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Stairwell Pressurization



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Editors Note:

There are very few installations of Stairwell Pressurization Systems that have been designed and installed in multistory buildings in Indian cities and fewer still that have been tested and documented after installation.

Nevertheless, the subject is important enough to warrant a serious attempt to collect as much material as possible on the matter in order to help the HVAC system designers, and planning engineers simplify their work on future projects. This article fulfills that need.

Fire safety is a critical design factor in tall buildings. Smoke is recognized as the major killer in fire situations. Building fires produce both smoke and heat. The most common cause of death is from the inhalation of carbon monoxide. In building fires, smoke often flows to locations remote from the fire, threatening life and damaging property.

Stairwells and elevator shafts can become smoke logged thereby blocking evacuation and inhibiting fire fighting. Once inside a protected route, people in a building should be able to make their way to a final exit and safety in the open air. **BS - 5588 Part-4 1978**

states "It is the smoke and toxic gases, rather than the flame, that will in the first instance inhibit this movement and the exclusion of the smoke and gases from the protected routes is thus of great importance"

Smoke management therefore assumes particular significance in high rise buildings because the time necessary for evacuation may be greater than the time for the development of untenable smoke conditions on stair cases.

Today, with the changes in interior building material, the nature of smoke is not the same in all building fires. Earlier most combustible material in building's were based on wood, paper or cotton which were varieties of the same basic substance cellulose. Its products of combustion are carbon monoxide, carbon dioxide and water. Today with man-made materials the scenario is different for various building fires and depending on the chemistry of the fuel source, strong acids such as hydrochloric began to appear routinely in smoke as chlorinated materials such as polyvinyl chloride (PVC) find increasing use. Similarly with the appearance of large amounts of nitrogen in plastics, nylon prompted worries about a possible appearance of hydrogen cyanide in smoke. Smoke being a silent killer, needs to be managed. Thus its prevention, mitigation and containment should be an essential part of any HVAC design. The protection and pressurization of stair towers and egress lobbies are of fundamental importance to the building occupants.

Most fire authorities worldwide now require that one or more escape staircases connecting to the outdoors at ground level should be maintained sufficiently free of smoke to enable mass evacuation.

Preliminary Design Consideration

ASHRAE Manual 1992, Design of Smoke Management System defines two basic approaches to fire protection:

- Prevent fire ignition and
- Manage fire impact.

While the building design team may incorporate features in the building to make it fire safe and keep the fire load low, the primary role in preventing fire ignition rests with the building managers and its occupants. However it should be recognized that it is impossible to prevent fire ignition completely. Thus managing a fire impact, assumes a significant role in fire protection design.

Examples of fire impact management include

- (a) Compartmentation
- (b) Fire suppression
- (c) Control of construction material
- (d) Smoke management.

Smoke control system in a building can be generally divided into

- (a) Shaft protection and
- (b) Floor protection.

Shaft protection can be further divided into staircase pressurization system and elevator hoistway system.

In this article attention is confined to the issue of smoke control in stair cases only.

The first line of defense in a building under attack by fire is the egress part. In the case of a high rise building this means the stair-tower or stairwell, not just one but all the exit towers connected to the ground level should be adequately protected from excessive smoke invasion.

Fire safety professionals have always considered the HVAC system as a potentially dangerous penetration of building membranes (walls, floors etc.) that can readily transport smoke and fire. For this reason, the air-conditioning system has traditionally been shut down when fire is discovered. Although shutting the system prevents fans from forcing smoke flow, it however does not prevent smoke movement through ducts due to various other driving forces that assist smoke to move.

What Causes Smoke to Move?

Frequently smoke flow follows the overall air movement within a building. Although a fire may be confined within a fire resistive compartment, smoke can readily spread to adjacent areas through openings such as construction cracks, pipe and duct penetration and open doors. NFPA 90A and National Building Code of India - 1993 (Amendment - 3) stipulate that escape routes like staircases, common corridors and lift lobbies shall not be used as return air passage and no ducts serving the main floor area should pass through a staircase enclosure. The principal factors that cause smoke to spread to areas outside a compartment are:

- Stack effect.
- Temperature effect of fire.
- Weather conditions, wind velocity and temperature.

