

# Stairwell Pressurization in a Cold Climate

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## ABSTRACT

*The three national model building codes<sup>1</sup> require pressurization systems for high-rise buildings. The goal of stairwell pressurization is to provide a relatively smoke-free evacuation route by maintaining a pressure differential across a stairwell door opening, thereby preventing smoke infiltration. This goal is difficult to attain in cold climates due to weather extremes that relate to stack effect, increased wind effect, and the additional problem of heating the stairwell.*

*This paper discusses the design, construction, testing, and computer modeling of the stairwell pressurization system of a 14-story hotel built in Minneapolis, MN.*

## INTRODUCTION

This paper provides an overview of the design process, construction monitoring, required local jurisdiction testing, and computer modeling of a high-rise stairwell pressurization system in a severe cold weather climate. The computer modeling uses the ASCOS (Analysis of Smoke Control Systems) program<sup>2</sup> and is included both to compare the modeled results with those of the actual occupancy testing and as a check on the hand calculations used in originally designing the system.

## DESIGN

The stairwell pressurization system of a 14-story Minneapolis hotel was designed to the requirements of the Uniform Building Code (UBC). The hotel was designed with two pressurized stairwells rather than using the design option of pressurizing only one stairwell and building a smoke vestibule in the other stairwell. This decision was based primarily on the cost of the hotel floor space that would be occupied by the vestibule. The design of the pressurization system was based on the data and information in Klote and Fothergill (1983).

The minimum criteria for the pressurization system of the two stairwells come from the UBC and good design

practice. The UBC requires the system to maintain a pressure differential of + 0.25 in w.g. across the building stair barrier with all doors closed while relieving 2500 cfm from a rooftop vent.

In addition to this requirement, the pressure differential across a closed stairwell door should not exceed + 0.55 in w.g. or be less than + 0.05 in w.g. The upper limit corresponds to the maximum force necessary to open the door in order to leave the building, while the minimum corresponds to the smallest pressure difference that will keep smoke out of the stairwell.

Since a single injection point system can uniformly pressurize only 4 to 8 stories and the building is 14 stories tall, multiple injection points were used. Multiple injection points require either a duct distribution from one fan or multiple fans.

The cost of floor space in hotel construction precluded the duct distribution choice; multiple fans were used instead. A system using centrifugal fans located at the top and bottom of the stairwell would have provided satisfactory results. However, recirculation of smoke at fan intake would have been a problem and space for the fans and intake ducts became a cost consideration. Single-wall propeller fans located at multiple points had been shown to work well at an Atlanta, GA, hotel. This method, however, would have required careful planning to implement in Minneapolis, with its extreme winter design temperatures. (See Appendix A for maximum and minimum allowable pressures.)

Use of the previously established criteria and the methods outlined in Klote and Fothergill (1983) resulted in a calculated need of 366 cfm per floor. Good design practice limited the effective range of each injection point to a maximum of eight floors, but the extreme cold necessitated a minimum number of penetrations to the exterior. A search of fan manufacturers revealed a style of five-bladed, supply-flow, direct-drive, sidewall propeller fans. Two of these fans, which are capable of delivering 7350 cfm at 0.75 in w.g. each, are used. This system exceeds the minimum calculated flow of 366 cfm per floor and allows a reasonable safety factor. The fans were located at floors four and ten to help pressurize the stairwell uniformly. Because the fans are capable of delivering a greater volume than required at a static pressure higher than a 50-lb door-opening force could produce, an overpressure

<sup>1</sup> Uniform Building Code (UBC), Building Operator's Code Association (BOCA), and Standard Building Code (SBC).

<sup>2</sup> The ASCOS program is available for use on personal computers from the Center for Fire Research Computer Bulletin Board System (Phone 301/921-6302), and information about this bulletin board system can be obtained from the Center for Fire Research of the National Bureau of Standards at Gaithersburg, MD.

