holes, the design of their ventilating systems should take this into consideration. A fan supplying air to the machine room and connected to the outdoors should be capable of developing the required system pressure losses plus the stack pressure. An exhaust fan, on the other hand, should be selected on the basis of the stack pressure acting in concert with the fan's developed pressure. In many cases, an exhaust fan for upper floor ventilation is not necessary since the stack pressure could provide for the proper quantity of exhaust air through controlled openings to the outdoors.
3. A possible solution is the installation of a pressuretrol in the elevator machine room which would modulate motorized dampers in louvered openings to the outdoors, in accordance with the stack pressure developed. This arrangement would utilize the stack effect as the pressure required for the proper exhaust of air. As the outdoor temperature increased and the stack pressure fell off, the machine room temperature would tend to climb due to improper ventilation. A room thermostat would automatically start the exhaust fan and possibly a supply air system through an electric interlock.
4. Although the stack effect in multi-story buildings is the single most important cause for air infiltration, it is well to mention that wind pressure too, plays a part in the overall picture.
5. Across entrance doorways, the effect of wind pressure would be added to the stack effect causing an increase in air infiltration. In the upper floors of tall buildings, there would be some air infiltration on the windward side of a building and an equal quantity of air exfiltrating on the leeward side.

These factors can be controlled to a great extent by shielding building entrances from the prevailing winds and the upper floor condition can be corrected by carefully sealing the skin of the building.