Stack effect or chimney effect, as it is often called is the pressure differential caused by the air inside the building being at a temperature different from that of the air outside the building which when there are openings on top and bottom will promote

natural airflow through the building. Upwards (normal stack effect), when the building air is warmer than the outside air, and downwards, (reverse stack effect) when it is cooler.

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

$$\Delta P = 7.64 (1/T_o - 1/T_i) h$$

Where

ΔP = Pressure difference inches of water.

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.

Figure 3 can also be used to determine the pressure difference due to stack effect. For normal stack effect $\Delta P/h$ the pressure difference is positive above neutral plane and negative below it. For reverse stack effect, $\Delta P/h$ the pressure difference is negative above neutral plane and positive below it. Thus the temperature difference between exterior and interior of the building causes stack effect and determines its direction and magnitude.

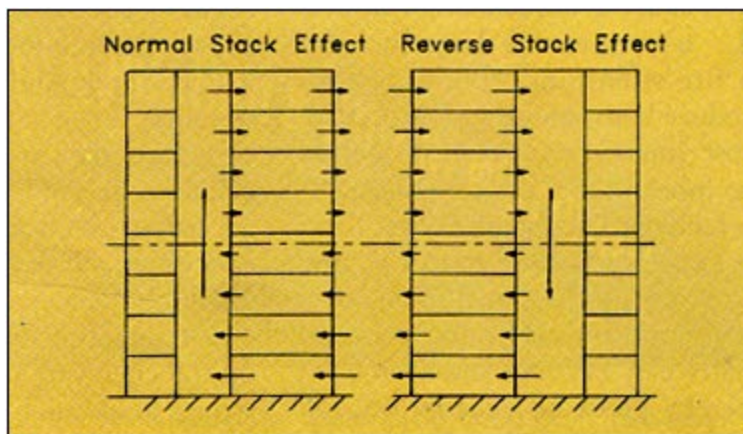


Fig. 1: Air movement due to normal and reverse stack effect.

Smoke movement from a building can be dominated by stack effect. Even during reverse stack effect conditions, in the case of hot smoke, buoyancy forces can cause smoke to flow upward. High temperature smoke from a fire has a buoyancy force due to its reduced density compared to the surrounding air. See **Figure 4**. The magnitude of critical velocity necessary to prevent smoke back flow depends on the fire heat release rate.

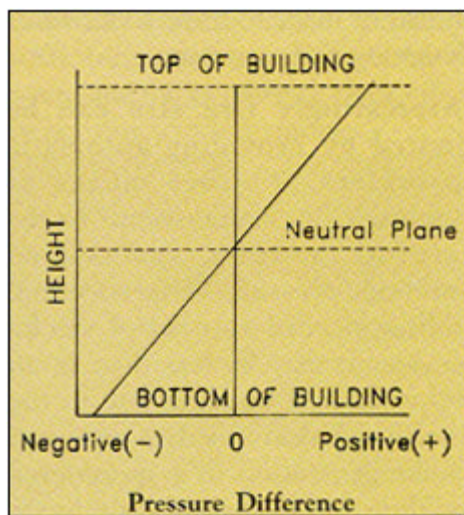


Fig. 2: Pressure difference between a building shaft and the outside due to normal stack effect.

Principles of smoke control

The two basic principles of smoke control can be stated as:

- Air pressure difference across a barrier can act to control smoke
- Air flow by itself can control smoke movement if the average air velocity is of sufficient magnitude.

If stairwell A, see **Figure 6**, has to be maintained at a higher pressure than space B, the space being connected by a closed but leaky door, there should be a leakage path from B, so that air flow from A to B can be maintained. If there were no leakage path from B, could not be prevented from spreading in to space A.