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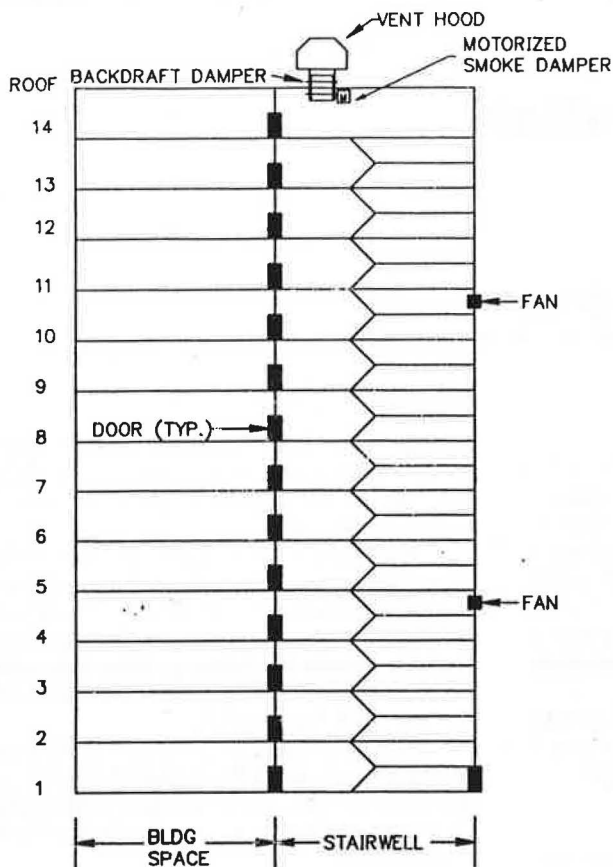


Figure 1 Stair elevation

relief damper was located at the top of the stairwell. This damper also provides for smoke venting. (See Figure 1: Stair Elevation, showing location of fans and relief damper, and Appendix A for calculation of minimum required flow.)

### WEATHERTIGHTNESS

Before the propeller fan system could be accepted, two design considerations had to be addressed. First, could the cold and wind effects be kept out of the stairwell and, second, would the winter stack effect be a problem? Careful integration of the louver, fan, and damper assembly was needed as a solution to the first problem.

For the exterior wall opening, a weather louver was selected that matched in size and color the architectural band of windows. The weather louver provides rain, snow, and wind protection. The louvers in the stair were located between the intermediate landing and the structural framing of the floor above. The fans were selected to fit into a wall sleeve behind the louvers. A sheet metal wall sleeve was constructed to attach to the louver, house the fan, and keep water, snow, and wind out of the building wall cavity. The wall sleeve was lined with 1 in of coated air duct liner for thermal isolation (see Figure 2: Wall Fan Section).

Careful thought went into the location of the fan and damper in the wall sleeve. The two choices placed either the fan or the damper adjacent to the louver. However, architectural as well as mechanical objectives had to be

met. The final design solution located the fan next to the exterior weather louver and placed the damper on the inside face of the wall sleeve. The inside damper location was selected in an attempt to make the fan assembly visually pleasing in the stairwell. The assembly was located at the floor level of the stair landing for occupant protection, and a mesh grille was added to the inside face to cover the damper opening.

The electric damper operator is outside the sleeve in a wall box inside the building wall. The box has a locked cover. As a final architectural touch, the sleeve, damper, and mesh grille were painted to blend with the stairwell color (see Figure 2: Wall Fan Section).

### STACK EFFECT

The stack effect is magnified in such an extreme cold weather climate as Minneapolis. A 1% ASHRAE design day of  $-16^{\circ}\text{F}$  and an interior temperature of  $70^{\circ}\text{F}$  will produce a stack effect differential of  $+0.18$  in w.g. (positive pressure above the neutral plane and negative pressure below). This compares to a stack effect of  $+0.12$  in w.g. for a more moderate climate with a design temperature of  $10^{\circ}\text{F}$ . The increased stack effect compounds the problem of maintaining a minimum and maximum pressure differential of  $+0.05$  in w.g. and  $+0.55$  in w.g., respectively, across each closed door (see Appendix B for calculation of stack effect).

In order to maintain the stairwell pressure between the maximum and minimum allowable pressures, the stairwell was supplied with a greater volume of air than required. As excess pressure builds, as in an emergency situation with all doors closed, the overpressure relief damper opens.

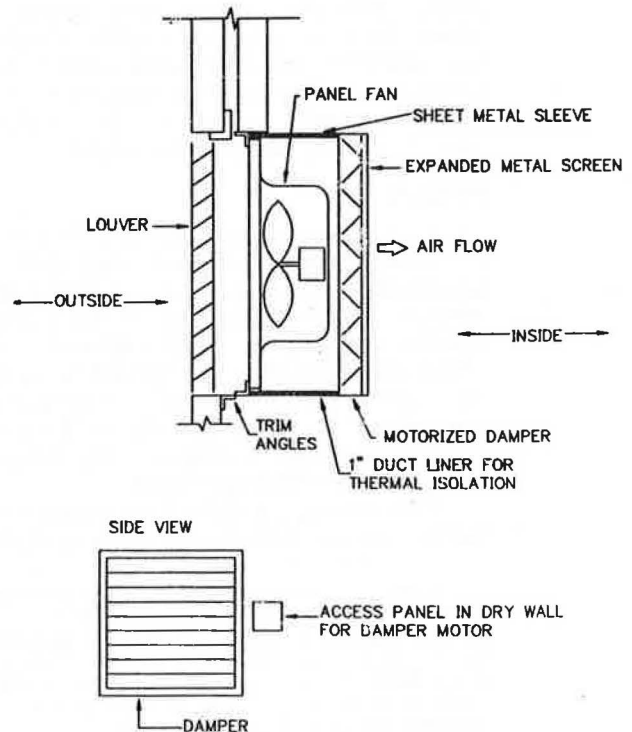


Figure 2 Wall fan section

The relief damper is a horizontally mounted damper located in the curb of the roof louvered exhaust housing. The blades of the relief damper are weighted to close as stairwell pressure drops, i.e., as stairwell doors are opened. Other advantages to weighting the blades to close with low pressure is that the blades will be less affected by wind moving across them and will form a more airtight seal when not in an emergency situation.

Tight stairwell construction helps reduce the stack effect. To ensure tightness in non-emergency situations, a UL 555 S low-leakage-rated smoke damper was mounted in the intake to the top vent. A motorized damper opens the smoke damper upon a fire alarm signal. In addition to specifying a low-leakage damper, care had to be taken in the construction of the stairwell. The construction company was cautioned that the pressurization system must pass an inspection test before occupancy. Therefore, care was taken to avoid any unnecessary building holes contributing to the stack effect.

The 14-story building has other systems that contribute to the stack effect. Toilet exhaust makeup air for the building is supplied from a corridor supply air system to each floor at 950 cfm per floor. This solution was used rather than supplying ventilation air through incremental wall heating and cooling units. The incremental-unit-mounted "vent" knob was then removed and the damper doors screwed shut. The corridor supply air system is also part of the corridor smoke control and purge system. The

elevator shaft vent openings at the top of the hoistway are provided with UL 555 S low-leakage smoke dampers. The dampers are normally closed and may be opened only by a remote signal from the hotel's fire control panel.

### STAIRWELL HEAT

The stairwell contains the fire hose wet standpipe for the building. A wet standpipe system was also used to supply the hotel's sprinkler system. There was a concern that the standpipe could freeze during a winter emergency with fans on. However, in the event of either real or false fire emergencies, freezing of the standpipe is not a fire department or building operator concern.

Each stair is heated by a cabinet unit heater at the lowest level to 65°F for comfort conditions. Operation of the system over the last two years has indicated that the tight stairwell construction has kept infiltration to a minimum. Much of the stairwell heat is conducted from the building itself.

### TESTING

The fan motors and dampers all become operational by a fire alarm signal. These units were all pretested before the city witness test was scheduled. The damper linkage of the vent smoke damper was used to set flow at 2500 cfm in the open position. The city fire department witnessed the gauge readings of 0.35 in w.g. with all doors closed and the vent opened. The pressure was almost uniform at each floor (see Figure 3). The system passed the city test the first time. This speaks well for the design volume selection and the tightness of the stairwell.