Simply stated the fire zone is kept at a lower pressure than the staircase area. Between the stairwell and accommodation there is a door. The high pressure side of the door can be a refuge area or escape route. Thus when such doors are closed, because of pressure difference, air flows through the cracks around the door and other construction cracks to the low pressure side and thus prevents smoke infiltration to the high pressure side.

However an openable door provided in a stairwell is a hole in the barrier. When the door is opened, the flow area increases, whereby the air velocity reduces. Hot smoke by virtue of buoyancy can flow against the air flow into the refuge area or escape route. Thus to prevent smoke backflow the air velocity should be high. ASHRAE manual 1992 - Design of Smoke Management System provides greater detail on these aspects.

Staircases can be pressurized by having a continuous input of outdoor air by mechanical means such as a fan. Pressurization provides a pressure difference that

opposes and overcomes forces generated by the factors assisting movement of smoke, as discussed earlier.

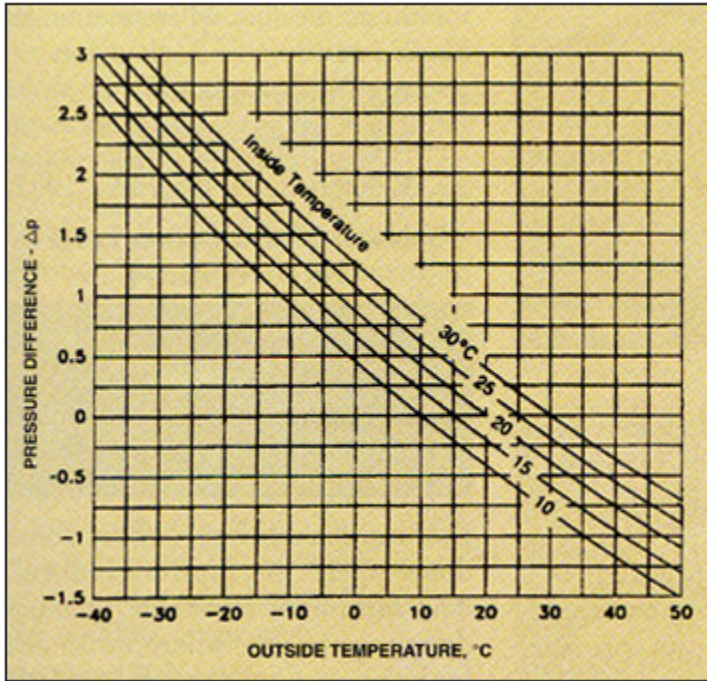


Fig. 3: Pressure Difference due to stack effect

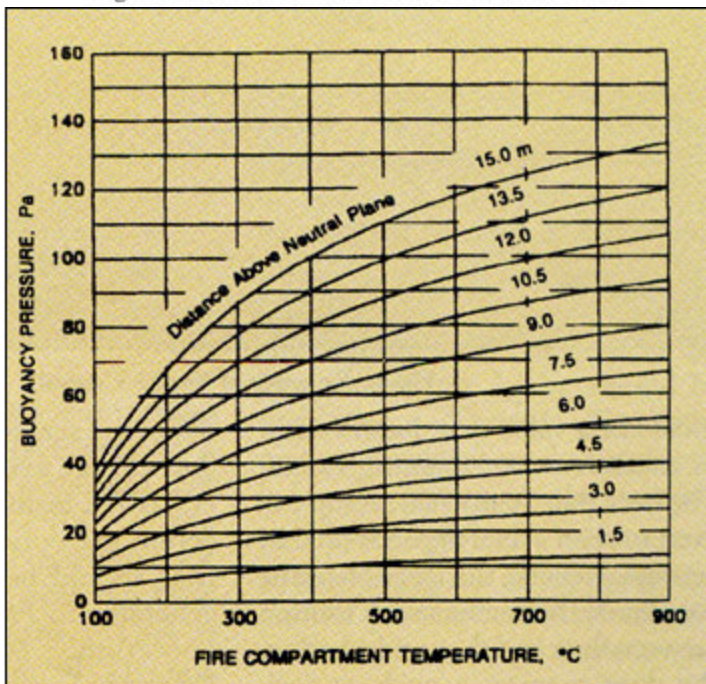


Fig. 4: Pressure Difference due to buoyancy

What should be the pressure difference across the door?