### COMPUTER MODELING

The original design calculations for the stairwell pressurization system were done manually using the data and methods in Klote and Fothergill (1983). For the purpose of comparison with the hand calculations and actual testing, the ASCOS program for steady air flow analysis was used. This computer program was written as an aid to analyzing zoned smoke control systems, pressurized stairwells, and pressurized elevators. The comparisons illustrate the program's effectiveness as a design tool.

The building was modeled using three shafts, one for each stairwell and one for all the elevators. The computer program was run for a variety of emergency and non-emergency situations.

The stack effect was the first area analyzed with the computer program. The worst stack effect would occur on a winter design day in a non-emergency situation that would have all stairwell doors closed, an interior temperature of 70°F, and an exterior temperature of -16°F. The results are a difference of -0.16 in w.g. at the base of the stairwell to +0.11 in w.g. at the fourteenth floor. This compares to a hand-calculated result of +0.18 in w.g. (positive at the top, negative at the base). The same situation, with the exception of a 10°F exterior temperature, resulted in a computer-generated result of -0.11 in w.g. at the base and +0.07 in w.g. at the top of the stairwell. This compares to a hand-calculated result of +0.12 in w.g. (see Figure 3).

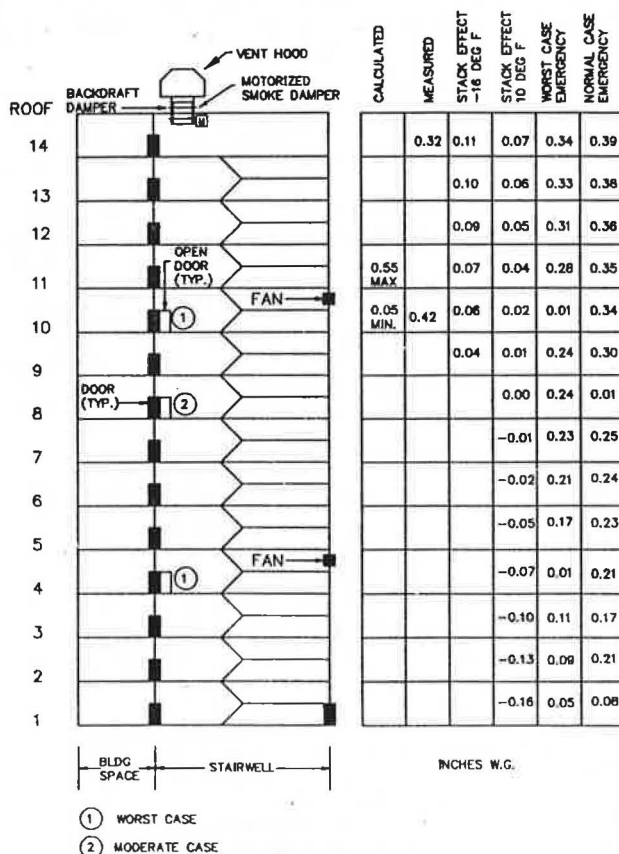


Figure 3 Data Summary

The differences between the computer program calculations and the hand calculations can quickly be seen in these comparisons. The computer analysis predicted a smaller pressure differential across the stairwell doors in both cases. This is due to the ability of the computer program to allow for vertical leakage between floors, primarily through the elevator shafts. The computer program also simulates the corridor supply air system, although it was found to have a negligible effect on the stairwell system. The use of the ASCOS program is most advantageous in situations where the conservative hand calculations predict a large stack effect, such as tall buildings.

The comparisons also illustrate the increased stack effect due to severe cold weather. As expected, the stack effect was greater for the colder climate. However, the computer program showed a smaller increase than expected due to the estimation of tight stairwell construction. This illustrates again the importance of quality stairwell construction with as few unnecessary paths to the exterior as possible.

Having compared the computer program results with the original design hand calculations, the next step was to compare them with the actual acceptance testing. The computer program modeled the stairwells for the same conditions as the previously described acceptance test. The computer analysis, however, produced a result of an almost uniform distribution of 3.6 in w.g. (not listed in Figure 3) across each closed door of the stairwell, compared to the 0.35 in w.g. witnessed at the acceptance test. Since the propeller fans can generate only 0.75 in w.g. and the system will relieve excess pressure through the relief damper, the computer model had to be modified to reflect these facts.