The maximum pressure difference should be a value that doesn't result in excessive door opening forces. The force that a particular person can exert to open a door depends on that person's strength, the location of the door knob, the coefficient of friction between floor and shoe and whether, the door requires a push or pull, NFPA 92A recommends the pressure difference across the door for various door closure forces. BS- 558 part 4, ASHRAE manuals and other codes define the optimum pressure level that should be

maintained. It is generally 50 Pa during emergency operation. Maximum pressure difference is expected to exist when all the doors are closed. Reference should be made to these codes while designing such a system.

Interestingly fire size can be limited by providing automatic sprinklers or other means of automatic fire suppression. In the case of a fully sprinklered building, pressure difference and airflow needed to control smoke movement may be less than in an unsprinklered building due to the likelihood that the fire size and smoke generation in a sprinklered building will be significantly lower than in an unsprinklered one.

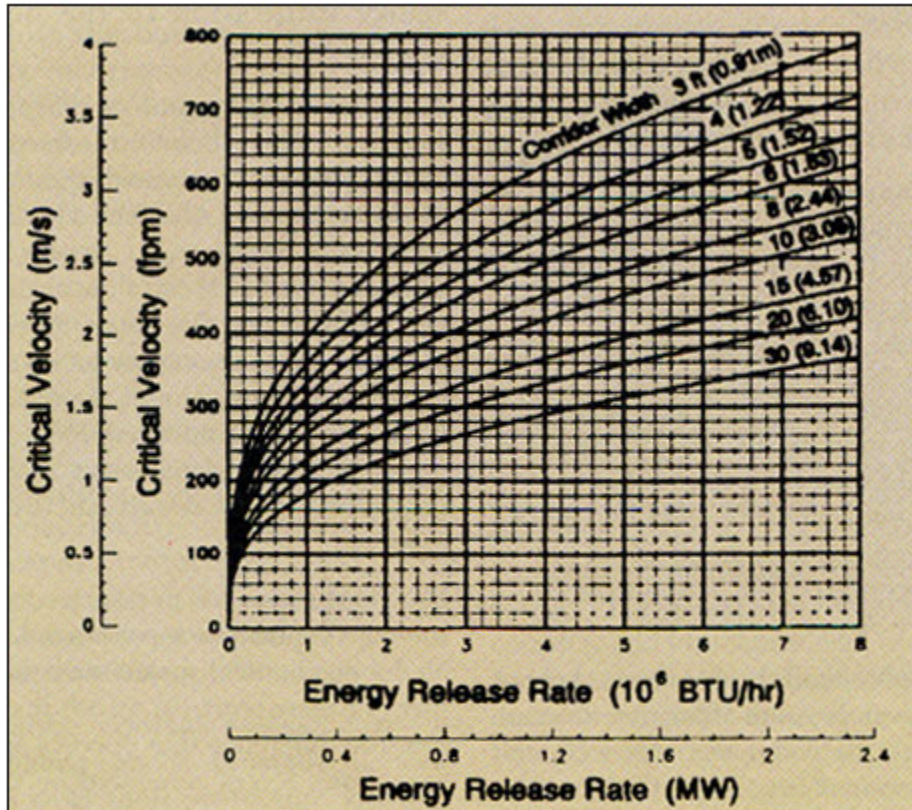


Fig. 5: Critical velocity to prevent smoke backflow in a corridor

Table 1 DX vs Chilled Water

Bldg. Type	Clg. Height	Design Press. Diff.
AS	any	12.45 Pa
NS	2.74 m	25.00 Pa
NS	4.57 m	35.00 Pa
NS	6.40 m	45.00 Pa

Notes:

1. For design purposes a smoke control system should maintain these minimum pressure differences under likely conditions of stack effect.