This analysis illustrates the strengths and weaknesses of using the computer as a design tool. In this particular case, the designer cannot use the computer program to predict the exact pressure differential in the stairwell with all doors closed. The program does not have the ability to increase the volume of air being relieved due to an increase in stairwell pressure, which is the actual situation. The computer program does have the ability, however, to calculate the volume of relief air needed to maintain stairwell pressure below the maximum value. This can be done through a trial-and-error method, which would be very long and cumbersome if done by hand, but can quickly be computed with the program. This information would then be used to size the relief damper.

With these characteristics in mind, the program was used to analyze a variety of emergency situations. A worst-case scenario, with doors open to the outside on the ground level and to the building on the fourth and tenth floors (across from the injection points), was modeled, as well as a more moderate situation with two doors open—one on the eighth floor and the other on ground level open to the outside. The results are shown in Figure 3. Both analyses show that the system has the ability to maintain an acceptable pressure differential across the closed stairwell doors. The pressure differential across the open doors dropped to a negligible amount, but the volume of air passing through the door greatly increased.

Cold temperatures are a concern for the designers of the stairwell pressurization system due to the increase in

the stack effect that accompanies colder temperatures and due to the necessity of constructing a stairwell to tighter than normal building trade standards. Tighter construction reduces the stack effect and heating requirements by reducing the amount of cold air entering the stairwell.

## CONCLUSIONS

Designing a pressurized stairwell system in a cold climate requires the designer to consider the variables of temperature, wind, and construction standards.

The use of the ASCOS computer will help the designer of the stairwell pressurization system. Hand calculations using the "Calculated Method for a Simple System" from Klote and Fothergill (1983) are relatively fast and easy. The results, however, give conservative design values. The results from the computer model generally agree with the hand calculations and actual test values. The usefulness of the computer models becomes more apparent as the height of the building increases. The computer also can be used to predict different airflow scenarios. For the system designer, the strengths of both methods can be used to optimize a stairwell pressurization system. The faster hand calculations should be used to set the parameters of the system and to estimate the size of equipment. The computer program can be used to verify the design of the system, or, in the case of very tall buildings, aid in selecting a more realistic equipment size.

A small problem with the use of the computer program is that the designer must become familiar with its methods and limitations before it is faster to use the program than do hand calculations. As the designer becomes more familiar with the ASCOS program, more and faster calculations can be made and evaluated.

## REFERENCES

- ASHRAE. 1984. *ASHRAE handbook—1984 systems*, chapter 38. Atlanta: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.
- Klote, J.H., and Fothergill, J.W. 1983. "Design of smoke control systems for buildings." Atlanta: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.
- McGuire, J.H.; Tamura, G.T.; and Wilson, A.G. 1970. "Factors in controlling smoke in high buildings" (ASHRAE Symposium Bulletin SF-7-2, Fire Hazards in Buildings, p. 8). (National Research Council of Canada, Division of Building Research, Technical Paper No. 341, June 1971.)

## APPENDIX A

### REQUIRED FLOW CALCULATIONS Design Values

$A_{BOW}$	= Wall area between the building and the outside per floor	= 4214 ft <sup>2</sup>
$A_{SBW}$	= Wall area between the stairwell and the building per floor	= 364 ft <sup>2</sup>
$A_{BO}$	= Flow area between the building and the outside	= 0.88 ft <sup>2</sup>
$A_{SB}$	= Flow area between the stairwell and the building when stairwell is closed	= 0.30 ft <sup>2</sup>
$N$	= Number of floors of stairwell	= 14
$H$	= Height top of highest floor served by stairwell	= 130.5
$T_O$	= Outside design temperature	= -16°F
$T_B$	= Building design temperature	= 70°F

$P_{MAX}$  = Maximum allowable differential pressure between the stairwell and the building.

NFPA Life Safety Code:

"Force to open any door in a means of egress shall not exceed 50 lb - .55 in w.g. in."

$P_{MIN}$  = Minimum allowable pressure differential between stairwell and the building. (Force to overcome door closure.)  
Not to exceed 0.05 in w.g.