2. AS: Sprinklered
NS: Nonsprinklered
3. Reference : NFPA 92A - 19993.

**Table 2: Pressurization Level BS
5588 Part-4**

Bldg. Height	Pressurization Level	
	Emergency Operation	Reduced Operation
Upto 12 m	50 Pa	8 Pa
Above 12 m	50 Pa _x	15 Pa

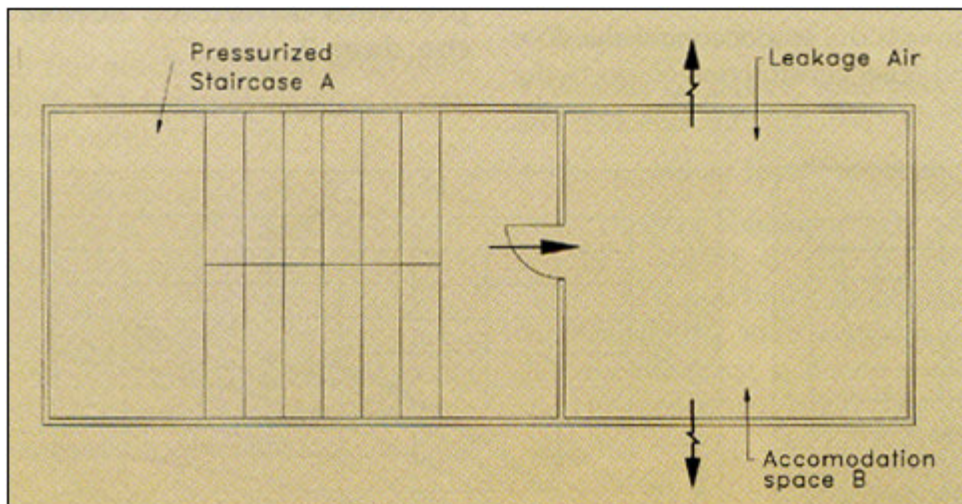


Fig. 6: Principle of Smoke Control

During emergency when some doors open, the pressure reduces. The minimum allowable pressure difference is that where no smoke leakage occurs during building evacuation. In this case the smoke control system must produce sufficient pressure difference to overcome forces of wind, stack effect or buoyancy of hot smoke.

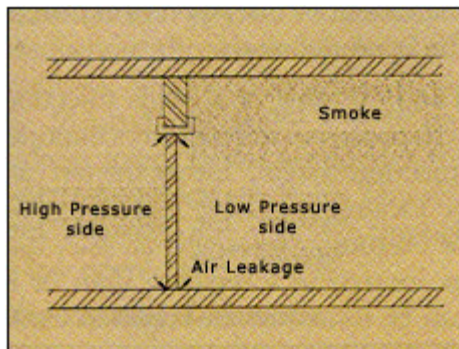


Fig. 7: Pressure difference across a barrier of a smoke control system preventing smoke infiltration to the high pressure side of the barrier

Designing these systems is complicated because an intermittent loss of effective pressurization occurs when occupants enter and leave stairs during evacuation.

Therefore, the pressurization system should have a supply air fan with sufficient capacity to provide effective pressurization system should have a supply air fan with sufficient capacity to provide effective pressurization to prevent smoke entry when doors are open. Opening of exterior stairwell door results in the largest pressure drop. This is because the air flow through the exterior doorway goes directly to the outside while air flow through other open doorways must also go through other building paths to reach outside. The increased flow resistance of the building means that less air flows through the open door ways than would flow through the exterior door. Thus, the exterior stairwell door is the greatest cause of pressure fluctuation due to door opening and closing. Also it is necessary to determine or assume the number of doors that may be open simultaneously during an emergency. This number will depend largely on the building occupancy.

Design Process

The designer should first identify the leakage paths, estimate their size and then calculate the airflow that will be needed to create and maintain the required pressure difference across the leakage paths. A constant air supply of this magnitude has then to be delivered to the space it is designed to pressurize. This is the condition when all the doors are closed.

To determine the amount of air required to maintain a specified pressure differential, the following equation must be applied:

$$Q = K_f A (\Delta P)^{1/2}$$

Q - Flow rate, cfm.

A = Flow area, ft²(leakage area)

ΔP = Pressure difference, inches water

K_f = Coefficient.

The flow coefficient depends on the geometry of the flow path, as well as turbulence and friction. As per ASHRAE HVAC Application handbook-1995, the flow coefficient is generally in the range of 0.6 to 0.7. For density of standard air as 0.075 lbs/ft³ and K_f = 0.65,

$$Q = 2610 A \sqrt{\Delta P}$$

For air quantity calculation, the air velocity through an open door should be established using the appropriate procedure defined in various codes and suitable adjustments should be done to meet the requirement of said codes.

Estimation of Effective Flow areas

The flow paths in a system can be in parallel, in series or a combination of series and parallel paths. The effective area of a system of flow areas is the area that results in the same flow as the system when it is subjected to same pressure difference over the total system of flow paths. This is analogous to flow of electric current through a system of electric resistance.

Effective area when the flow path is in series :

$$1/A^2 \text{ total} = 1/A_1^2 + 1/A_2^2 + 1/A_3^2 + 1/A_4^2$$

Effective area when the flow path is in parallel

$$A \text{ total} = A_1 + A_2 + A_3 + A_4$$

From crack areas and other air leakage details for various types of doors and windows reference can be made to BS-5588 Part-4.

From the architectural floor plan and details of doors and a windows such leakages areas can be estimated. Also ASHRAE Application handbook 1995 indicates typical crack areas in wall/floor construction. Stairwell walls for instance can be expected to have construction cracks of $0.11 \times 10^3 \text{ ft}^2$ in area for every one square feet of wall area. A common difficulty arises in connection with the clearance at the bottom of the door. If the thickness of floor covering is changed from what was assumed, the gap between the floor and bottom of the door increases which results in a droop of pressure over design.

It is therefore necessary that the construction quality is very good. If the construction is of concrete, it will probably be satisfactorily leak-proof. But if the construction is of block/ brick work it will probably need to be plastered to make it leak proof.

If there is a lobby, that separates the staircase from the accommodation area and the lobby has doors to lifts and toilets, the lobby should be separately pressurized. The lobby pressure should be equal to or slightly below the pressure in the staircase, (not below 5 Pa).

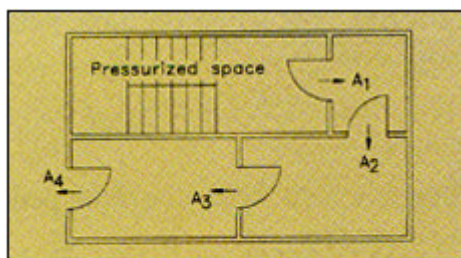
In calculating the air supply needed for the pressurization system two major assumptions have to be made:

- That the leakage areas of doors, lift doors, windows that have been used in the calculation will apply to the components when the building is completed.
- That there are no unidentified leakage areas out of the pressurized spaces.

To allow for these assumptions British standard 5588 recommends that an allowance of 25% be added to the calculated value of supply air.

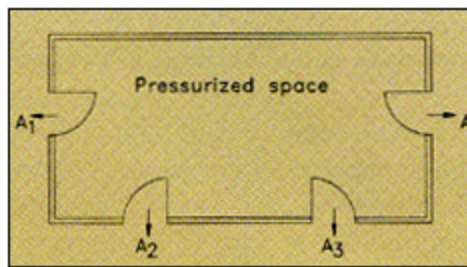
Apart from this, it also recommends to add another 15% to take care of any leakage from sheet metal ducting.