The remaining design values can be found in the charts available in the *Design of Smoke Control Systems*.

#### STEP 1—ESTABLISH REMAINING DESIGN VALUES

Calculate  $A_{BO}$   
 $A_{BOW} = 4214 \text{ ft}^2$   
Average leakage ratio for exterior wall of average tightness.

From Table C.1 =  $0.21 \times 10^{-3}$ .

$A_{BO} = 4214 \text{ ft}^2 (0.21 \times 10^{-3}) = 0.88 \text{ ft}^2$ .

Calculate  $A_{SB}$

$A_{SBW} = 364 \text{ ft}^2$  per floor  
Average leakage ratio for stairwell wall of average tightness.

From Table C.1 =  $0.11 \times 10^{-3}$

Leakage Area =  $364 \text{ ft}^2 (0.11 \times 10^{-3}) = 0.04 \text{ ft}^2$ .

Door Crackage =  $0.26 \text{ ft}^2$ .

$A_{SB} = .04 + .26 = .30 \text{ ft}^2$ .

#### STEP 2—CALCULATE TEMPERATURE FACTOR

Equation:  $b = \frac{gP}{R} \left( \frac{1}{T_O} - \frac{1}{T_B} \right)$

From Figure B.7

For  $T_O = -16^\circ\text{F}$

$b = 0.0028$  in w.g. per ft.

$g$  = Acceleration of gravity,  $\text{ft}/\text{sec}^2$

$P$  = 1 atmosphere pressure

$R$  = Gas constant for air

#### STEP 3

Choose  $P_{SBb} = 0.08$  in in w.g.  
(Chosen larger than  $P_{MIN}$  of 0.05 to provide extra degree of protection.)

#### STEP 4—CALCULATE $P_{SBt}$

$P$  @ top of stairwell

$$P_{SBt} = P_{SBb} + \frac{bH}{1 + (A_{SB}/A_{BO})^2}$$

$$P_{SBt} = 0.08 + \frac{0.0028 (130.5)}{1 + (0.30/0.88)^2} = 0.407 \text{ in w.g.}$$

Less than  $P_{MAX}$  .55, therefore acceptable

#### STEP 5—CALCULATE FLOW FACTOR G

From Figure B.8

$P_i = 0.407$  in w.g.

$P_b = 0.080$  in w.g.

$P_i - P_b = 0.327$  in w.g.

$G = 1220$  fpm

#### STEP 6—CALCULATE SUPPLY AIR QUANTITY

$Q_{SB} = GN_{ASB}$

$(1220) (14) (0.30) = 5124$  cfm minimum (total system supply)

$(1220) (0.30) = 366$  cfm minimum (per floor)

### APPENDIX B Stack Effect Calculation

#### SEVERE CLIMATE STACK EFFECT

Building Height = 130.5 ft.

Distance above neutral plane = 63.5 ft. =  $H_N$

$T_O = -16^\circ\text{F} + 460^\circ = 440^\circ\text{R}$

$T_i = 70^\circ\text{F} + 460^\circ = 530^\circ\text{R}$

$K = 7.64$

$$\begin{aligned} P \text{ (in w.g.)} &= (K)(H_N) \left( \frac{1}{T_O} - \frac{1}{T_i} \right) \\ &= (7.64) (63.5 \text{ ft}) \left( \frac{1}{444} - \frac{1}{530} \right) \\ &= \pm 0.18 \text{ in w.g.} \end{aligned}$$

#### MODERATE CLIMATE STACK EFFECT

$H_N = 65.3$  ft.

$T_O = 10^\circ + 460^\circ = 470^\circ\text{R}$

$T_i = 70^\circ + 460^\circ = 530^\circ\text{R}$

$K = -7.64$

$$\begin{aligned} P \text{ (in w.g.)} &= K(H_N) \left( \frac{1}{T_O} - \frac{1}{T_i} \right) \\ &= 7.64(65.3 \text{ ft}) \left( \frac{1}{470} - \frac{1}{530} \right) \\ &= \pm 0.12 \text{ in w.g.} \end{aligned}$$