The fan should be selected accordingly and the total pressure against which the fan has to work is the summation of resistance of air distribution system and emergency pressurization level.



Note: The doors shown are normally Shut and the airflow shown takes place at the crack around the doors.

Fig 8: Leakage paths in series



Note: The doors shown are normally shut and the airflow shown takes place at the cracks around the doors.

Fig. 9: Leakage paths in parallel

Plan for Air Venting

The arrangement for release/escape of the pressurizing air from the building should be considered, and an appropriate venting method should be adopted. If the building has openable windows on each floor, it is possible that the leakage through the window cracks will be sufficient to allow satisfactory venting of pressurizing air. Or else special vents should be planned and provided on all sides of the building.

Air Distribution

There are two types of air distribution systems, single injection and multiple injection.

In the single injection system the pressurizing air is supplied to the stair tower at one location. The most common injection point is at the top of the building.

A single injection system can fail when a few doors are open near the air supply injection point. All of the pressurizing air can be lost through these open doors and the system will then fail to maintain positive pressure across the doors farthest from the point of injection. Because of this reason BS 5588 recommends that a single supply entry point is not to be used unless the building has three floors or less. ASHRAE however suggests that with careful analysis such system can be used up to eight floors.

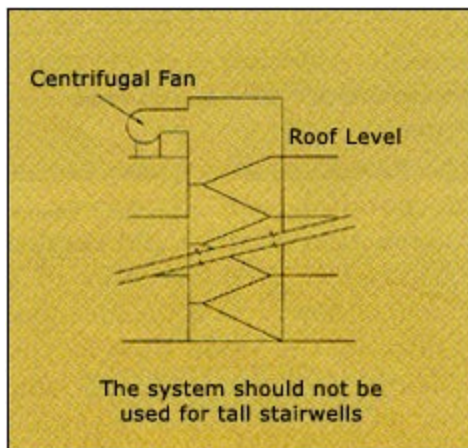


Fig. 10: Stairwell pressurization by single injection with roof - mounted fan

Single injection with bottom air entry is prone to failure. Since the exterior door is opened most of the time, some of the air will short circuit the system by directly flowing out of the open doorways.

The limitation of a single injection system can be overcome by a multiple injection system. Either the fan can be located at ground level or it can be on roof. The supply air duct can be located in a separate shaft or it can be routed in the stairwell itself.

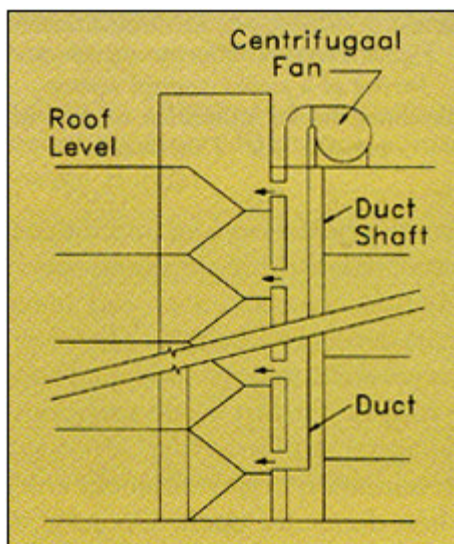


Fig. 11: Stairwell pressurization by multiple injection with roof - mounted fan

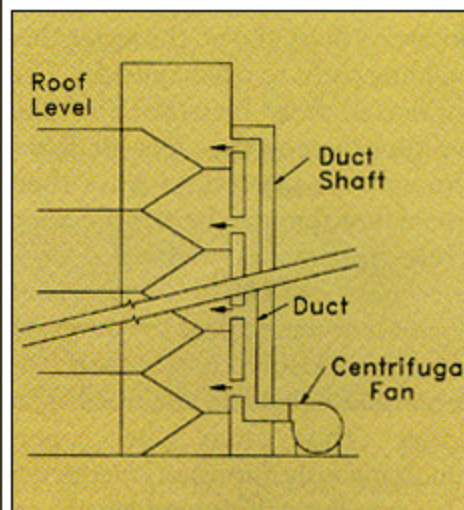


Fig. 12: Stairwell pressurization by multiple injection with fan located at ground level

In this case care has to be taken that the duct should not interfere with the evacuation passage. The air supply to the pressurized staircase should be evenly distributed throughout the whole height of the staircase. The air outlet grilles should be located not more than three storeys apart. Better would be if the air is injected at each floor. This will prevent loss of pressurization through a few open doors.

Air intake Location

The supply air intake should be separated, from various exhaust shafts and roof smoke and heat vents. Open vents of elevator shafts or other building openings that may expel smoke during a fire should be located remotely from the intake air location. This

separation should be as great as possible or else smoke will be fed in. One approach could be to locate all inlets on one side of the building and smoke outlets on the other side. However with any stair tower pressurization system, there is a potential for smoke feedback into the stair tower. Therefore the capability of automatic shut down in such events should be considered.

Single or Two Stage System

A pressurization system designed to work only in an emergency is called a single stage system. Alternatively a continuously operating low level of pressurization can be achieved by way of normal ventilation, with provision of attaining higher pressure level during emergency.

Since a single stages system is envisaged to work only during emergency, one needs to maintain the system periodically so that the system operates when called for. On the other hand a two stage system is always in running condition. In case there are two single speed fans in parallel, duty cycling should be considered to keep the fans in operating condition.

Non Compensated and Compensated System

A single speed fan supplying air to the stair tower will maintain one pressure difference with all doors closed and another when some doors are open. This means there is a variation in pressure level with door openings. This is called a non compressed system. These systems are of open loop type with no feed back.

A compensated system is one which can maintain pressure difference as designed by adjusting itself to various combinations of door openings and door closures. This is achieved by a variable air flow rate by varying the fan speed, or using a fan bypass damper or varying the number of fans in operation or otherwise. The control signal is obtained from a pressure sensor controller that senses the static differential pressure between the stair tower and the occupied zone and gives feed back for corrective action.

Conclusion

One should select a system that is most appropriate for the type of application and occupancy. The system could be activated through smoke detectors, heat detectors sprinkler flow switches or manually by fire department personnel. There should be a periodical planned maintenance schedule and mock drills.

The reliability of electrical power source to drive the fan during emergency should be carefully studied. Whatever be the arrangement, the electrical supply to the

pressurization fans should not be interrupted. Even if an emergency generator is provided the route by which the power is brought to the fans should be such that it is not likely to be affected by the potential fire.

It is also important that the protected staircase does not contain any combustible material which can possibly start fire. Staircases should not be encroached upon. Also, doors opening out of a pressurized space should have a door closer that can keep the doors shut against the pressure. It is also necessary that door closers be suitably calibrated. The floor tiles near the doors should not be very smooth so that pushing the door to open is not difficult. The protected staircase should have proper emergency illumination. Also the doors enclosing a pressurized space should not be connected by any corridor or lobby to an unpressurized staircase.

During the design stage it is practically impossible to estimate all the leakage paths correctly. Thus all calculations for air flow rate for smoke management are only approximate.

Even after considering all the above design details, the protected escape stair tower cannot be expected to be completely smoke free as there are many variables discussed above. The objective as defined in NFPA 92A is to maintain a tenable environment in the areas to be protected to enable rapid evacuation. It is thus necessary, with this objective in mind that the building service engineer should endeavor to integrate the air-conditioning system with an adequate smoke control system for staircases.

However to render the building fire safe, all aspects of fire suppression and smoke control should be considered together. **It is well known that one of the best ways to deal with smoke problems is to stop and prevent smoke generation.**

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